HyTunnel-CS
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Dimensionless correlation for blast wave decay in a tunnel

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Blast wave in a tunnel
Outline

- ❖ Numerical details
- ❖ Model validation
- ❖ Simulation results
- ❖ Conclusions
- ❖ Recommendations

LES model of blast wave and fireball

Numerical details 1/2

- LES of shock and reacting compressible flow using Fluent 2021R2 as an engine
- The density-based solver
- The tunnel walls and floor are specified as non-adiabatic to allow heat transfer from the combustion, the ground is no-slip wall
- The external non-reflecting boundary is defined as pressure outlet
- The governing equations are based on the filtered conservation equations for mass, momentum, and energy in their compressible form with Redlich-Kwong real gas EoS

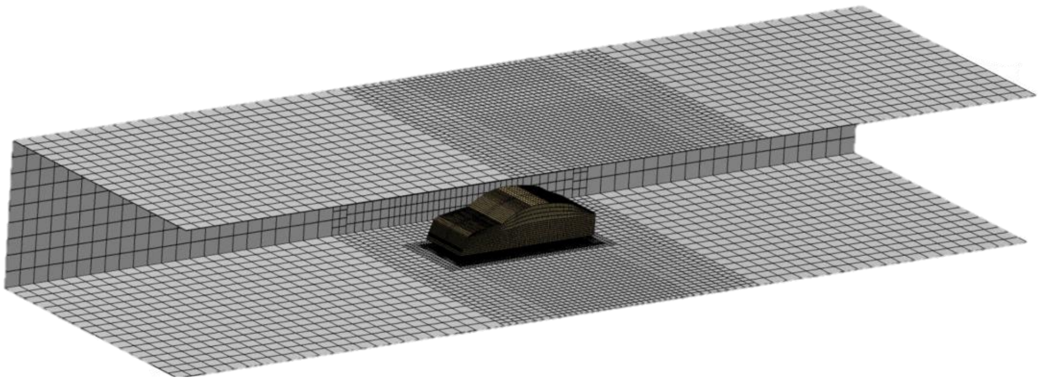
LES model of blast wave and fireball

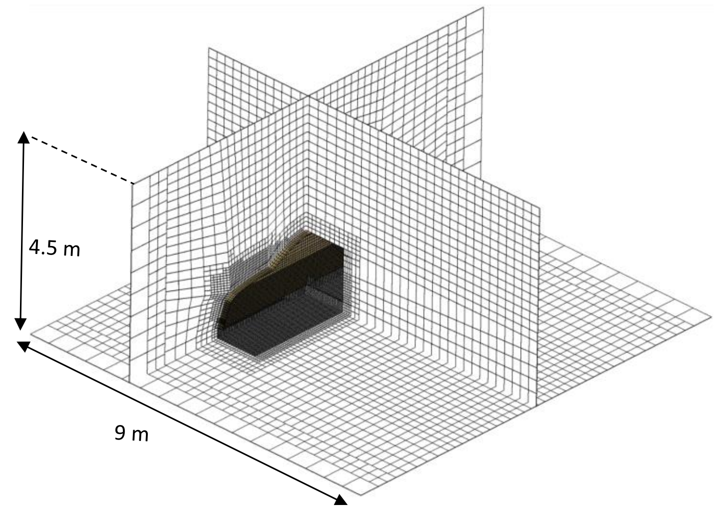
Numerical details 2/2

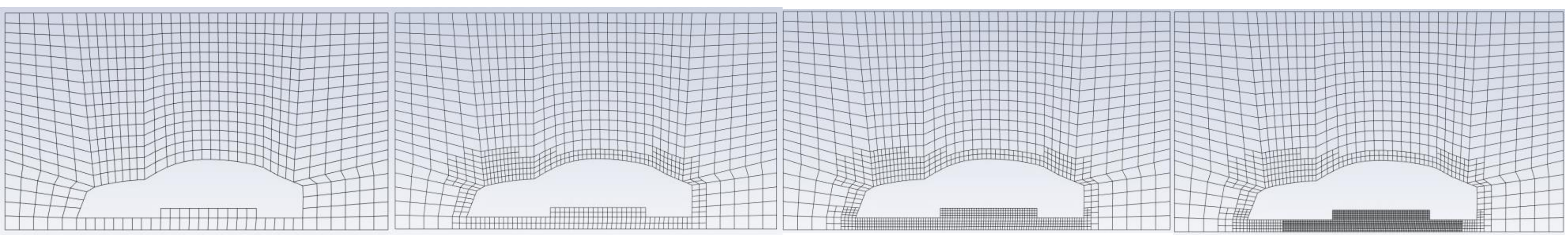
- The Least Square Cell-Based and second-order upwind scheme were used for convective terms.
- The time step adapting technique was employed to maintain a constant Courant-Friedrichs-Lewy (CFL) number at the value of 0.2 until the blast wave left the tunnel at 1 s and gradually increased up to the value of 2 during 100 time steps to speed up the simulation of a fireball
- The Smagorinsky-Lilly model for the SGS turbulence modelling
- Turbulence-chemistry interaction by FRC model with one-step Arrhenius chemistry

Numerical model

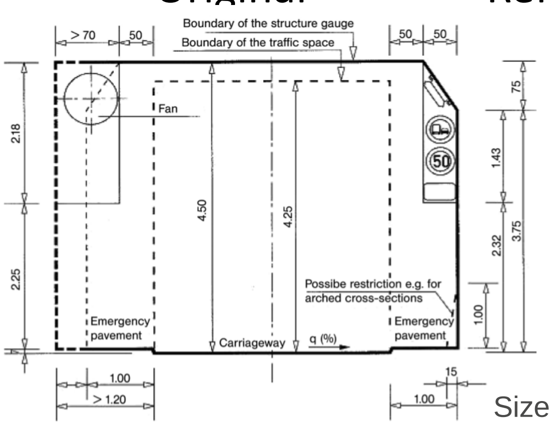
Grid







Original | Refined 2x (+6.7k CV) | Refined 4x (+24.7k CV) | Refined 8x (73.2k CV)



Size of the tunnel lanes according to Maidl, 2014

- Refinement-derefinement applied
- Dynamic CFL increase

Numerical details

Tunnel and tank parameters

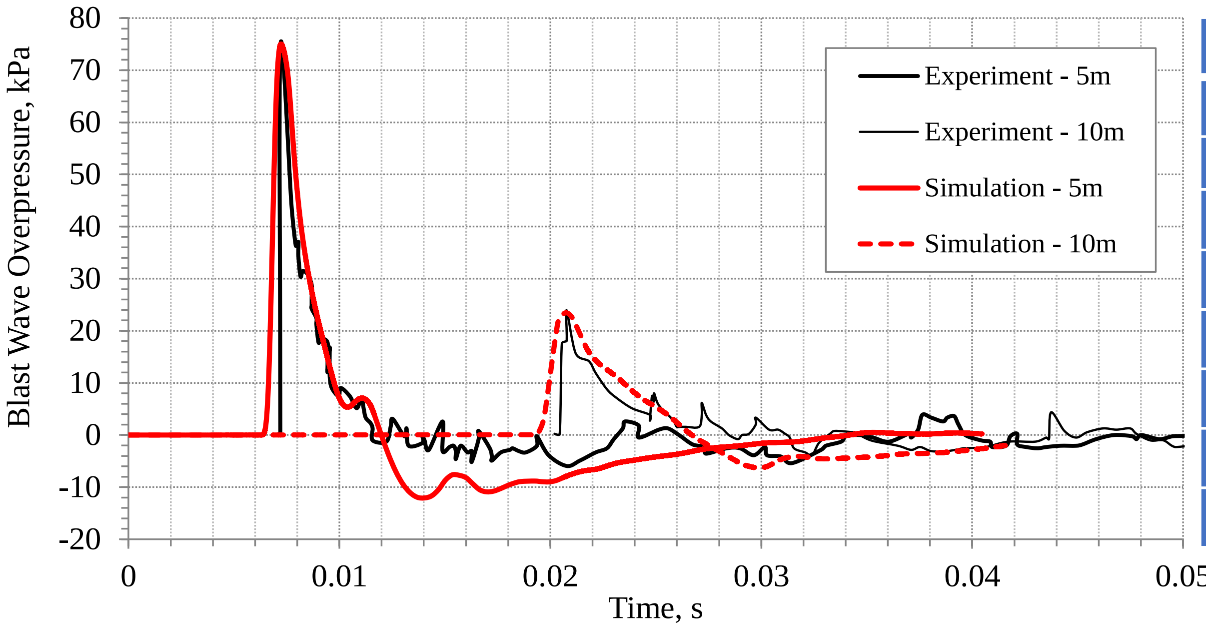
Tunnel cross section, m^2	Tunnel length, m	Tank volume, L	Tank mass, kg	Tank pressure, MPa	Grid CV number
24 (SL) 40 (DL) 139 (FL)	750 m 1500 m (DL, mid)	15	0.61	95	SL 457.4k
		30	1.22		DL 460.2k
		60	2.45		FL 876k
		120	4.9		

Tank volume, L	Pressure, MPa	E_m, MJ		E_{ch}, MJ		E_{tot}, MJ
		E_m	αE_m	E_{ch}	βE_{ch}	$\alpha E_m+\beta E_m$
15	95	2.43	4.38	73.45	8.81	13.19
30		4.86	8.75	146.90	17.63	26.38
60		9.72	17.50	293.81	35.26	52.76
120		19.45	35.01	587.62	70.51	105.52

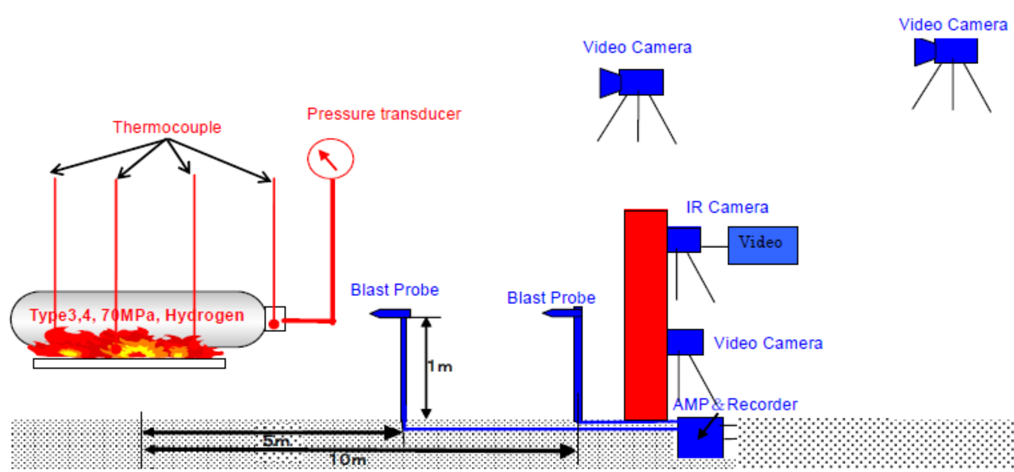
Note:
- SL – single lane, DL – double lane, FL – five lane
- Mechanical energy contribution $\alpha=1.8$
- Chemical energy contribution $\beta=0.12$
- 70 MPa tank ruptures at 95MPa

Model validation

Japanese experiment – open space



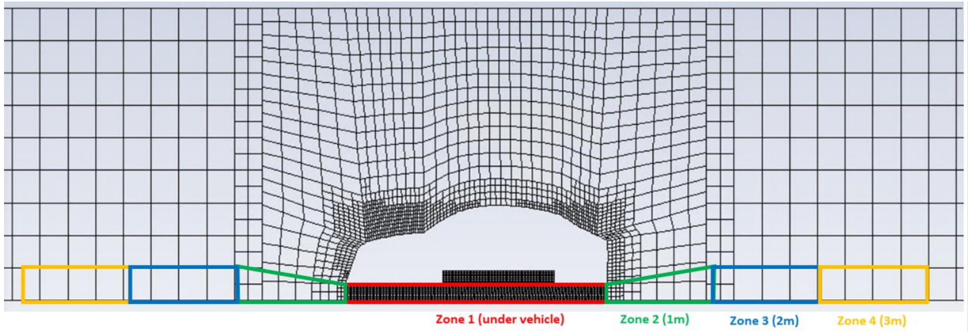
Pressure initial	70.69MPa
Temperature initial	282 K
Pressure before burst	99.47 MPa
Temperature before burst	398K
Tank Volume	36L
Rupture time	654sec
Blast wave (5m)	74.3kPa
Blast wave (10m)	23.4kPa
Fireball diameter	About 20m

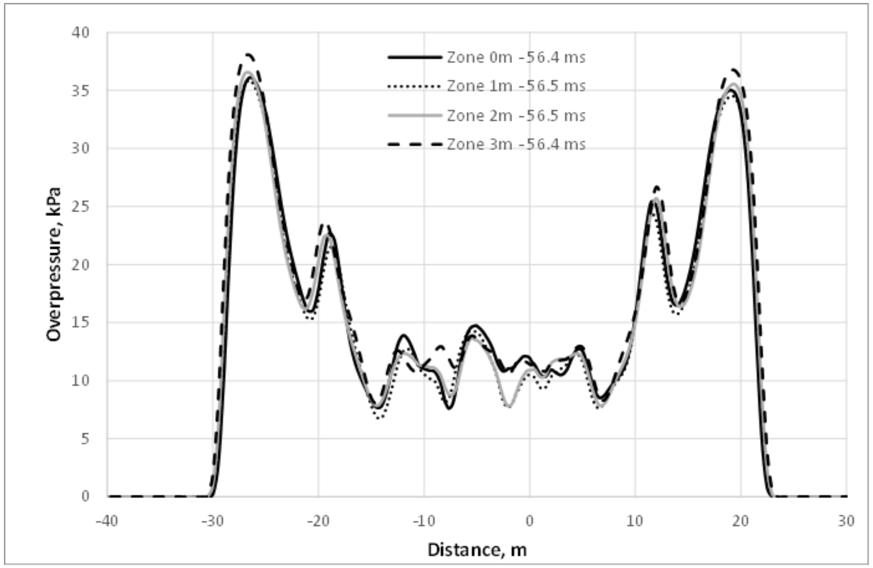


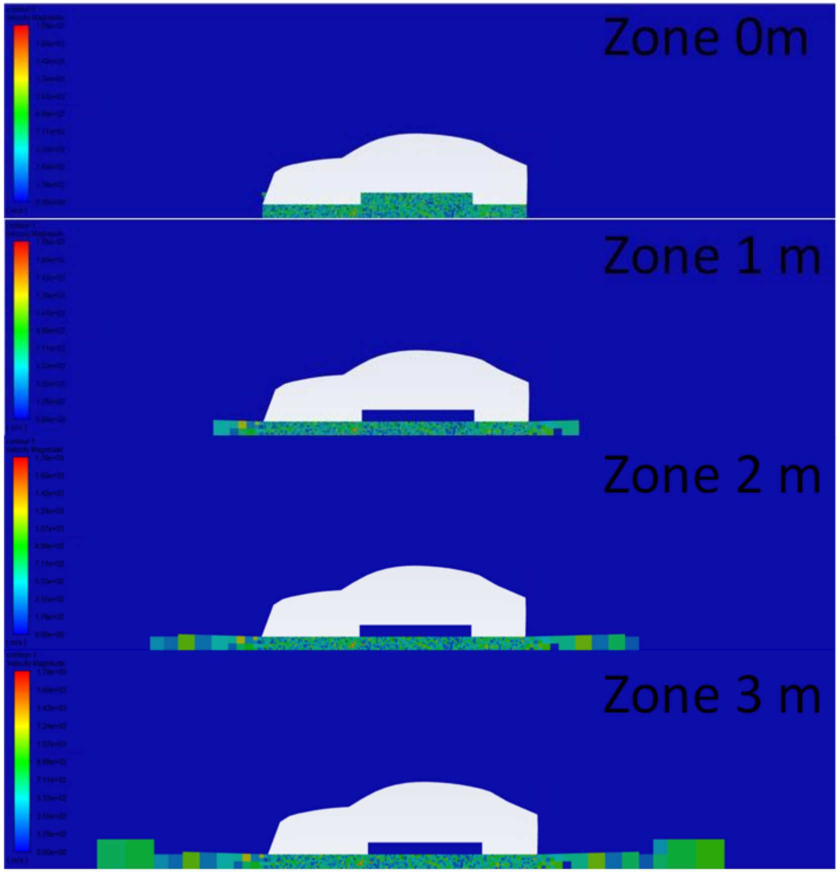
Y. Tamura, M. Takahashi, Y. Maeda, H. Mitsuishi, J. Suzuki, and S. Watanabe, "Fire Exposure Burst Test of 70MPa Automobile High-pressure Hydrogen Cylinders," The Society of Automotive Engineers of Japan Annual Autum Congress 2006, Sapporo, 2006.

Model with car in a tunnel

Initial turbulence

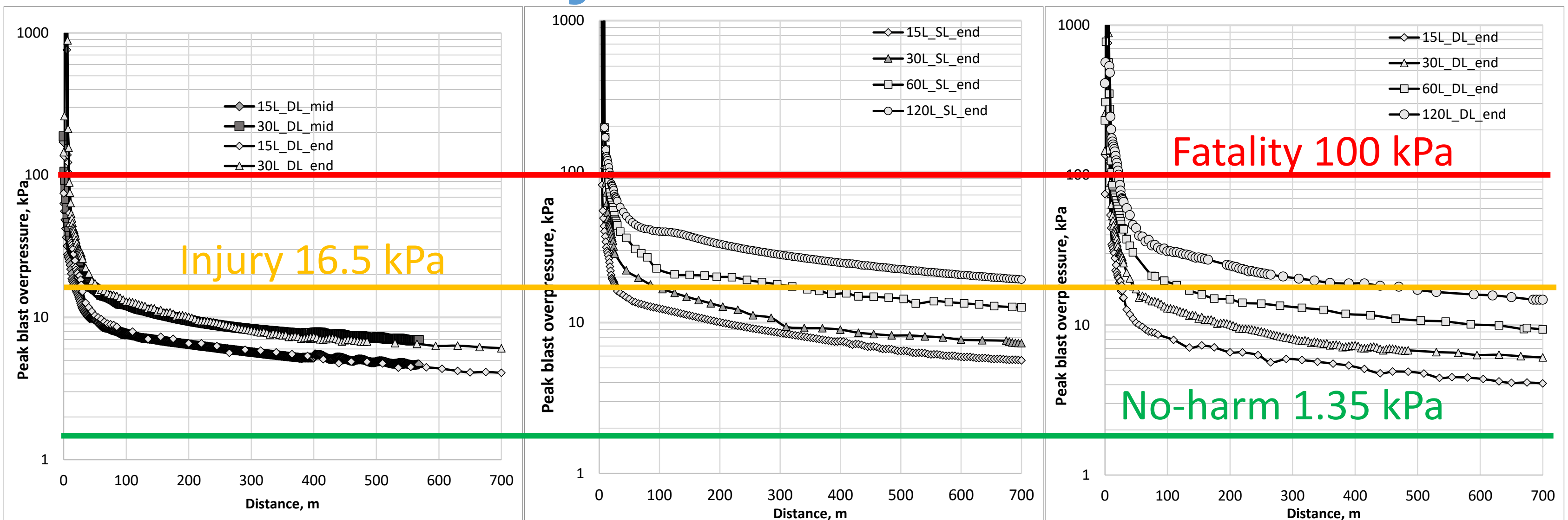


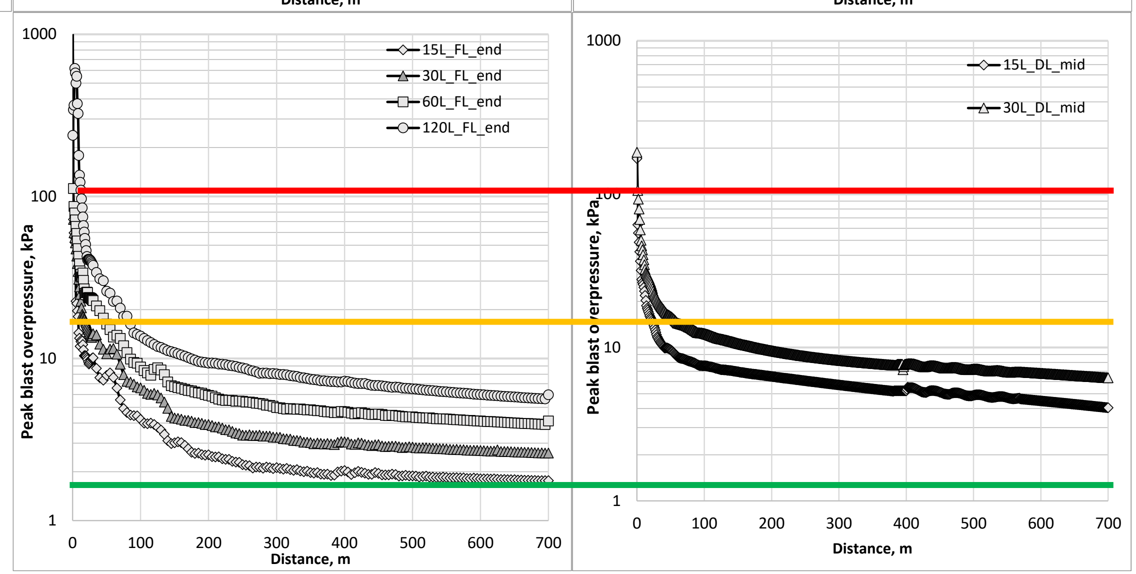




Results

Blast wave decay in a tunnel



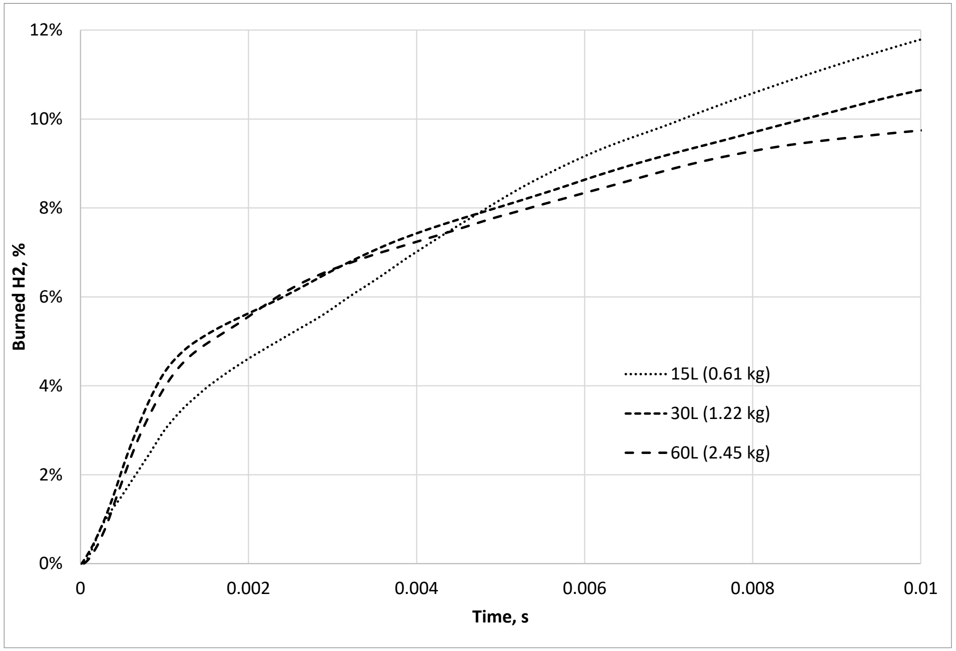


No-harm was not reached

Correlation

Contribution of chemical energy β

Under-vehicle tank



Stand-alone tank

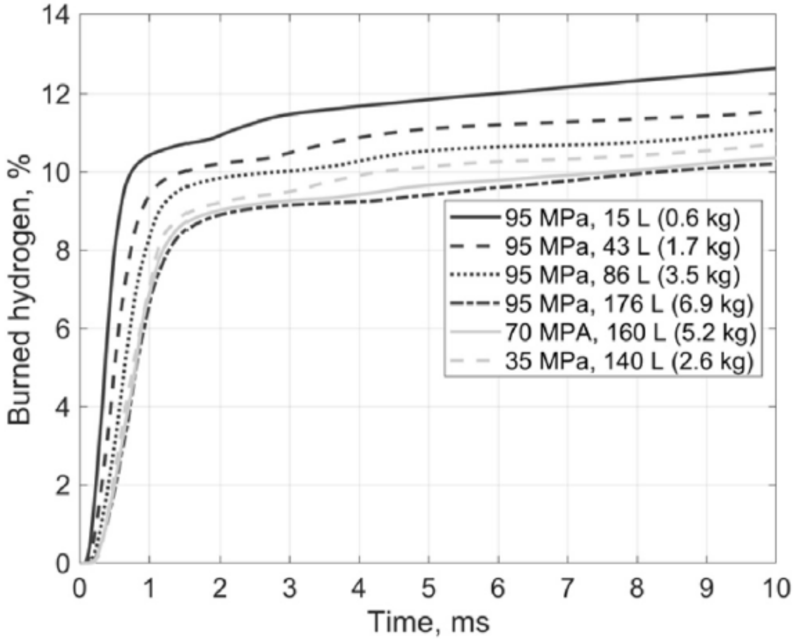
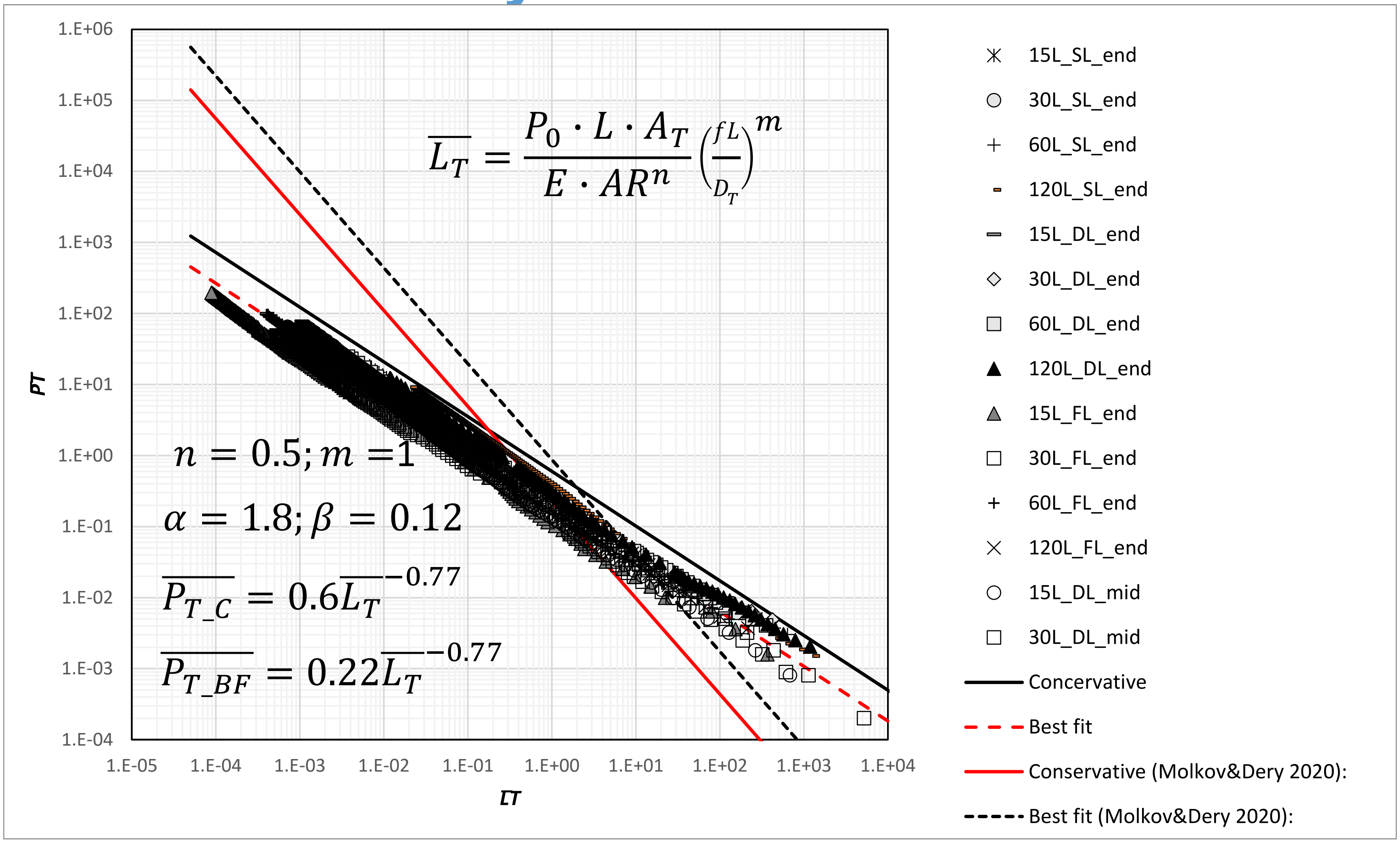


Fig. 7 – Burned hydrogen as a function of time for various tanks (within the first 10 ms).

Molkov, V., Dery, W., 2020. The blast wave decay correlation for hydrogen tank rupture in a tunnel fire. International Journal of Hydrogen Energy https://doi.org/10.1016/j.ijhydene.2020.08.062

Correlation

Blast wave decay to include vehicle



Molkov, V., Dery, W., 2020. The blast wave decay correlation for hydrogen tank rupture in a tunnel fire. International Journal of Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2020.08.062

Correlation

Example and methodology

Estimation of blast wave at fixed distance:

1. Hydrogen mass in the tank $m = \rho V = \left(\frac{P_G}{P_G b + RT/M}\right) V$
2. Mechanical energy $E_m = \frac{(P_g - P_0)(V - mb)}{\gamma - 1}$
3. Chemical energy $E_{ch} = m \cdot H_C$
4. Total energy $E = \alpha \cdot E_m + \beta \cdot E_{ch} \quad \alpha = 1.8, \beta = 0.12$
5. Tunnel hydraulic diameter $D_T = 4A_T/P$
6. Dimensionless tunnel length $\overline{L_T} = \frac{P_0 L A_T}{E \cdot AR^n}\left(\frac{fL}{D_T}\right)^m \quad f = 0.0055$
7. Dimensionless pressure $\overline{P_{T\_C}} = 0.6\overline{L_T}^{-0.77}$ $\overline{P_{T\_BF}} = 0.22\overline{L_T}^{-0.77}$
8. Dimensional overpressure $\Delta P = \bar{P} \cdot P_0$

Conclusions

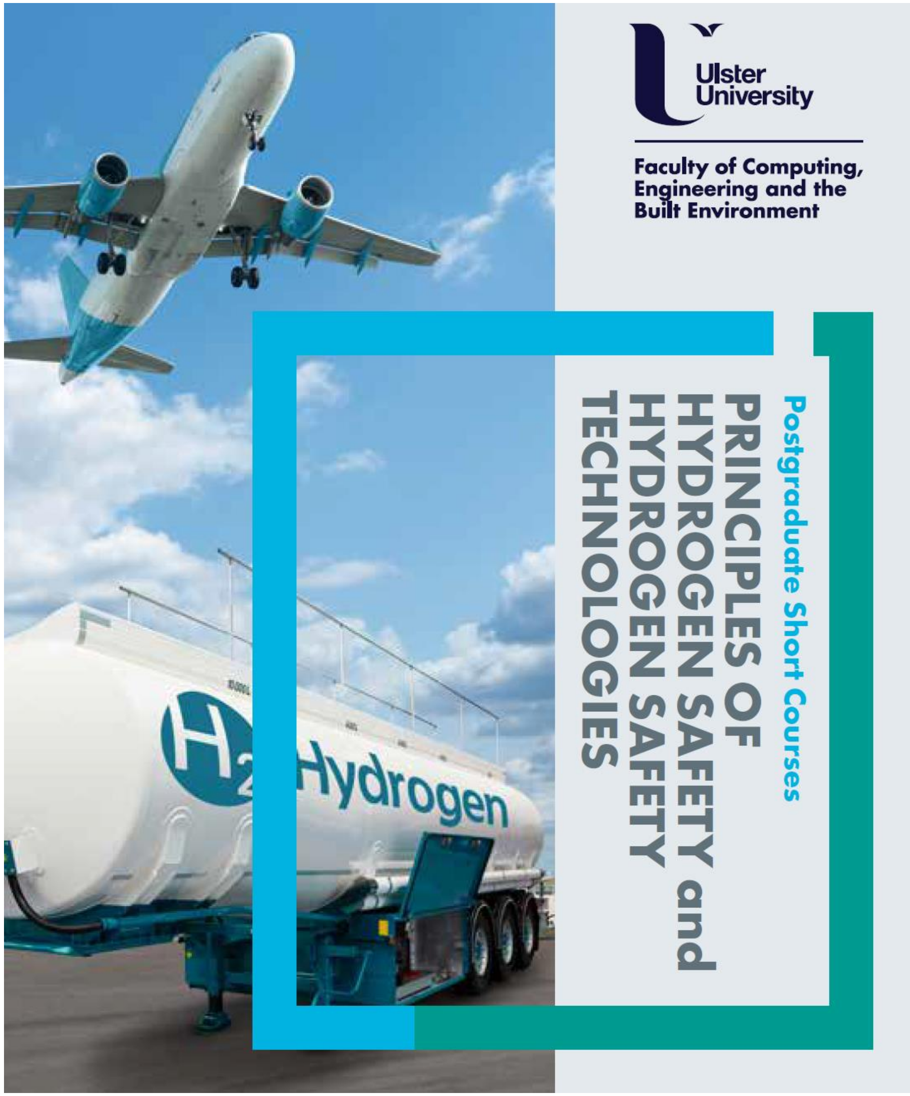
- The study of blast wave after under-vehicle tank rupture in a fire in a tunnel was performed.
- The CFD model was validated against experiment.
- The correlations to assess the blast wave decay after high-pressure hydrogen tank rupture in a tunnel are proposed on compressed hydrogen tank rupture in a fire.
- The correlations have been compared with the numerical simulation to assess the dynamics of blast wave.
- It could be stated that none of simple correlations can be applied for the blast wave hazard distance in a tunnel due to dynamics of its propagation.

HyTunnel-CS in education

Postgraduate Certificate in Hydrogen Safety

Distance learning course (will be updated by HyTunnel-CS outcomes), more information at:

https://www.ulster.ac.uk/research/topic/built-environment/hydrogen-safety-engineering/study



Get in touch

If you would like to speak to our course team, please get in touch by email or call us directly at the number below. We will be happy to answer your questions:

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tunnel HP

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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