Some Thoughts on Squish Action

1. Introduction

During the last 35 years, but more so during the last 18 months I have been taking an intensive look at the effects of squish. This is part of an attempt to include a combustion model into simulation software where the model calculates its parameters rather than having it prescribed by the user. Determining the values to prescribe combustion accurately one requires a fairly sophisticated engine test cell with the capability to record combustion pressure traces. As part of this exercise I have changed my views on squish quite a bit. Some of what I found will be described next.

2. Turbulence

Discussing squish without first taking a brief look at turbulence is a waste of time as the main function of squish is to increase the turbulent intensity in the combustion chamber. Without turbulence in the combustion chamber we would burn the mixture at the laminar burning rate which is ten to twenty times slower than the turbulent rate. This would make practical engines that rev higher than about 1500rpm an impossibility.

Turbulence in a 2stroke engine is caused by three mechanisms. The first and most important of these is the scavenging process. The kinetic energy of the inflowing scavenge streams is converted at a specific rate to turbulent kinetic energy which leads to an increase in turbulent intensity. At the same time this turbulent intensity is being damped out by the viscosity of the fluid (air/fuel mixture) and converted to heat. From this there follows at least the following two conclusions:

- The turbulence generated by the scavenging process influences the combustion rate so it is to be expected that a 2port system will have different combustion characteristics from a 7port system.
- The faster an engine turns the less time there will be for the turbulence to be damped out by the viscosity thus increasing rpm will, inside some limits, increase the burn rate provided that the turbulence created by the scavenging process does not decrease faster with the increase in rpm.

The next generator of turbulence is the piston movement. As the piston displaces fluid during the up stoke it imparts kinetic energy to the fluid which gets converted at a certain rate to turbulence. Obviously this increases with rpm so higher rpm will have a higher turbulent intensity and thus faster burn rate unless the dissipation rate is greater than the generation rate.

And then, the third generator of turbulence is the squish action. The squish action causes gas to flow towards the center of the cylinder. The speed of this flow is what we calculate with various pieces of software and is known as MSV or maximum squish velocity. Now to repeat what has been said in the previous two paragraphs; this kinetic energy is converted to turbulence at a rate depending on the conditions inside the cylinder at that time. Also, MSV is a function of squish band geometry and rpm. This leads to the following conclusions:

- As rpm increases so does MSV, and so does the available kinetic energy that can be converted to turbulent intensity. If this does get converted the burn rate will increase.
- As the squish area ratio increases and or the squish clearance decreases the MSV also increases with the same results as for the previous point.

The picture that emerges from this is that depending on the residual turbulence in the cylinder at the time of the squish action, the squish action can either increase the turbulent intensity or have no effect on the turbulent intensity. This can translate into some of the following:

- On an old 2stroke with two transfer ports and high primary compression the squish action can increase the burn rate so much that maximum pressure occurs so early that a large amount of negative work is done, a lot of heat is generated and power is lost unless the timing can be adjusted. On older engines that can sometimes not be done so a squish head is detrimental.

- On some engines the increased turbulent intensity can shorten the burn times after max power so much that it kills over-rev. On others where the burn time was too long it can improve over-rev.

- If the port and pipe combination is a bad mismatch that loses a lot of fresh charge (and thus kinetic energy) during the open cycle increasing the MSV will usually help such an engine and vice versa.

There are many more such examples but the general trend is clear: Without knowledge of the turbulent intensity inside the combustion chamber at the time of combustion it is not possible to say whether the engine needs more or less squish.

3. Squish Action

There are unfortunately not many papers published on squish action, mostly because in most 4strokes it is of lesser value. They have to make space for valves which is more important. They do however generate turbulence through tumble and swirl which is not really practical for loop scavenged 2stroke engines. There is one class of 4stroke engines that use squish though and that is the diesel engines with the bowl in piston type combustion chamber.

Measurements on these engines have shown that the calculated squish velocity using the MSV equations corresponds well with the measured results. The conclusion is that the MSV calculation is acceptable, the problem is with its value.

Another side effect of the increased squish velocity is that the convection heat transfer between the gas and the piston and head is increased. This is often claimed as the primary reason to use squish action to stop detonation. Preliminary calculations have shown that this effect, especially in high revving engines, is almost negligible.

4. Combustion Picture

To help with forming a better mind picture of the combustion process a simulation was done on an YZ250U engine and the dimensions of the burnt sphere of gas calculated for each time step. This, together with the piston position from TDC was written to file and a series of seven pictures generated from this.

A squish clearance of 1.2mm and a squish area ratio of 50% were used. This resulted in a MSV of 33m/s at 10deg BTDC.

In the model the following assumptions were made:

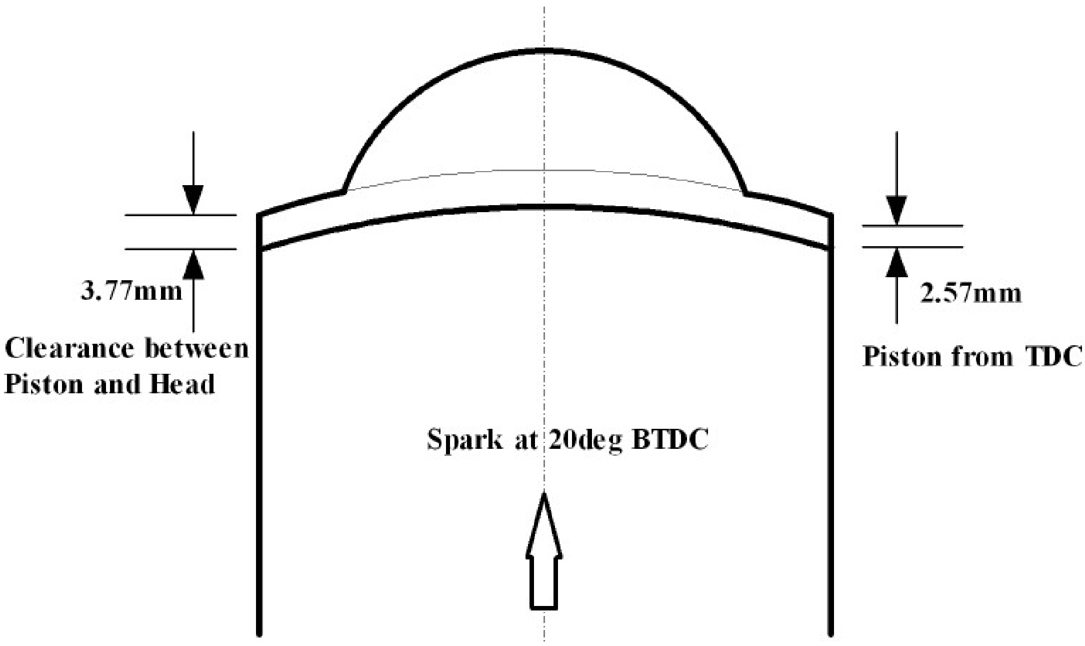
- Combustion proceeds in a spherical shape. This is not far from reality but without a detailed computational fluid dynamic simulation not possible to predict.

- The ignition timing is set at 20deg BTDC. For the tested engine it was 19deg but as the pictures were generated at 10deg intervals this was changed.

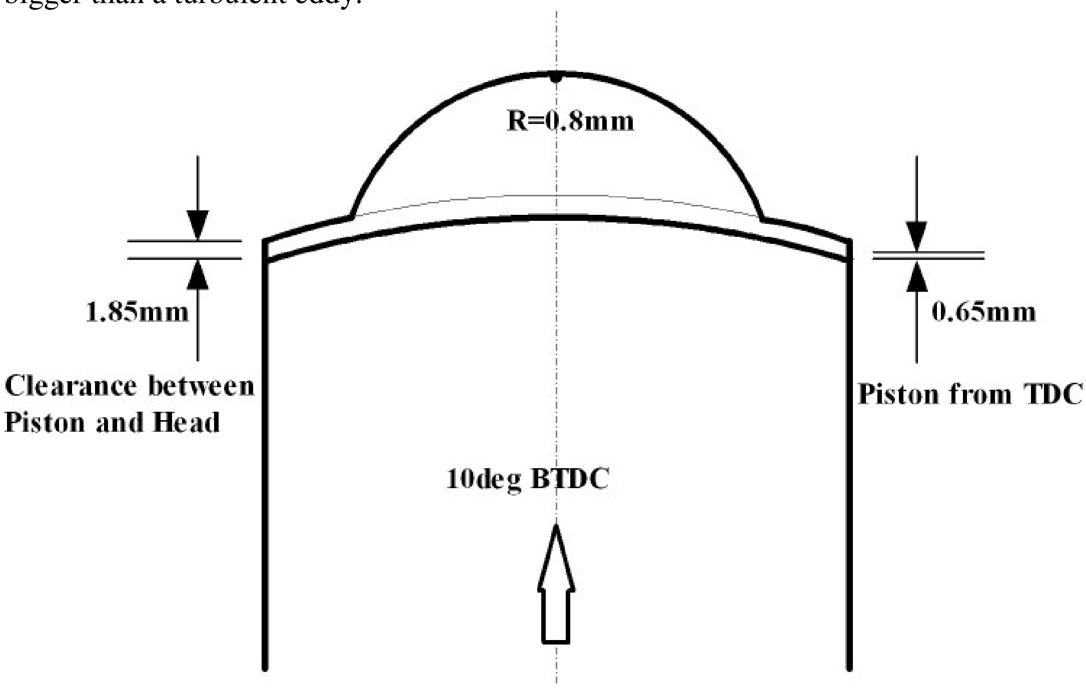
- The measured delay period was 9deg but this was changed to 10deg to get the combustion to start at the measured position and to correspond to a 10deg interval.

- The actual combustion period was 51deg but was changed to 50deg once again to correspond to the 10degree intervals.

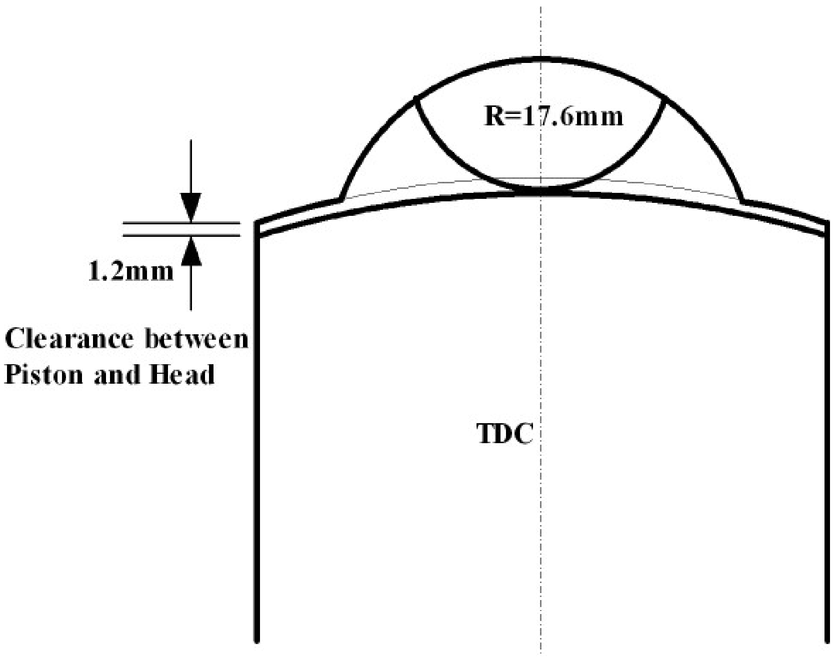
The first picture shows to scale where the piston is relative to the combustion chamber at the point of ignition.



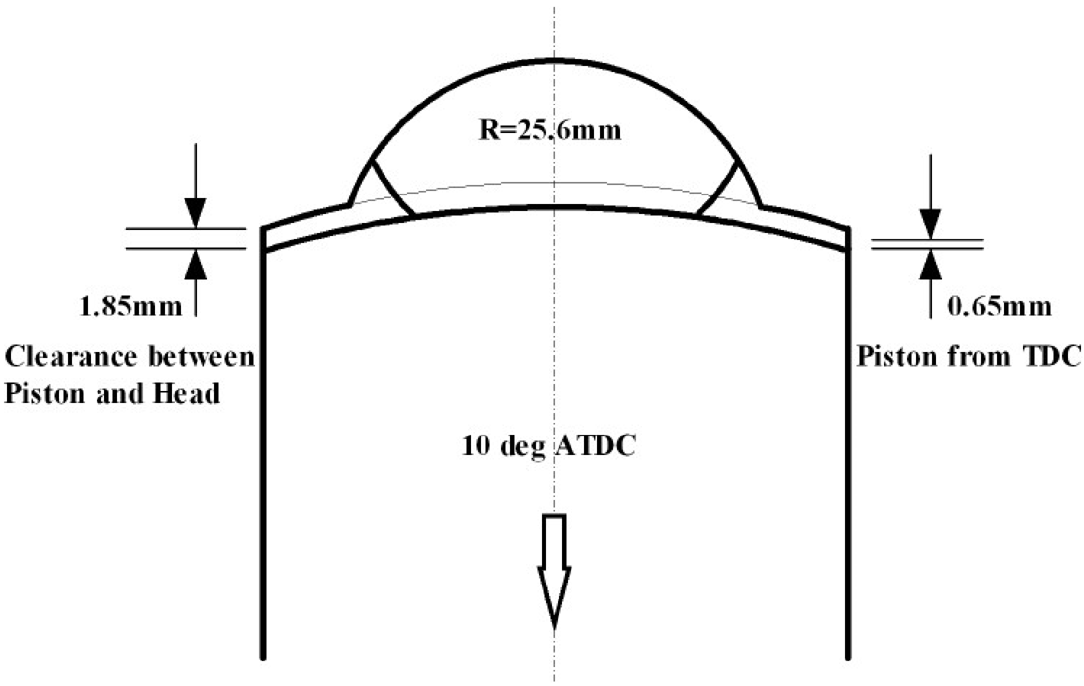
The second picture shows the piston position at the end of the delay period and thus the start of turbulent combustion (10deg BTDC). This is also the point where the squish velocity is at a maximum (MSV). The flame kernel is now bigger than a turbulent eddy.



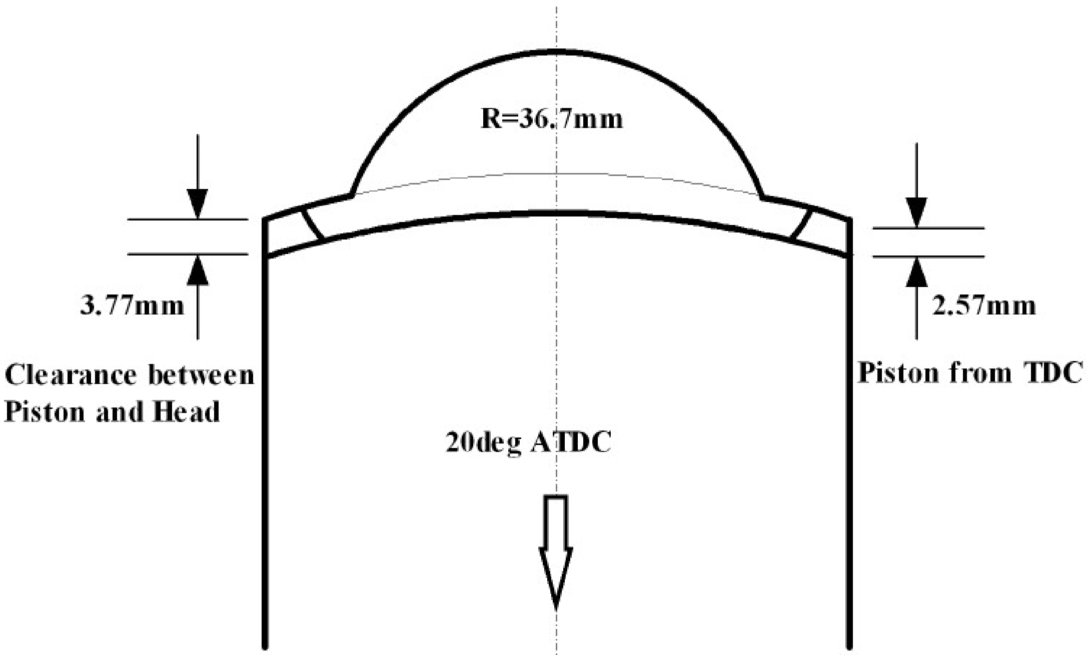
The next picture shows the piston at TDC. As can be seen the flame sphere has grown substantially in size and is just beginning to touch the piston crown. If a plug with a protruding tip was used the flame would have touched the piston a few degrees sooner.



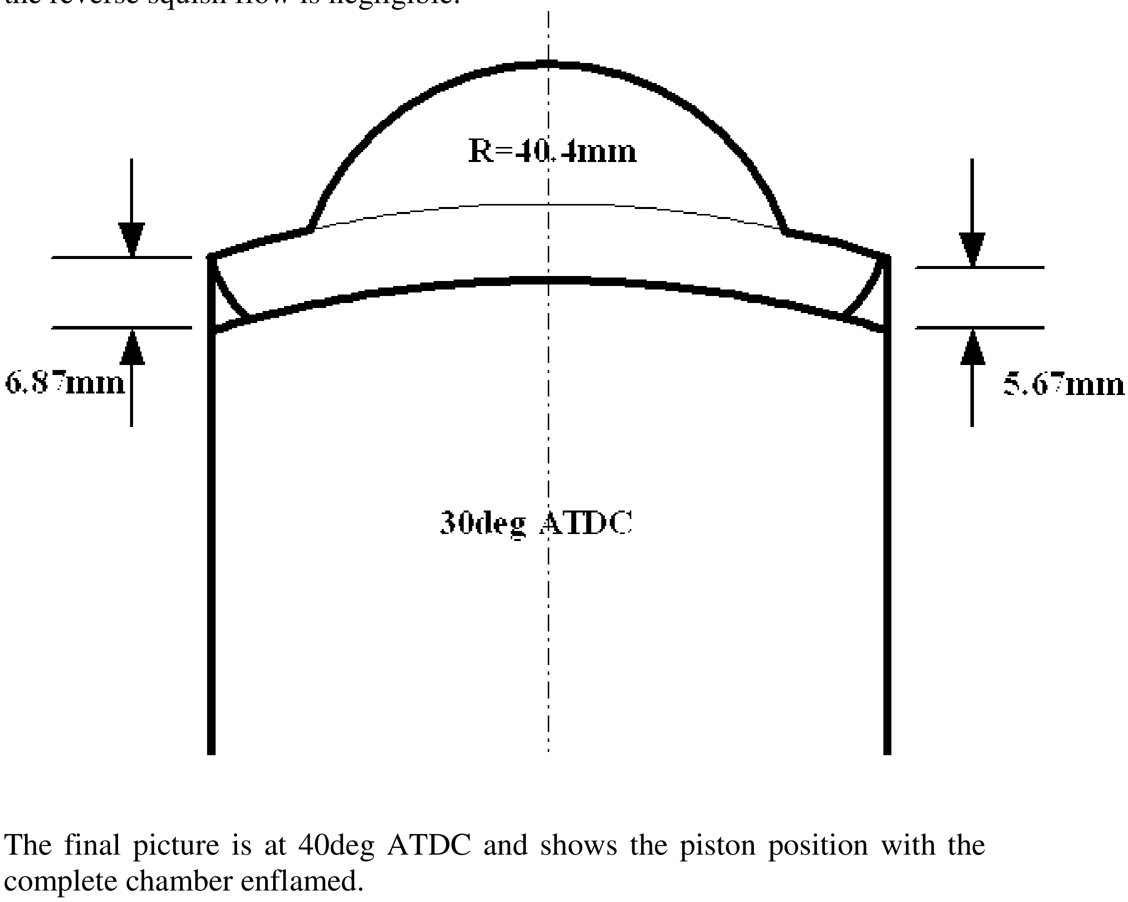
At 10 degrees after TDC the hemisphere of the chamber is almost fully enflamed and the flame front is on the point of moving into the squish area. As can be seen the squish area is rapidly opening up and will be experiencing reverse flow.



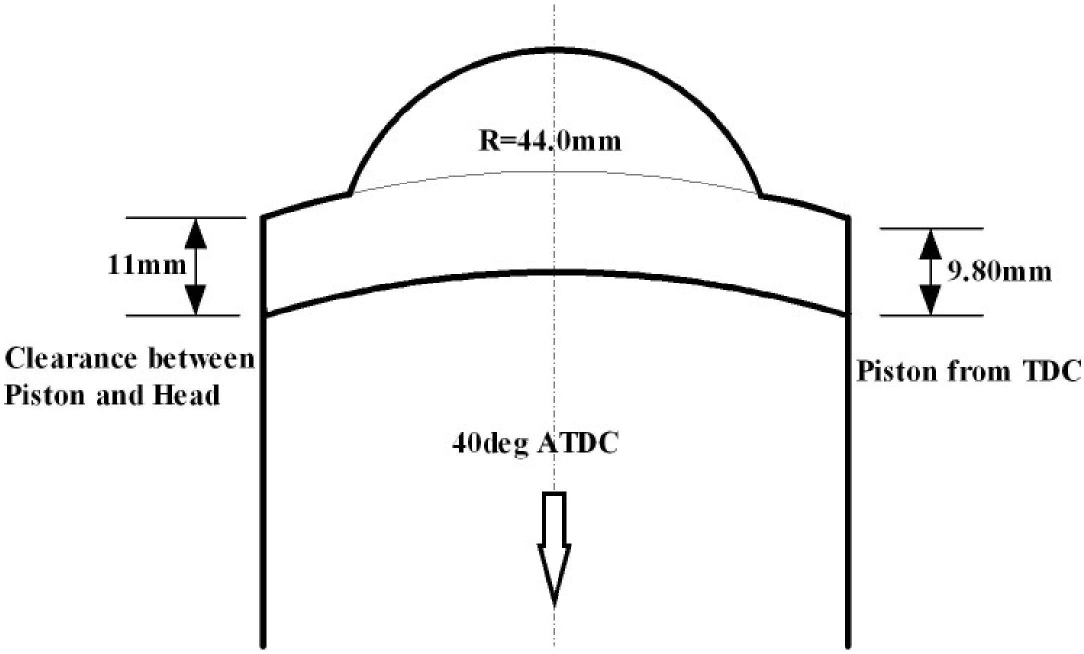
At 20deg ATDC the flame front is about halfway into the squish area and the squish clearance is quite big already. No chance of the flame in the squish area getting quenched.



At 30deg ATDC the squish area is now fully enflamed and only a small part of the piston crown and of the cylinder bore is not yet enflamed. At this point even the reverse squish flow is negligible.



The final picture is at 40deg ATDC and shows the piston position with the complete chamber enflamed.



This is still way before the exhaust port opens which points to the fact that for burning mixture to exit the exhaust port something serious has to be wrong with the combustion process.

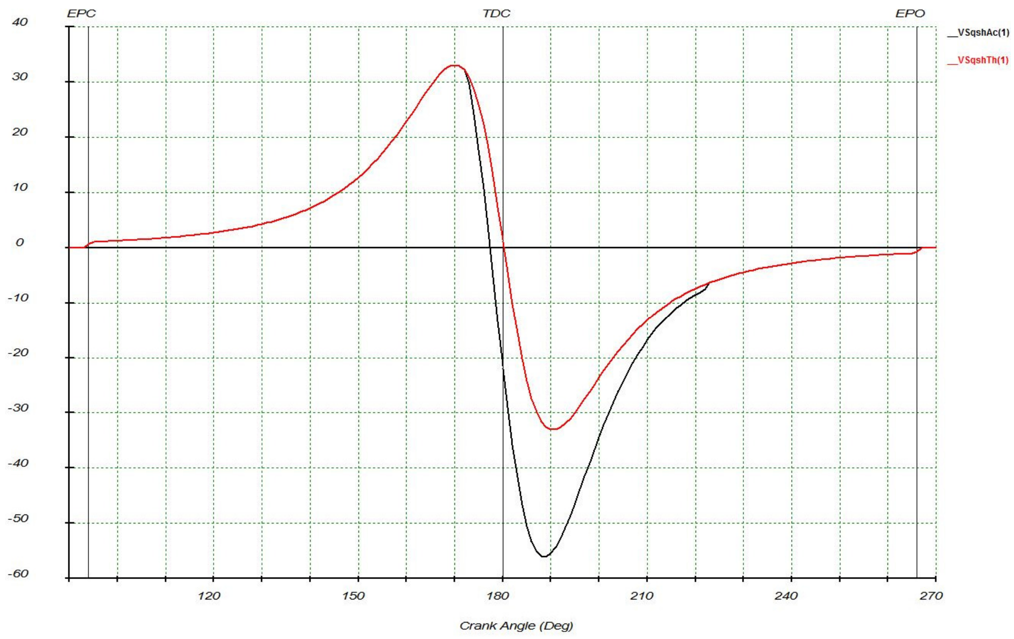
5. Squish Velocity

During the simulation the squish velocity is also calculated. This is done in two ways:

- Theoretical Velocity – this uses the volume change from the piston motion
- Actual Velocity – this uses the volume and pressure change

Up to the end of the delay period these are the same but once combustion starts the expansion of the burnt zone slows down and reverses the squish flow even though the piston is still moving up.

The next plot shows the two values plotted for this simulation. It is clear that reverse squish flow happens well before TDC and from new publications (from the four stroke world!) reverse squish also plays a major role. The red line is the theoretical value and the black line the “actual” value.



6. Summary

So what have we learned:

- As far as squish is concerned whether it helps or not depends on the residual turbulence at the time of combustion.

- As for squish quenching the flame at the edge of the squish band to stop detonation is not looking very likely.

This is not the final word on the subject. As I learn more I keep changing my mind and I am sure it will continue to happen for a while yet. Hopefully somebody reading this will be able to help me right where I am still misunderstanding squish and definitely turbulence!