Comp Turbo Technology Tech Bulletin No. 4

Matching A Turbocharger To An Engine

The primary objective in matching a turbocharger to an engine is the selection of a compressor that covers the engine air requirement at the highest possible compressor efficiency. The engine air requirement must be either known or estimated before a match can be made. If the air requirement is not known, a rough estimate can be made using the following equation:

$$Q = V_E \times Q_D \times P_r \times \frac{(540^{o})}{T_3}$$

Where:

Q = compressor inlet volume flow - CFM
V_E = engine volumetric efficiency
Q_D = engine displacement volume flow - CFM
P_r = estimated total pressure ration
540°= ambient air temperature = 80°F + 460° = 540°R
T_3 =intake manifold air temperature - °R

The volumetric efficiency V_E of a turbocharger engine is usually assumed to be 1.0 for a gasoline engine that has a reasonably low allowable boost pressure. Commercial diesel engines are boosted to higher levels so that a volume efficiency of 1.10 can be assumed. For racing engines that are boosted to very high levels, the volumetric efficiency should be assumed to be 1.25 or higher for very highly rated engines.

Since many compressor performance maps are plotted using inlet air mass flow, W in pounds per minute, Q in cubic feet per minute can be converted to W in pounds per minute by multiplying Q by an ambient air density of .0735 pounds per cubic foot.

The displacement airflow Q_D in CFM can be obtained as follows:

$$Q_D = \frac{D_E}{1728} \times \frac{RPM}{2}$$

for a 4-cycle engine

Q_D = displacement airflow - CFM
D_E = engine displacement - cu.in.
RPM = rated engine speed

P_r is obtained by dividing the compressor outlet pressure by the inlet pressure. Total pressure values are usually used when plotting compressor maps, which means that the compressor outlet pressure is the static outlet pressure plus the outlet air velocity converted to pressure. The inlet total pressure is the barometric pressure minus the inlet vacuum, converted to pressure, measured at the compressor wheel inlet.

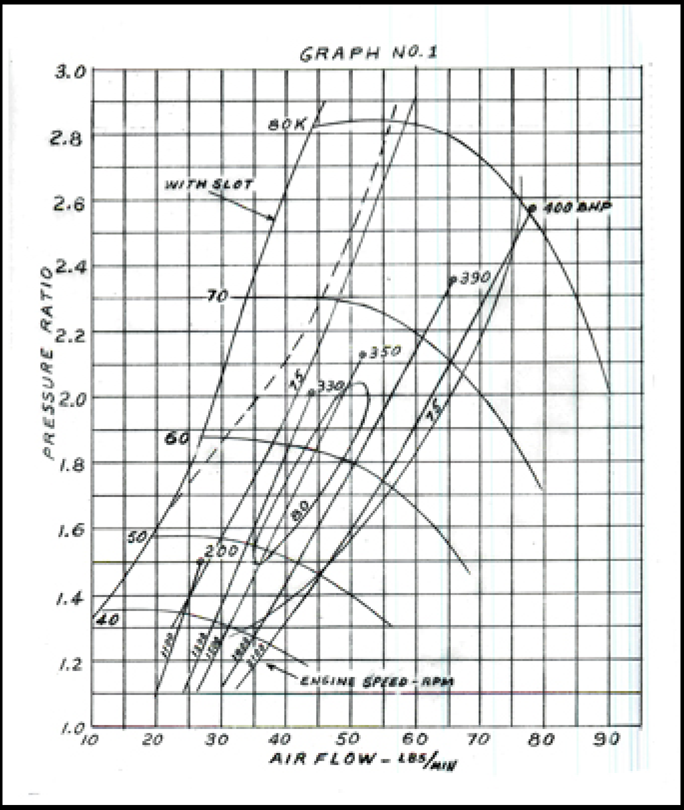
A rough estimate, however, of the pressure ratio can be made by estimating the intake manifold pressure needed to develop the rated engine horsepower and dividing it by the barometric pressure at sea level.

The value of the intake manifold temperature, T_3, can be obtained from the graph of temperature versus pressure ratio presented in our Bulletin No. 3, if the engine is not aftercooled. If the engine is equipped with an air-to-air aftercooler, the value of T_3 can be estimated as 120°F for an ambient air temperature of 80°F and an assumed aftercooler effectiveness of 80%. The value of T_3 for substitution in the above equation must be converted to absolute temperature by adding 460°.

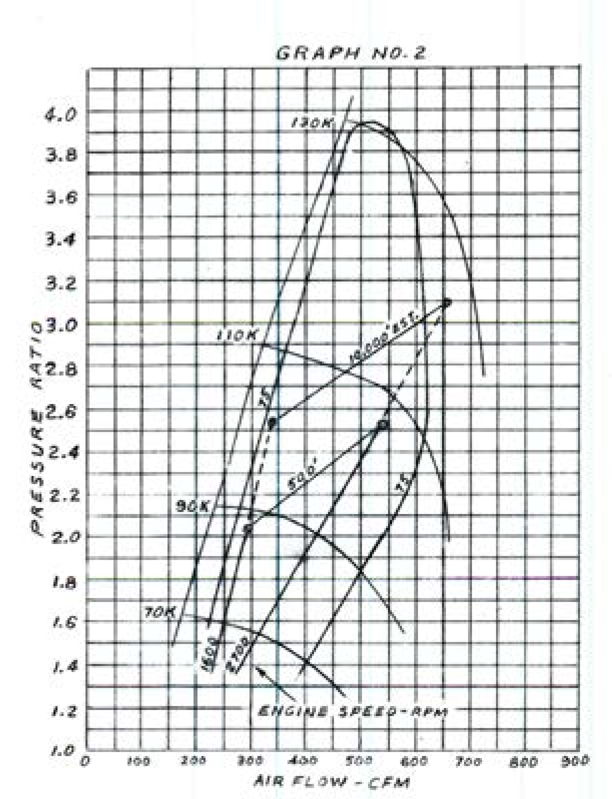
Once the rated engine pressure ratio and inlet airflow have been estimated, a compressor performance map can be selected to match these values at a reasonably high compressor efficiency. This point must be far enough out on the compressor flow range to allow for a reasonable torque rise (for example 20%) as the engine speed is reduced at full throttle. The maximum compressor efficiency should occur in the middle of the engine operating range.

Examples of correctly matched compressors to specific engine air requirements are shown as follows:

Graph No 1. This Graph shows the performance of a compressor with a 3.8" diameter compressor wheel matched to the air requirement of an 855 cu.in. diesel engine with a 20% torque rise. Note that the engine air requirement stays within the 75% compressor efficiency envelop and utilizes the maximum efficiency of 78% in the

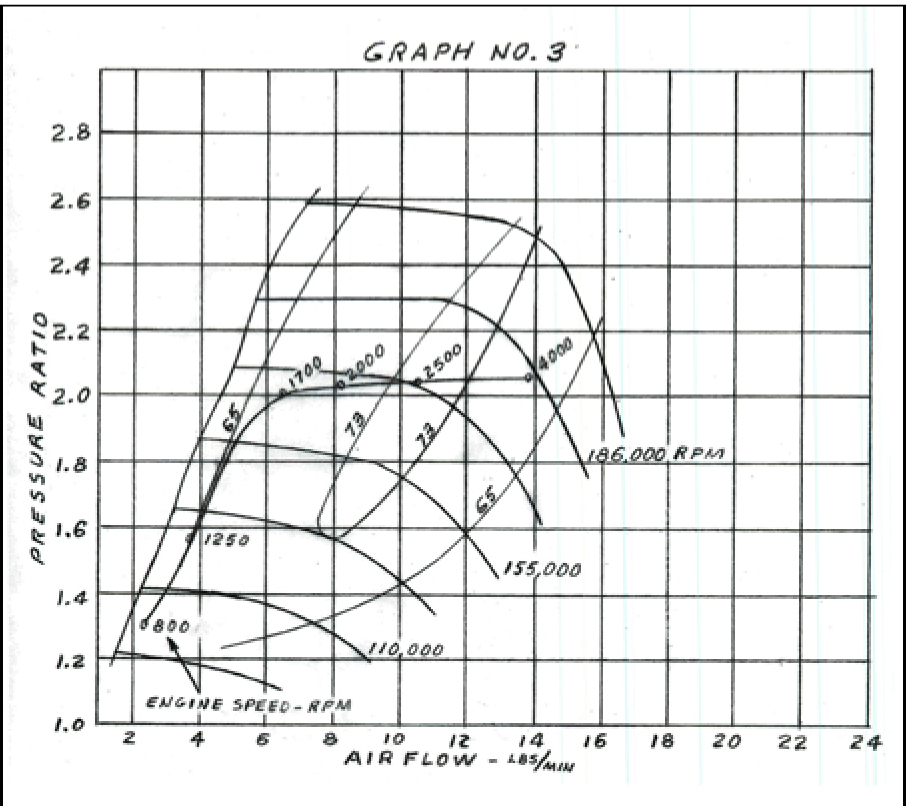


Graph No. 2. This graph shows the performance of a compressor with a 2.9" diameter compressor wheel properly matched to the air requirement of a 5.9 liter diesel engine . Here again, the engine air requirement stays well within the 75% compressor efficiency envelop at sea level. The estimated increase in turbocharger speed as the engine is operated at altitudes above sea level is indicated on the graph. Since the ambient air pressure decreases as altitude increases, the turbocharger turbine has the benefit of a lower back pressure at high altitudes and the turbine can develop more horsepower due to a greater expansion ratio. This results in the turbocharger operating at a higher speed and allows the compressor to deliver a greater volume of the less dense ambient air to the engine cylinders. The higher turbocharger speed at altitudes higher than sea level compensates for the drop in air density and allows the engine to be rated at sea level power rather than be de-rated as it is operated at altitudes higher than sea level.



Graph No. 3. Passenger car engines need to develop high torque at low engine speed to facilitate fast acceleration of the vehicle. Thus, the matching of a turbocharger to a passenger car engine entails the use of a turbocharger that produces high boost at low engine speeds. Graph No. 3 shows the match of a compressor with a 1.96" diameter compressor wheel that has a flow range broad enough to cover the air requirement of a passenger car engine.

Since the compressor is forced to provide high boost at the low engine speeds, it would exceed its maximum allowable operating speed at high engine speeds unless it is prevented from doing so by providing an exhaust gas bypass valve in the turbine casing. The bypass valve, or waste gate , limits the turbocharger speed and holds the boost pressure nearly constant from torque peak to full rated engine speed. In Graph No. 3, the boost level is nearly constant from 1700 RPM to 4000 RPM engine speed by the use of a waste gate that bypasses exhaust gas around the turbine wheel and limits the turbocharger speed over the high speed range of the engine.



The matching of the turbine component of the turbocharger consists of selecting a turbine casing size that will operate the turbocharger at a speed that produces the intake manifold pressure required to reach the rated horsepower of the engine. Several turbine casing sizes are usually tested on the engine to find a size that operates the turbocharger at the desired boost level without imposing an undesirable back pressure on the engine which would have a negative effect on fuel consumption.

For additional information about matching a turbocharger to engines of various types, contact the Comp Turbo Technology, Inc. Technical Department.