An Investigation into measuring Chapman-Jouguet Pressure in a Cylinder Expansion Test

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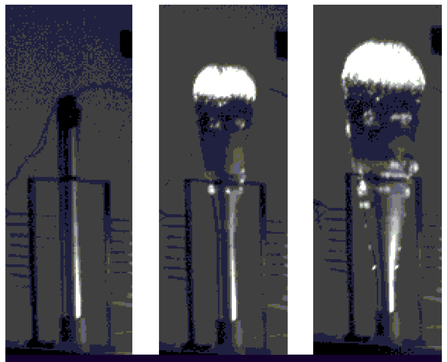
Summary
A series of Cylinder Expansion (CylEx) experiments were conducted to compare an experimental set-up for determining the Chapman-Jouguet pressure (P_{CJ}) with two new methods: DALEX and McDAX. The new methods utilised heterodyne velocimetry to make the measurements with the view to replace Manganin stress sensors. Thirteen firings were conducted in total with the plastic explosive PE8; one with a steel tube and twelve with copper tubes. The resultant measurements of the velocity of detonation (VoD) and calculation of the Chapman-Jouguet pressure (P_{CJ}) for PE8 were compared to one another, those for other explosive materials and to previous work undertaken by the author. The existing method was shown to be affected by the planarity of the shock wave down the tube which gave a low precision or reliability in the results. The DALEX method, which involved measuring the velocity of a free-flying copper plate, allowed for two calculation methods, doubling the chance of a result being calculated and increasing the reliability of the method. The McDAX method, which involved measuring the particle velocity of a copper plate in a PMMA window, was found to be the most accurate of the methods investigated. The reliability of the DALEX method could be further improved in future work by using a thicker plate to improve its rigidity.

It is hoped that the use of DALEX and McDAX for future cylinder expansion tests will improve the quality of the data captured and therefore the models based upon that data leading to more accurate predictions of explosives behaviour, better validation and comparison of different materials and an improved ability to compare data between different government institutions.

Cylinder Expansion (CylEx)
A CylEx test consists of an annealed C101 half hard copper tube, with a wall thickness one tenth of the tube diameter and a length of 12 times the diameter, filled with an explosive material [1].
When the explosive fill is detonated, the copper tube begins to expand in a cone-like shape as can be seen right.
Its behaviour through the test is measured using several instrumentation techniques. Heterodyne velocimetry (het-v) is used to measure the wall expansion, pins measure the velocity of detonation (VoD). Stress sensors measure the Chapman-Jouguet pressure at the base of the tube.



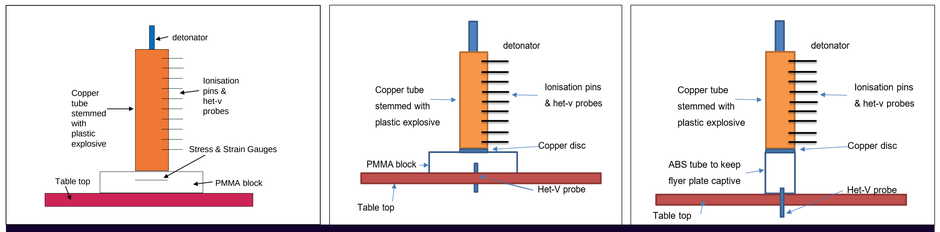
Series showing a PE8 filled copper tube being expanded into ionisation pins following detonation at the top.

Chapman-Jouguet Pressure (P_{CJ})
The P_{CJ} is the gas pressure of the reactants at the point they start to expand behind the reaction zone. A material's VoD and P_{CJ} can be found from experimentally recorded measurements, and the P_{CJ} can be calculated from the VoD

Velocity of Detonation (VoD)
The VoD is the velocity at which the reaction zone, immediately behind the shock wave, passes through a material and it is always supersonic for a detonation.

McDAX
McDAX is a variation on the CylEx test which uses a copper foil in a PMMA block at the base of the tube in place of the stress sensor [2]. The shock from the explosive passes into the foil generating a particle velocity (U_P) inside the foil. The velocity is proportional to the Chapman-Jouguet pressure and varies with the density of the copper plate and explosives. The particle velocity goes through multiple states; the first is related to the Von Neumann spike, the P_{CJ} is in between the third and fourth.

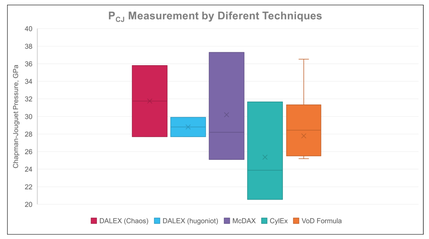
DALEX
A combination of the Disc Acceleration Experiment (DAX) and Cylex to reduce the uncertainties in each [3].
The same copper tube and ionisation pins are used as in CylEx but the stress sensor is replaced with a copper flyer plate.
The particle velocity and velocity of the plate are measured with heterodyne velocimetry. Together with the densities of the explosives, plate and velocity of detonation, the particle velocity and flyer plate velocity can each be used to calculate the Chapman-Jouguet Pressure. The flyer plate velocity uses a formula developed by Chaos [4]. The particle velocity uses a formula based on the Hugoniot curves [3].

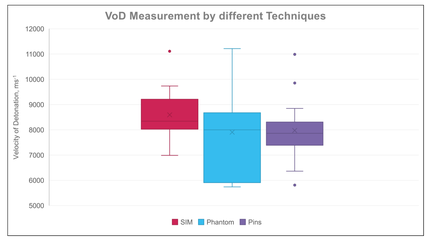


The three experimental set-ups; Standard CylEx (left), McDAX (centre) & DALEX (right)

Results
The P_{CJ} for RDX which is the main constituent of PE8 [5] is 30GPa [6], therefore the DALEX set-up with the Chaos formula appears to be the most precise and accurate. The two measurements techniques also give increased reliability in the DALEX set-up.
Improvements to the het-v measurements, such as using a thicker flyer plate, would improve the McDAX and DALEX measurements and the results from the Hugoniot formulas.
The accuracy and precision of the VoD formula is dependent on the set-up of the VoD measurement (see bottom right graph) which could be improved by using different techniques such as Chirped Fibre Bragg Gratings (CFBG).
The effect of changes in the explosives density down the tube should be investigated further.

Method	P_{CJ} (Gpa)	σ (Gpa)
Cylex	25.4	5.7
McDAX	30.2	6.3
DALEX (Chaos Formula)	28.8	1.9
DALEX (Hugoniot Formula)	31.8	6.1
VoD Formula	27.8	5.8





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