VERIFICATION - CALIBRATED EXPLOSIVES

Solver version: 8.1.603
Date: October 2, 2023

https://www.impetus.no

Introduction

This document presents the verification of the calibrated explosives available in the software.

There are currently 16 calibrated explosives available in the software. Explosives are calibrated and added on request from users. Users can also calibrate explosives on their own with the object ”Controlled expansion test”, available on IMPETUS Market.

Version control

The tests presented in this document are subjected to version control, meaning that the models are run and evaluated prior to release of a new solver. This document is updated in conjunction with official releases of the software.

Calibrated explosives

The discrete particle module currently offers the following calibrated explosives:

- ANFO
- C4
- COMP. A-3
- COMP. B (grade A)
- HMX
- LX-10-1
- LX-14-0
- MCX-6100
- NSP-711
- OCTOL 78-22
- PBXN-110
- PBXN-9010
- PETN
- TETRYL
- TNT
- m/46

Calibrated explosives are included to an analysis with the command *PARTICLE_HE.

Explosives in the discrete particle module

Explosives are defined by the following parameters in the discrete particle module:

ρ_0	-	Density of undetonated composition
e_0	-	Energy per unit volume
γ	-	Fraction between C_p and C_v at zero co-volume (ideal gas regime)
v	-	Co-volume at $\rho = \rho_0$
D	-	Detonation velocity

ρ_0, e_0 and D are found in literature whereas γ and v must be calibrated. For the calibrated explosives, the calibration was done with the model described in section "Controlled expansion test". Parametric values used for the calibrated explosives are presented in Table 1.

Table 1: Data of explosives available in the software. ρ_0, e_0 and D are taken from Ref. whereas γ and v are calibrated.

Explosive	ρ_0 [kg/m^3]	e_0 [GPa m^3/ m^3]	γ [-]	v [-]	D [m/s]	Ref.
ANFO	782	2.9	1.280	0.235	5000	2
C4	1601	9.0	1.270	0.347	8193	1
COMP. A-3	1650	8.9	1.442	0.259	8300	1
COMP. B (grade A)	1717	8.5	1.428	0.270	7980	1
HMX	1891	10.5	1.345	0.334	9110	1
LX-10-1	1865	10.4	1.606	0.211	8820	1
LX-14-0	1835	10.2	1.576	0.222	8800	1
MCX-6100	1710	7.6	1.404	0.262	7486	3
NSP-711, m/46	1500	7.05	1.315	0.308	7680	4
OCTOL 78-22	1821	9.6	1.598	0.210	8480	1
PBXN-110	1672	8.7	1.375	0.283	8330	5
PBXN-9010	1787	9.0	1.451	0.276	8390	1
PETN	1770	10.1	1.621	0.188	8300	1
TETRYL	1730	8.2	1.442	0.265	7910	1
TNT	1630	7.0	1.299	0.315	6930	1

Controlled expansion test

The model consists of the explosive under consideration, detonated inside a confined volume as visible in Figure 1. The confined volume is increased gradually in a prescribed manner from 1.05 to 5.0 times the volume of the undetonated charge. A discrete particle sensor is positioned in the explosive and the pressure in this sensor is compared to the pressure calculated with the JWL (Jones-Wilkins-Lee) equation of state.

Parameter γ and v are calibrated so that the pressure in the sensor match the pressure from the JWL equation of state for the investigated range of volume.

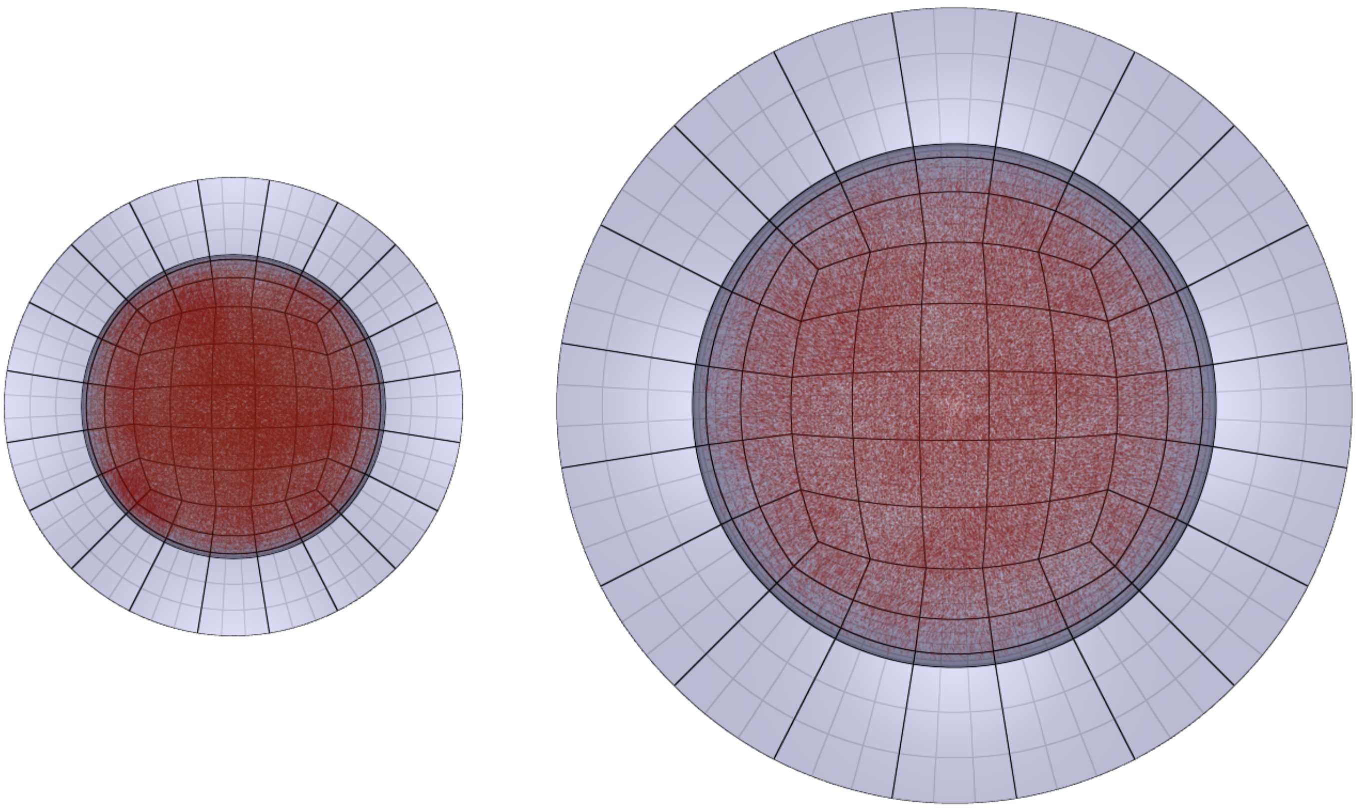

Figure 1: The model of the controlled expansion test in which parameter γ and v are calibrated. The confined volume is increased gradually from the initial state (to the left) to the final state (to the right).

The JWL equation of state is defined as:

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega e_0}{V}$$

P	-	Pressure
V	-	Ratio volume detonation products and volume undetonated explosive
A and B	-	Linear coefficients
R_1, R_2 and ω	-	Non-linear coefficients
e_0	-	Energy per unit volume

JWL coefficients used in the calibration of the explosives are presented in Table 2. Energy per unit volume is presented in Table 1.

Table 2: Coefficients for the JWL equation of state. All coefficients are taken from Ref.

Explosive	A [GPa]	B [GPa]	R_1 [-]	R_2 [-]	ω [-]	Ref.
ANFO	75.2	-0.82	4.1	1.25	0.44	2
C4	609.8	12.95	4.5	1.4	0.25	1
COMP. A-3	611.3	10.65	4.4	1.2	0.32	1
COMP. B (grade A)	524.2	7.68	4.2	1.1	0.34	1
HMX	778.3	7.07	4.2	1.0	0.30	1
LX-10-1	880.7	18.36	4.62	1.32	0.38	1
LX-14-0	826.1	17.24	4.55	1.32	0.38	1
MCX-6100	759.8	7.0	4.88	1.10	0.35	3
NSP-711, m/46	759.9	12.56	5.1	1.5	0.29	4
OCTOL 78-22	748.6	13.38	4.5	1.2	0.38	1
PBXN-110	950.4	10.98	5.0	1.4	0.40	5
PBXN-9010	581.4	6.8	4.1	1.0	0.35	1
PETN	617.0	16.93	4.4	1.2	0.25	1
TETRYL	586.8	10.67	4.4	1.2	0.28	1
TNT	371.2	3.23	4.15	0.95	0.30	1

The pressure from the sensor and the pressure calculated with JWL equation of state for all calibrated explosives are presented in Figure 2 - Figure 16. The left plot in these Figures shows the pressure with linear scale whereas the right plot shows the pressure with logarithmic scale.

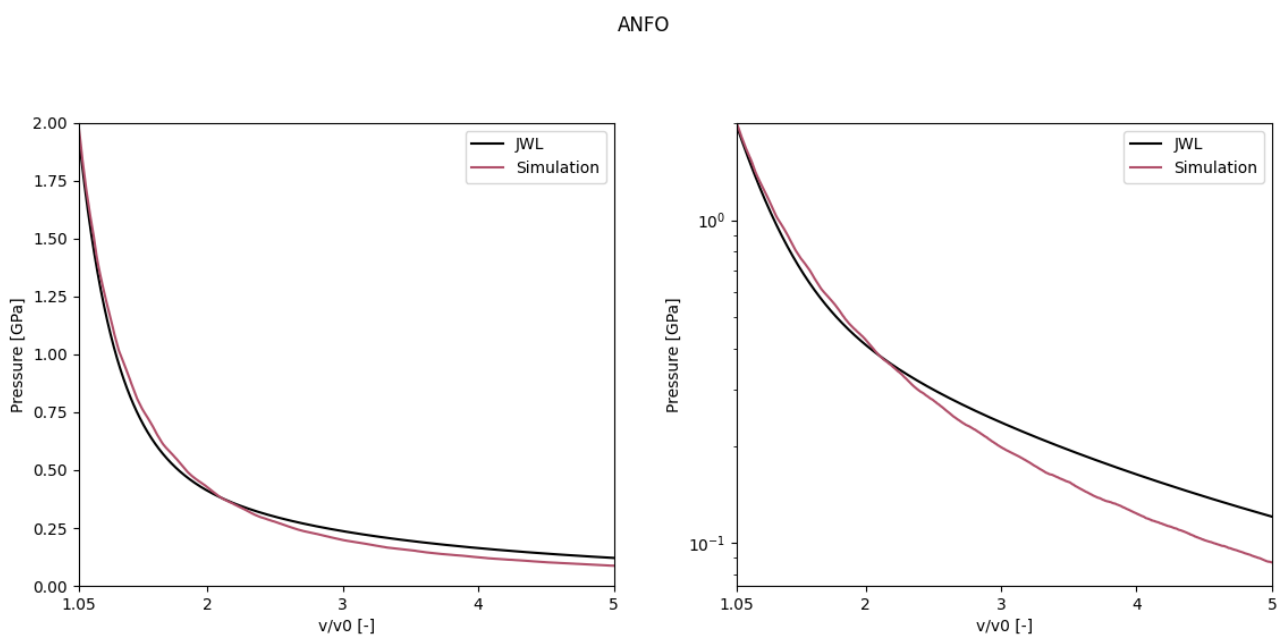

Figure 2: Results from the controlled expansion test with calibrated ANFO.

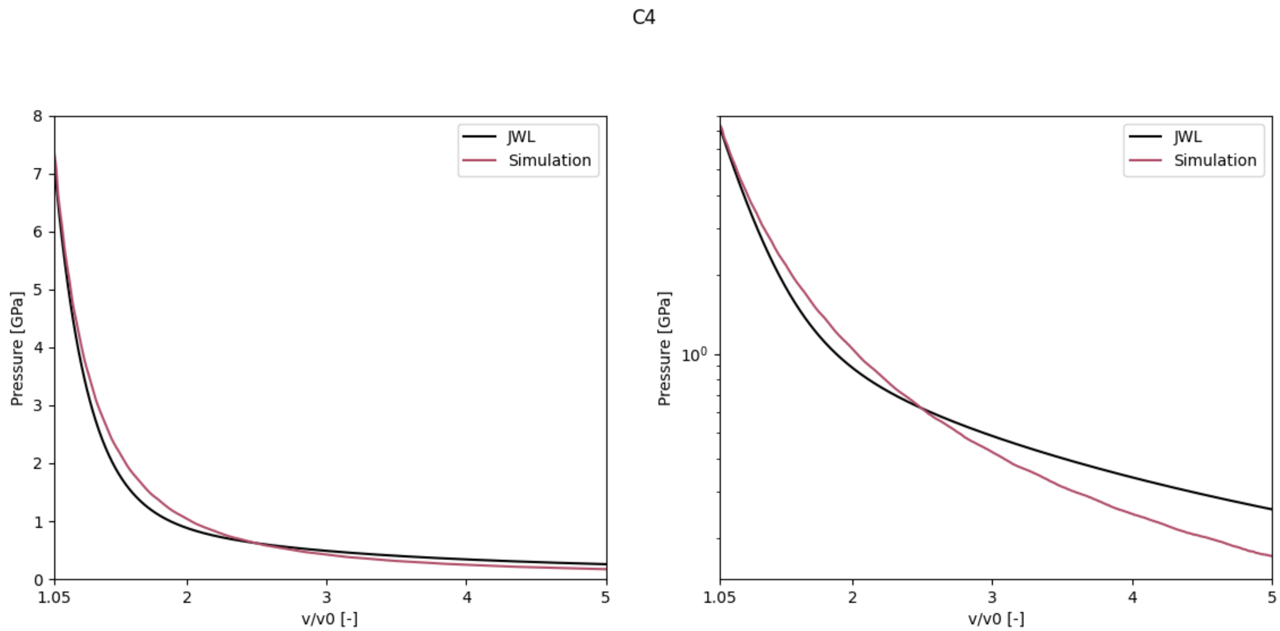

Figure 3: Results from the controlled expansion test with calibrated C4.

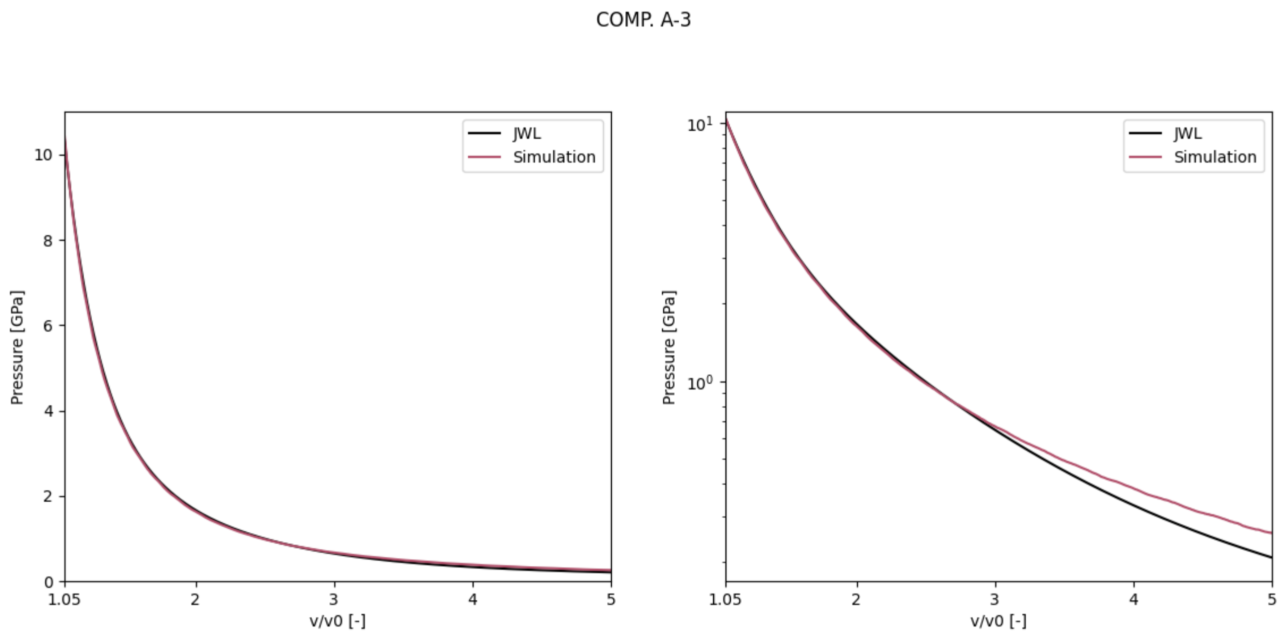

Figure 4: Results from the controlled expansion test with calibrated COMP. A-3.

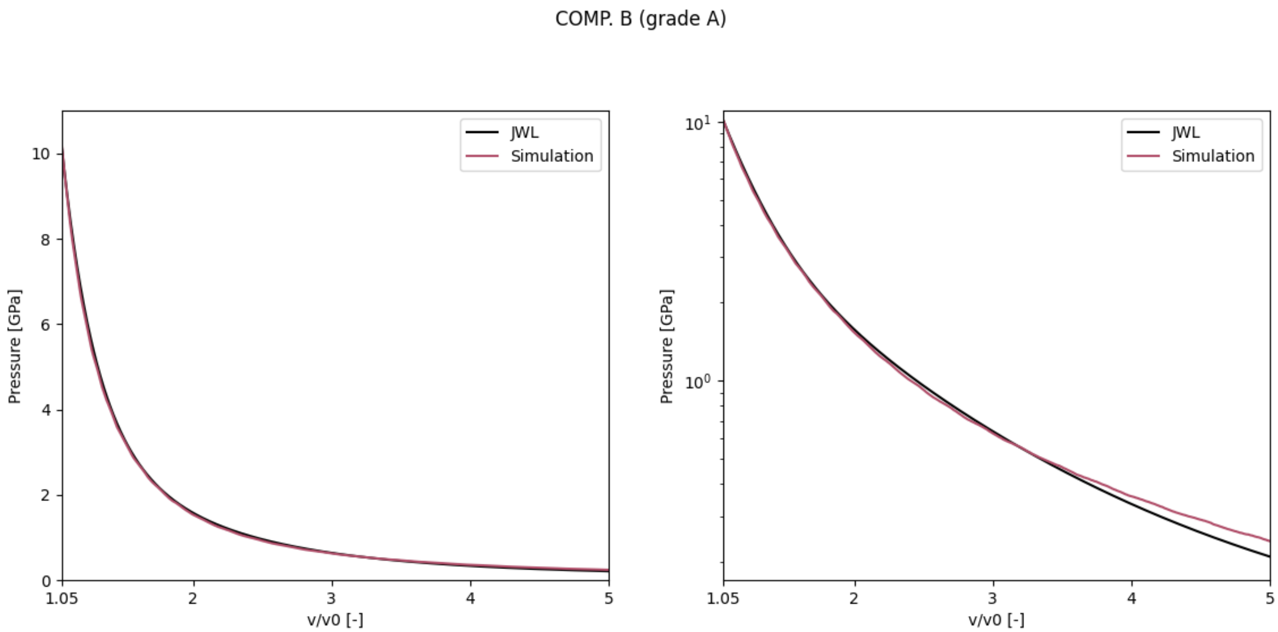

Figure 5: Results from the controlled expansion test with calibrated COMP. B (grade A).

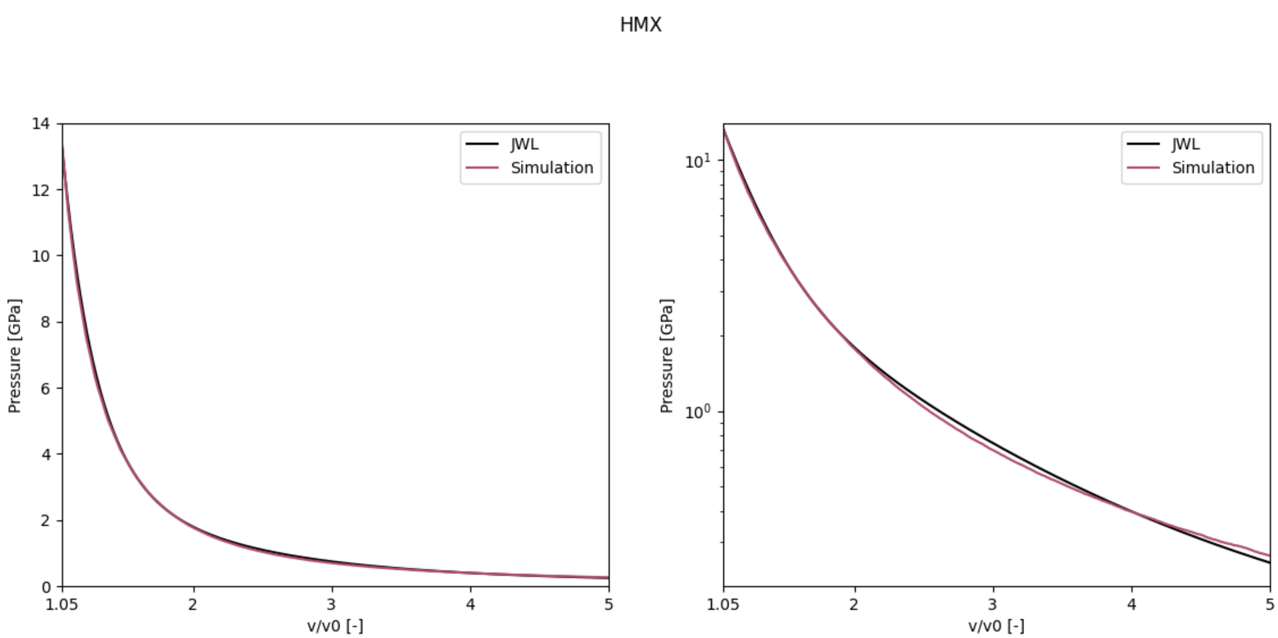

Figure 6: Results from the controlled expansion test with calibrated HMX.

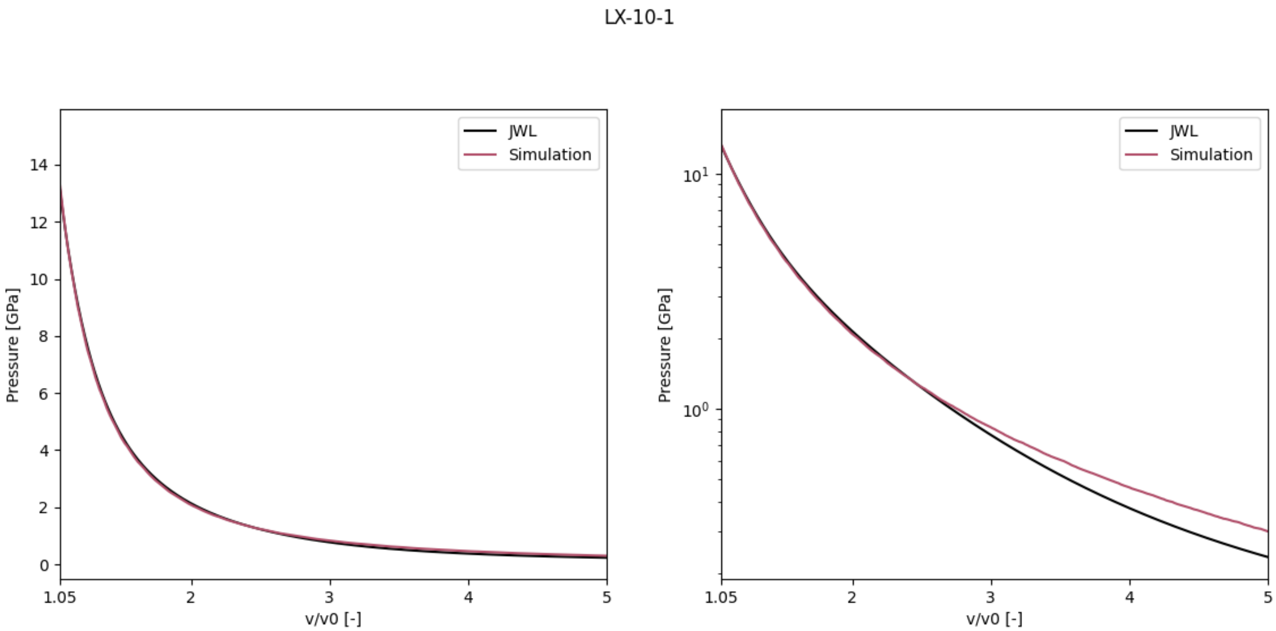

Figure 7: Results from the controlled expansion test with calibrated LX-10-1.

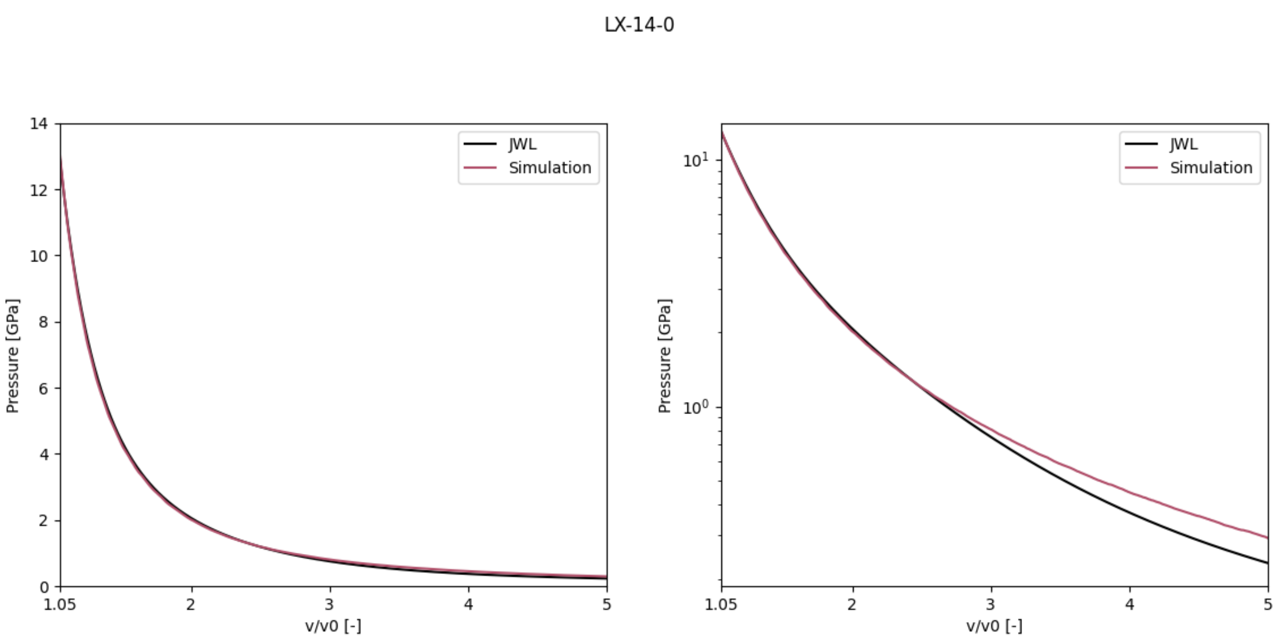

Figure 8: Results from the controlled expansion test with calibrated LX-14-0.

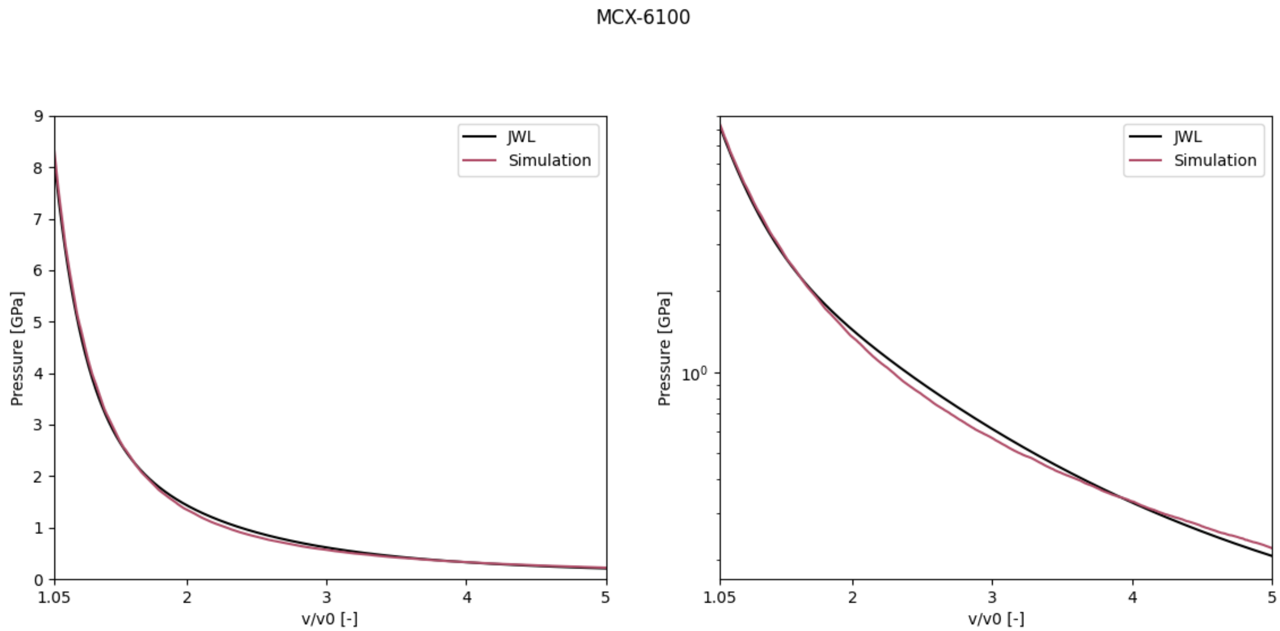

Figure 9: Results from the controlled expansion test with calibrated MCX-6100.

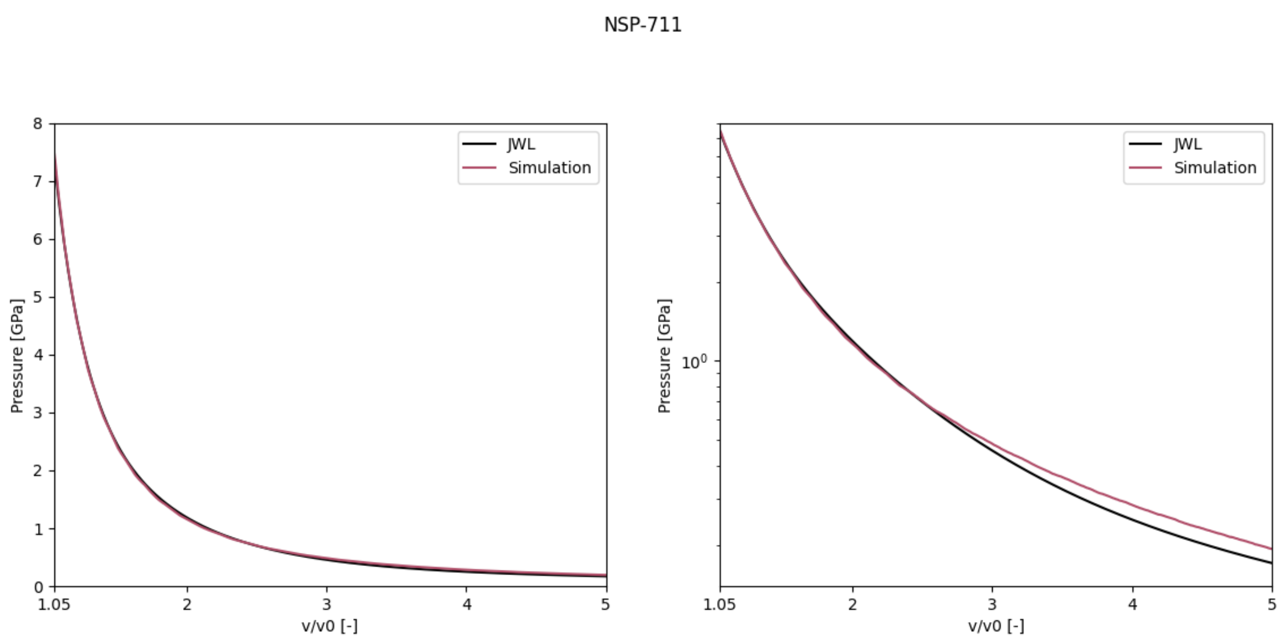

Figure 10: Results from the controlled expansion test with calibrated NSP-711, m/46.

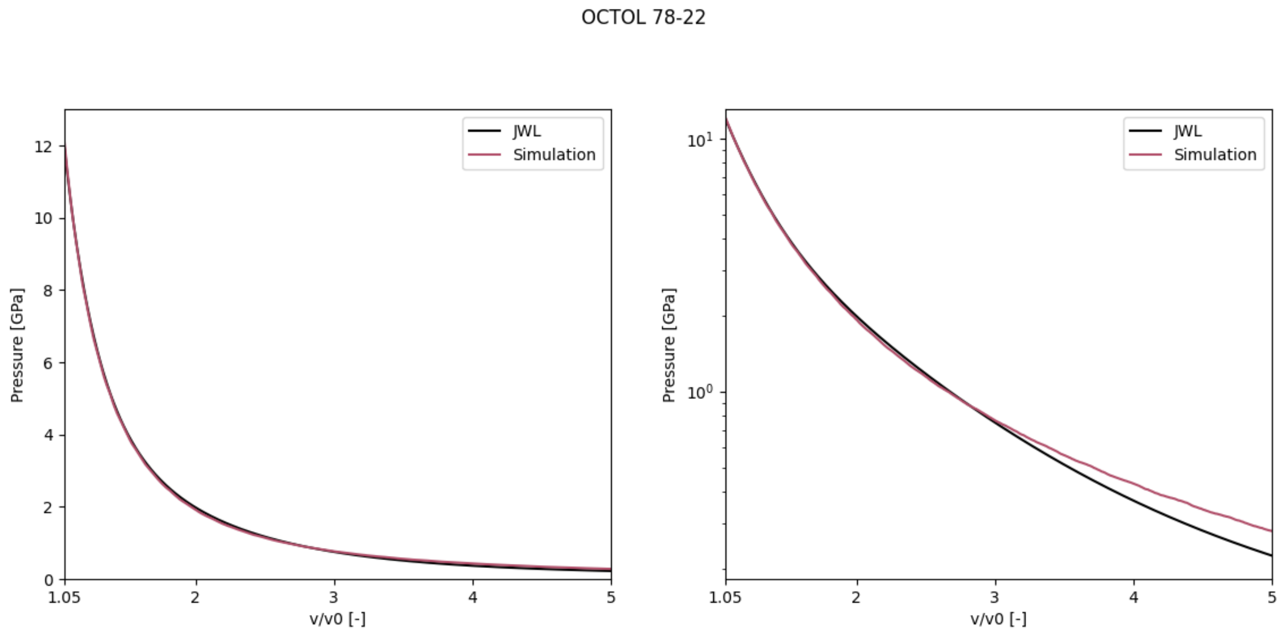

Figure 11: Results from the controlled expansion test with calibrated OCTOL_78-22.

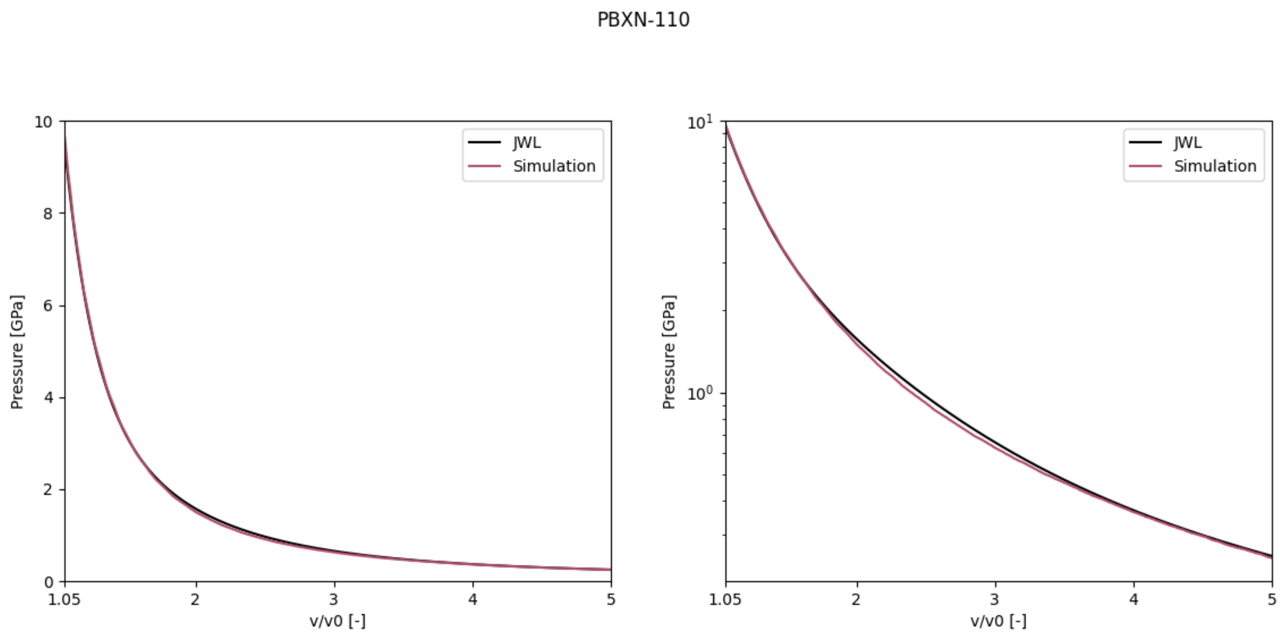

Figure 12: Results from the controlled expansion test with calibrated PBXN-110.

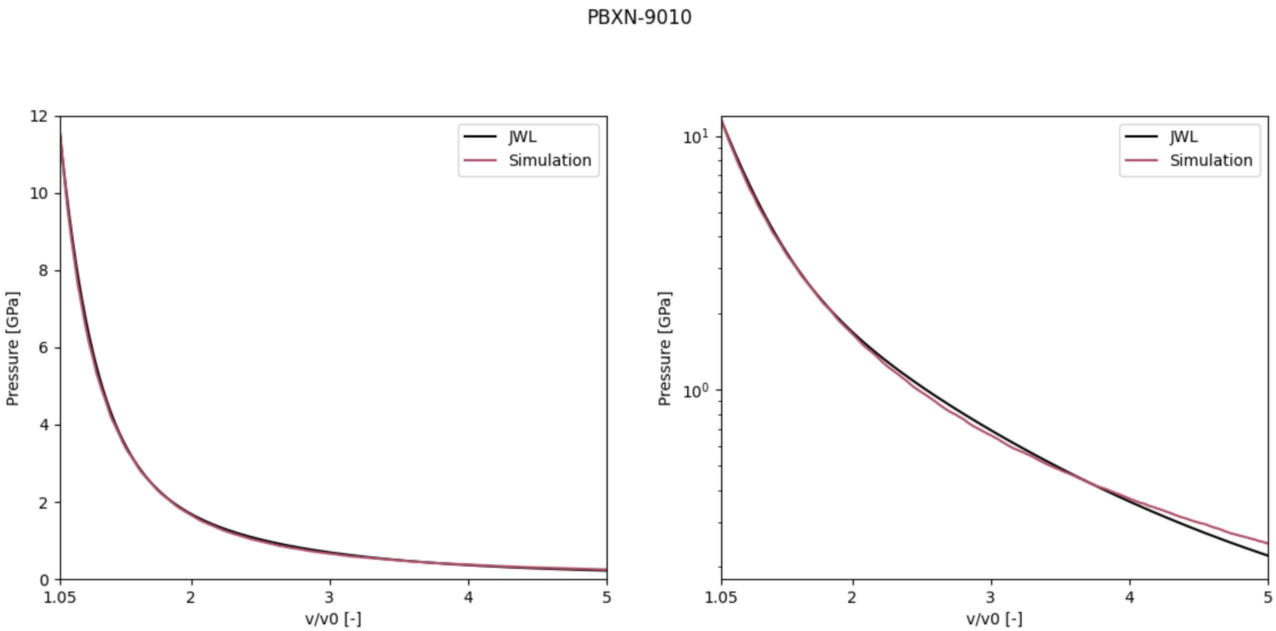

Figure 13: Results from the controlled expansion test with calibrated PBXN-9010.

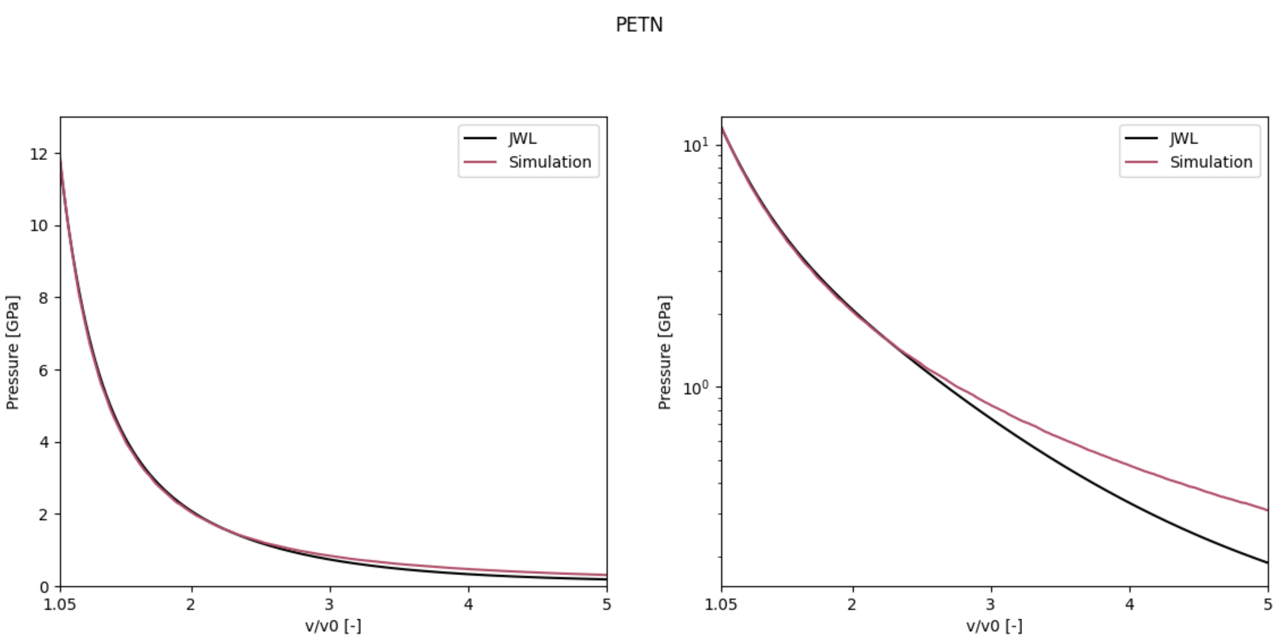

Figure 14: Results from the controlled expansion test with calibrated PETN.

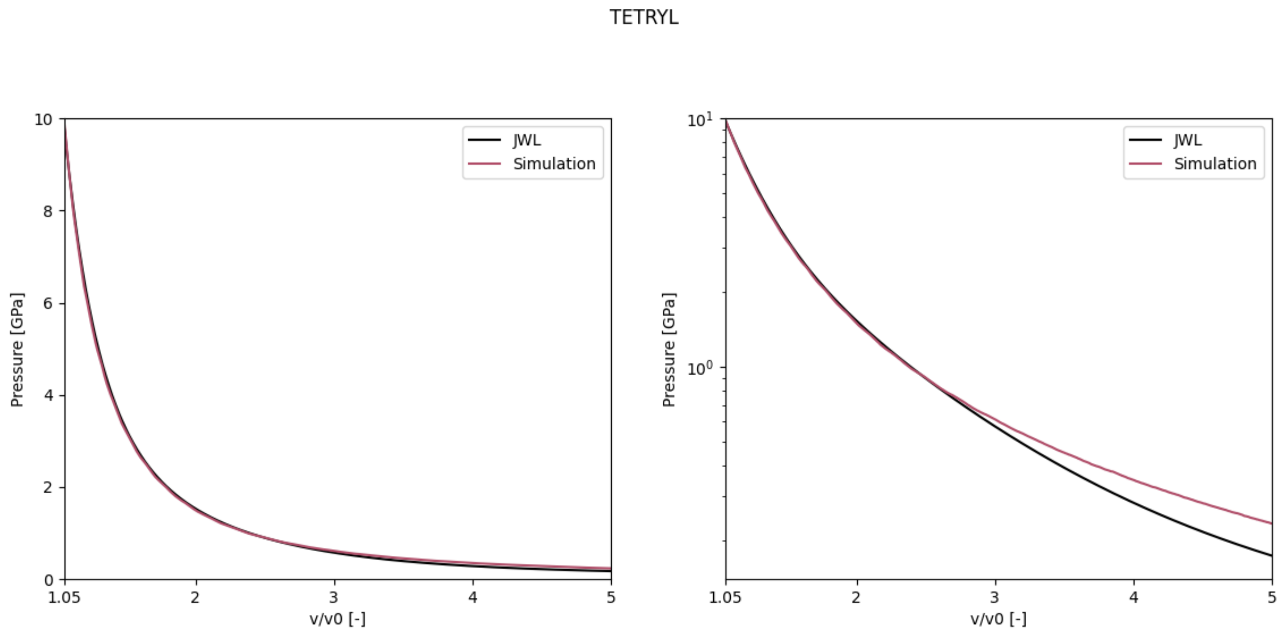

Figure 15: Results from the controlled expansion test with calibrated TETRYL.

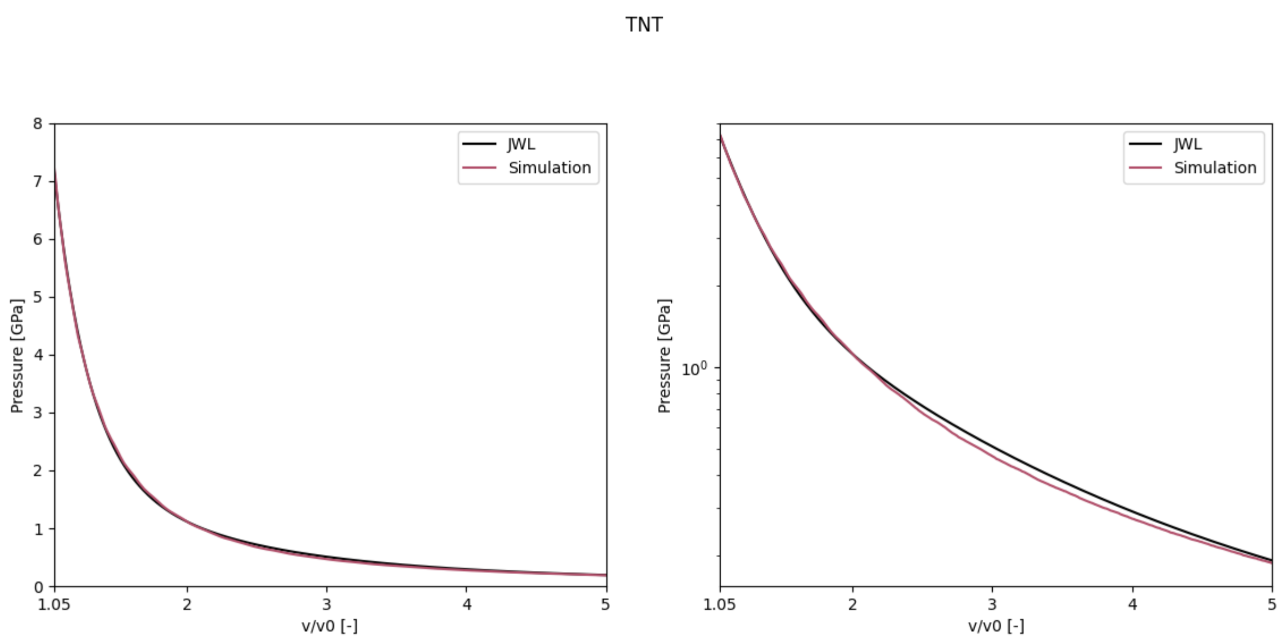

Figure 16: Results from the controlled expansion test with calibrated TNT.

Data required for calibration of explosives

Users can calibrate explosives of interest by downloading the controlled expansion test model from IMPETUS Market. The following data is required to calibrate an explosive for the discrete particle module:

ρ_0	-	Density of undetonated composition
e_0	-	Energy per unit volume
D	-	Detonation velocity
A, B, R_1, R_2 and ω	-	JWL coefficients

References

[1] - B. M. Dobratz, P. C. Crawford, LLNL Explosives Handbook - Properties of Chemical Explosives and Explosive Simulants, Lawrence Livermore National Laboratory, 1985.

[2] - L. Penn, F. Helm, M. Finger, E. Lee, Determination of Equation-of-State Parameters for Four Type of Explosive, Lawrence Livermore Laboratory, 1975.

[3] - G. O. Nevstad, Determination of detonation velocity and pressure for MCX-6100, FFI-rapport 2015/02323, 2015.

[4] - A. Helte, J. Lundgren, H. Örnhed, M. Norrefeldt, Evaluation of performance of m/46, FOI-R–2051–SE, 2006.

[5] - O. Ayisit, The influence of asymmetries in shaped charge performance, International Journal of Impact Engineering, volume 35, pages: 1399 - 1404, 2008.

Tests

This benchmark is associated with 16 tests.

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driving precision

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