The Link between Combustion and Volumetric Efficiencies

The Otto Cycle internal combustion engine is basically a pump that extracts mechanical (shaft) energy from the air/fuel mixture we supply to it. An engine that rotates at a higher speed will pump more air/fuel and generate a higher power output. The key to maximizing the shaft power available to do work (on a race engine) lies in maximizing inlet and exhaust efficiencies, minimizing frictional losses , optimizing combustion efficiencies, minimizing heat losses to cooling systems, and minimizing the overall weight of the actual engine as this weight requires power to be accelerated and decelerated in the car on the track.

Another aspect that determines how much power an engine can produce is the displacement of the engine (volume that it can pump when completing one cycle -in this case this is two revolutions). Usually, racing governing organizations regulate this part and many other aspects of the engine for their particular series.

Assuming there is a maximum displacement allowed by the rules, it is obviously impossible to increase the speed of the engine beyond the mechanical limits of the components used in the engine, so there is a practical limit to the ultimate output of a spark-ignited engine due to this constraint alone.

For our Porsche air cooled racing engines we are primarily dealing with one intake and one exhaust valve mounted across from each other in a hemispherical combustion chamber with either one or two spark plugs. The sides of the piston and are machined such that they come very close to the sides of the combustion chamber and, generally speaking, the intake and exhaust valves require relieve pockets in the piston shape to provide adequate clearance for these components. At the end of the compression stroke when all of the air/fuel 'trapped' in the cylinder gets ignited by the spark plug, the piston almost touches the cylinder head and squishes the mixture from the sides into a smaller sub-volume. This squish of the air and fuel mixture generates a very fast and turbulent velocity which enhances the combustion process and reduces the tendency to detonate (see article on detonation). There is a certain time element required for the mixture to 'burn' all the way. The 'burning' of the mixture cause the gases of combustion to expand and in so doing creates a large increase in pressure inside the piston/cylinder. Obviously there is a maximum pressure that is possible (based on the amount of mixture present during combustion). The moment in time of this pressure peak relative to the position of the piston in the engine is also very important to maximize conversion of as much of this pressure into shaft work (by the piston). Most Otto Cycle engines benefit from having this peak occur at ~14 degrees after the piston passed through top dead center (TDC). In order to 'match' these criteria, the time when the spark is given to start the ignition relative to the engine position is carefully set. Some engines with single spark plugs and relatively 'inefficient' combustion chambers may require the spark to be ignited up to 40 degrees before TDC just so that the maximum pressure peak coincides with the ~14 degrees after TDC that is desirable for the mechanical conversion of this energy. This means that the mixture burned for a total of 54 degrees of engine rotation to reach the optimal value. The side effect of this phenomenon is the work required by the engine to move the piston to TDC such that any pressure rise could actually do the work as opposed to requiring work to be done on it. Clearly it is beneficial to have a combustion chamber system that requires less timing advance and still provide the optimal peak pressure point. Converting the engine to dual plug does this as it ignites the mixture from two sides and reduces the amount of spark advance required. Proper squish control and the associated "quench" it provides is another element that can be used to influence this process. Lastly, the actual shape of the piston with respect to the combustion chamber and valves also has an effect on this efficiency of combustion.

The challenge is that the combustion process (combustion efficiency) is linked to the process used to get air/fuel into the engine (volumetric efficiency) via the shape of the combustion chamber, the piston and the valves. Depending on circumstances, it may be beneficial to trade off combustion efficiency to gain volumetric efficiency if we can achieve a higher total pressure peak due to more mixture being available (in spite of it perhaps being burned a little less efficiently).

The process used to get the mixture into the engine (volumetric efficiency) is linked to the process of expelling the gases of combustion from the engine once their function has been completed. In fact, there is a portion of the cycle where the exhaust valve and the intake valve are open simultaneously while the piston is rising in the cylinder. One would think that this is detrimental since intake charge (fresh air and fuel) could go directly into the exhaust. The fact is that this “linking” between intake and exhaust allows us to use some of the kinetic energy in the exhaust to act on the intake (like creating a low pressure moment that “pulls” the intake into the cylinder in spite of the piston moving up rather than down).

This example illustrates a trade off between combustion efficiency and volumetric efficiency. As long as the increase in volumetric efficiency exceeds the decrease in combustion efficiency, horsepower will continue to increase. Through extensive research and DYNO testing Elite has determined the optimal trade offs, and has designed each of its individual engine components so that they function most effectively together to generate maximum horsepower.