GENERAL DYNAMICS
Ordnance and Tactical Systems–Canada

A General Pressure Generation Model for Granular Propellant Fires

Frederick Paquet, Hoi Dick Ng and Mario Paquet

YOUR MISSION IS OUR MISSION

General background

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Since applications vary widely in their requirements, propellants can exhibit a large array of combustion behaviors.

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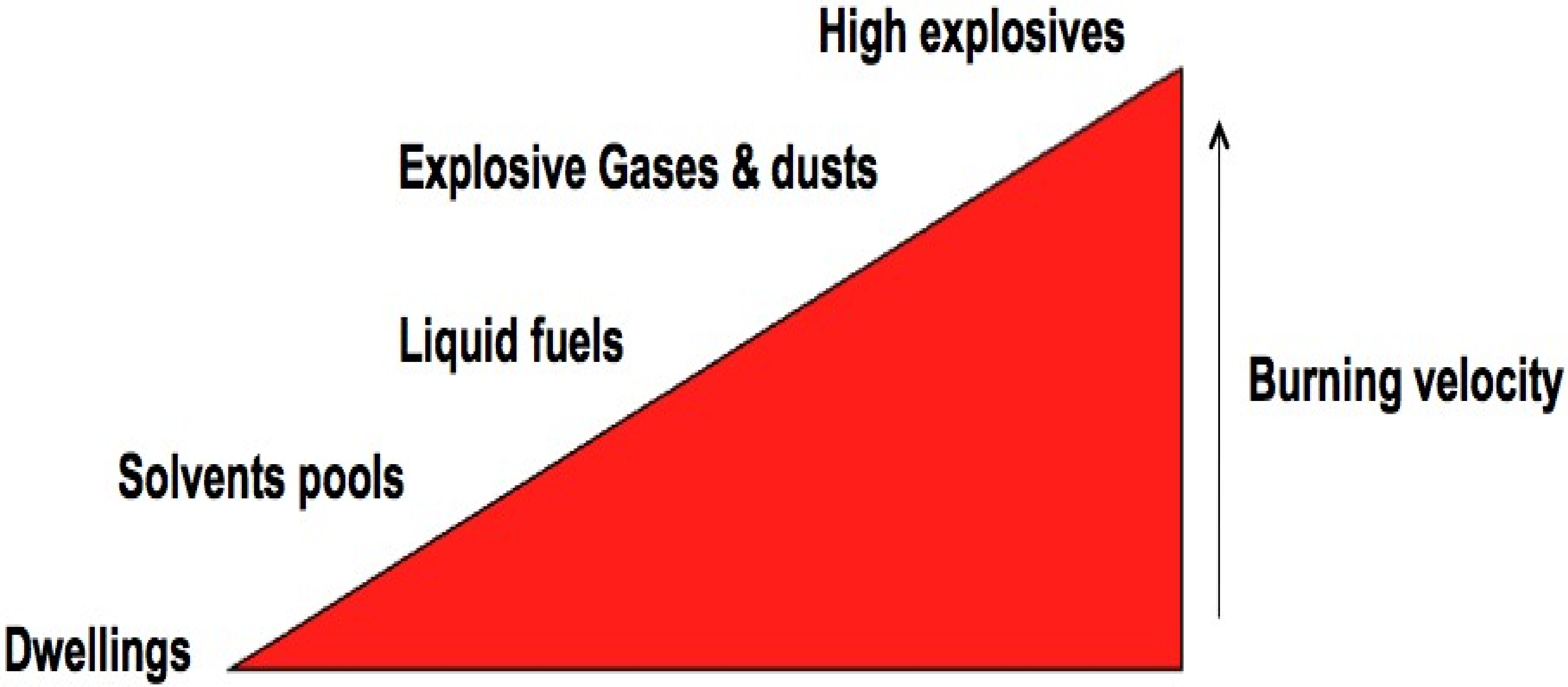

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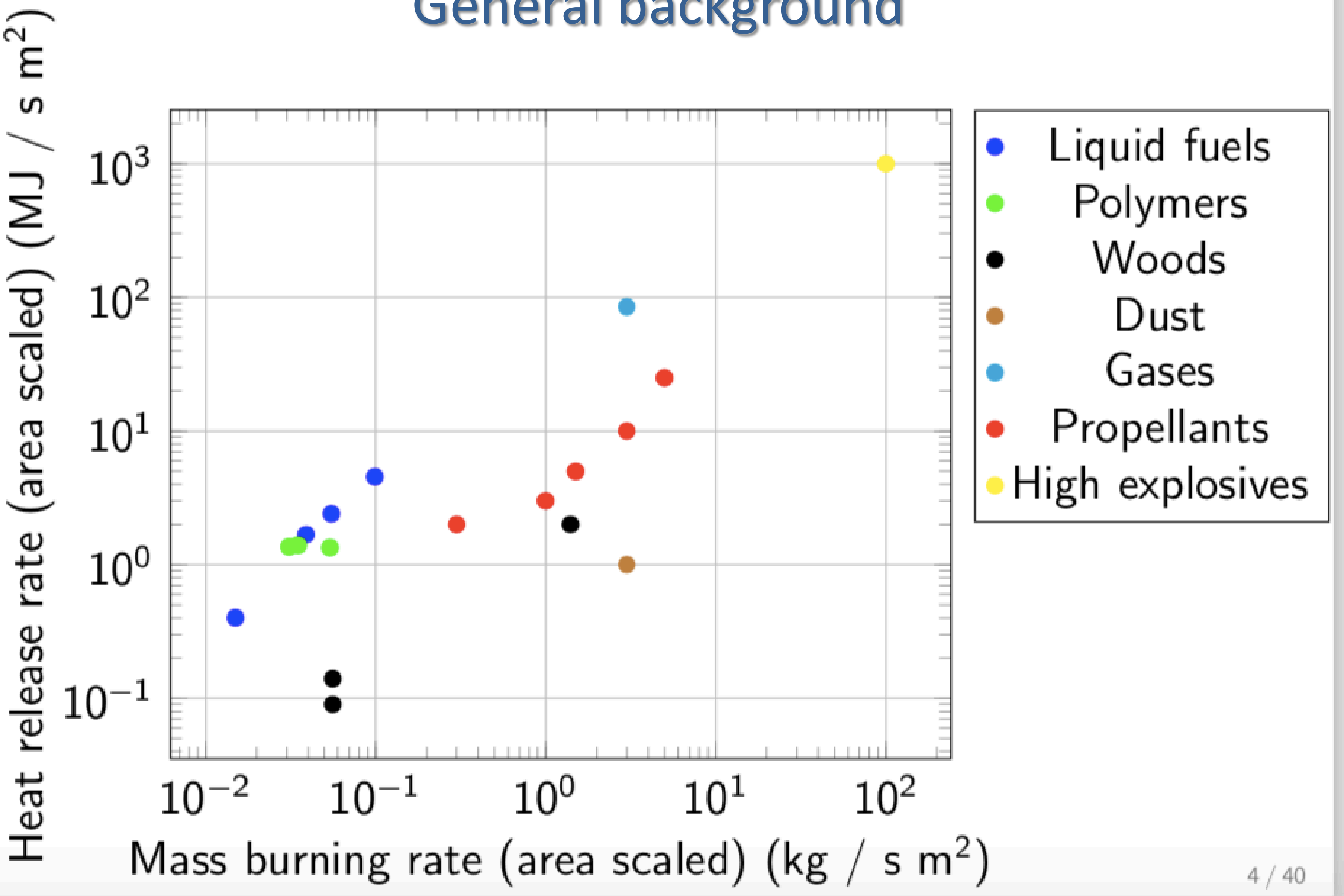

Previous work

An attempt was made by Graham to model explosion venting and define a critical vent area ratio by equating pressure rise and decrease terms:

$$\frac{A_v}{S_B} = \frac{RT_B\rho\alpha}{MC_DA^*(A - BT_o)}$$

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A number of empirical relations have been published for gas and dust equations (see NFPA 68 for examples).

- Gas explosions: $A_v = CA_sP_{red}^{-1/2}$
- Dust Explosions: $A_v = 10^{-4}K_{st}V^{0.75}\left(\frac{P_{max}}{P_{red}}\right)^{1/2}$

$\rightarrow$ Deflagration index, K_{st} , and reduced pressure, P_{red}.

Theoretical background

Equation of state:

Nobel-Abel:

$$P(V - b) = NRT$$

when

$$X = cb \gg 0.01$$

Most cases can use the ideal gas law:

$$PV = NRT$$

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Spatial pressure variation:

$$\chi = \frac{m_{air} c_{air}}{\dot{m}_{gen} d}$$

Lumped parameters

$$\rightarrow \chi \gg 1$$

Case	χ (dimensionless)
0.7 L closed vessel with a fast burning propellant	0.9
0.7 L closed vessel with a slow burning propellant	5.6
60 L tank with a fast burning propellant	420
1800 L enclosure with a fast burning propellant	561
10^6 L enclosure with a fast burning propellant	675

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Compressibility:

Studied pressures below 10 kPa

$$\rightarrow Ma<0.30$$

Bernoulli's law:

$$v=\left(\frac{2P}{\rho_{gas}}\right)^{1/2}$$

Other cases: isentropic eq.

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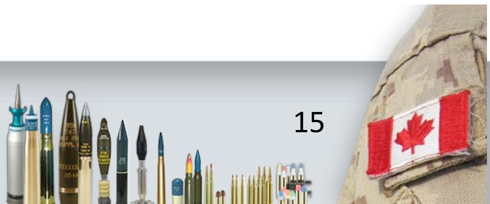

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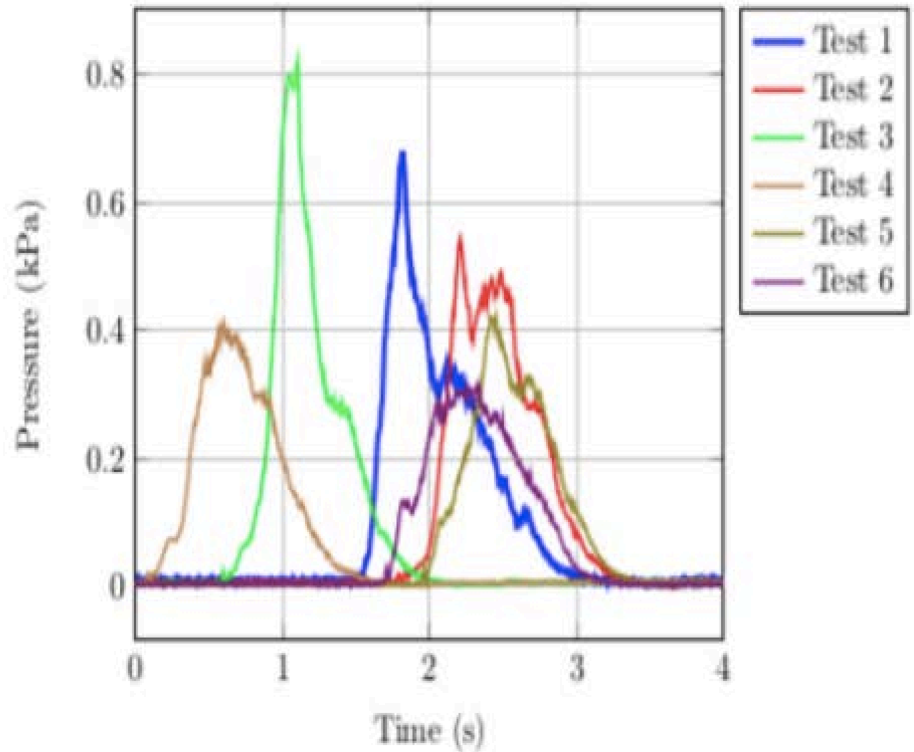
$$\dot{m}_e + C_D A \left(\frac{2\rho_{gas} R T}{M_w V} \right)^{1/2} m_e^{1/2} = 0 \qquad when\ t > t_{burn}$$

Testing

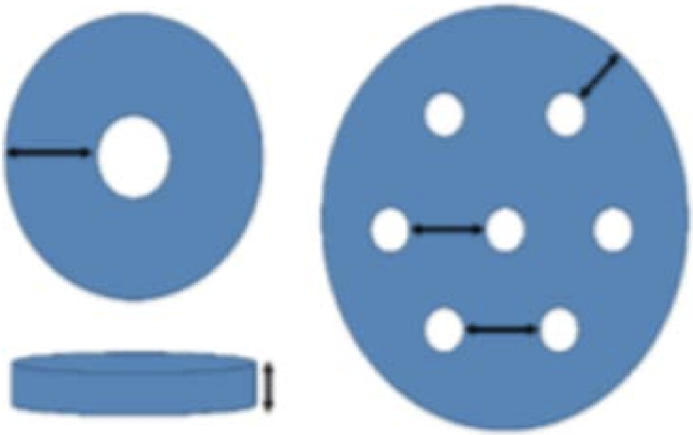
1800 L setup



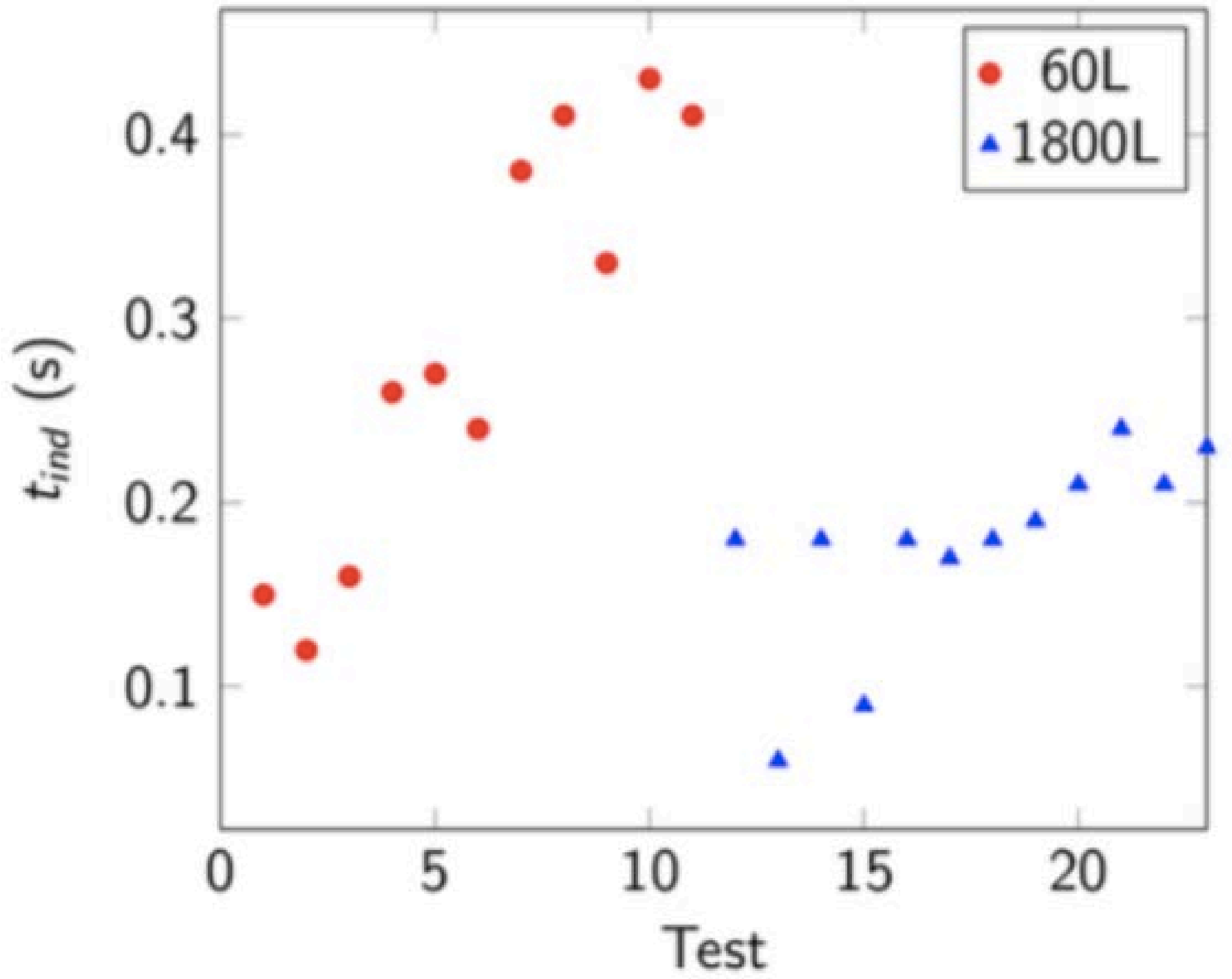
Typical measurement

Testing

Propellant	Geometry	Heat of explosion (J/kg)	Composition
SB1	Unitubular	3871	NC: 98% / Inert: 2%
SB2	Unitubular	3135	NC: 90% / Inert: 10%
DB1	Cord	5392	NC: 60% / NG: 39% / Inert: 1%
DB2	Unitubular	4490	NC: 73% / NG: 25% / Inert: 2%

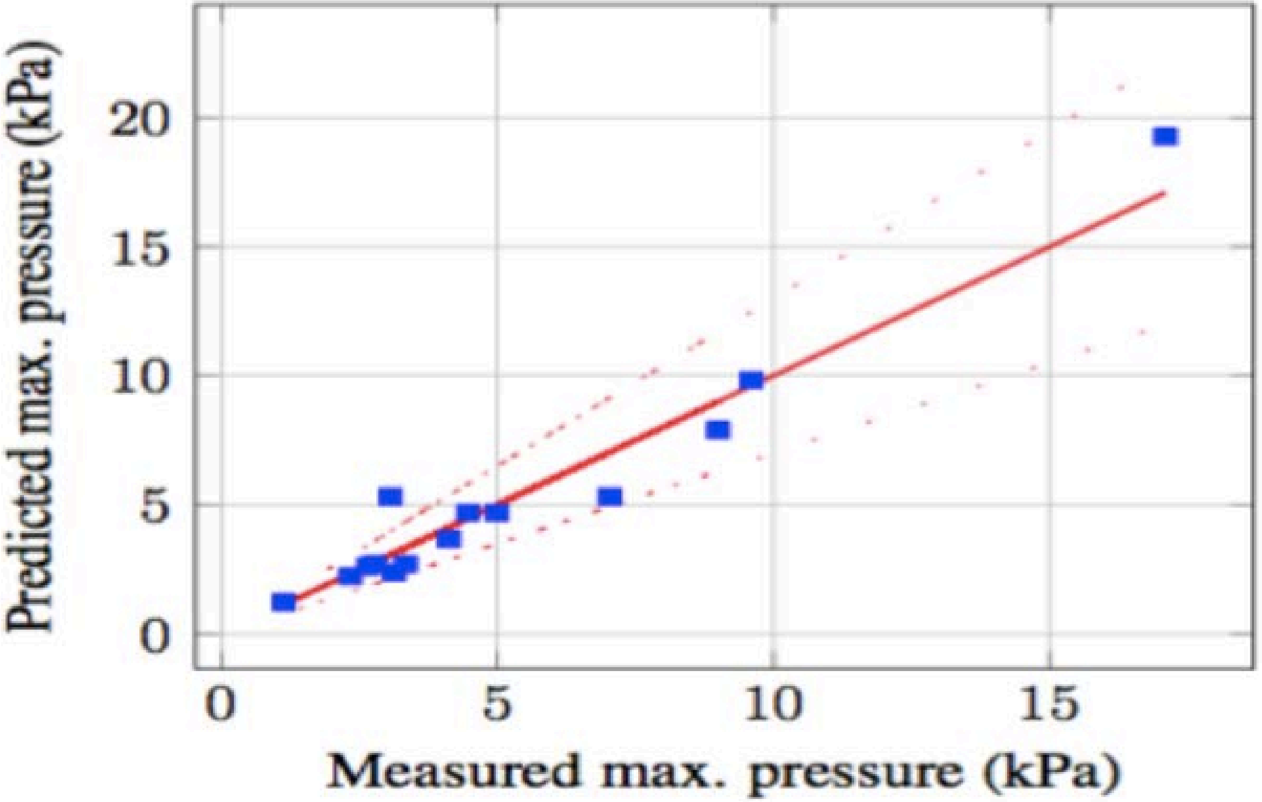


Flame propagation – Induction time



Data analysis

Best statistical model: $P_{max} = \frac{194.6 m^{0.97}}{A^{1.34}}$ (with $r^2 = 0.91$)



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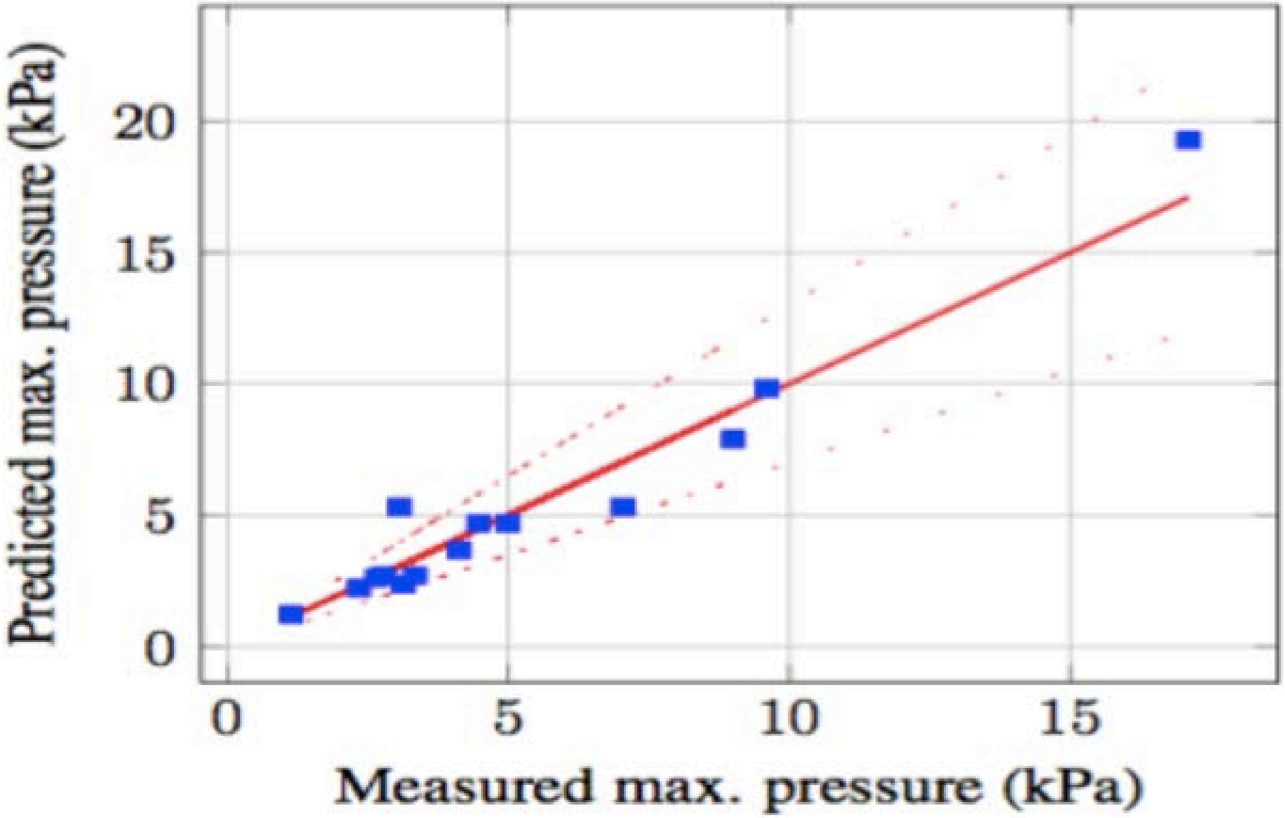

Departure from theoretical form suggests: $C_D \approx A^{1/2}$

Numerical model

Starting with the previously derived mass balance:

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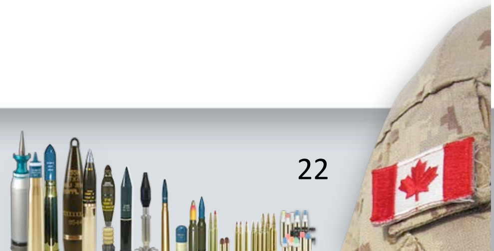

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An energy balance is also considered:

$$\Delta T = \frac{\dot{m}_{gen} E \Delta t - C_v \dot{m}_{vent} T \Delta t}{C_v (m_{air} + \rho_{gas} V)}$$

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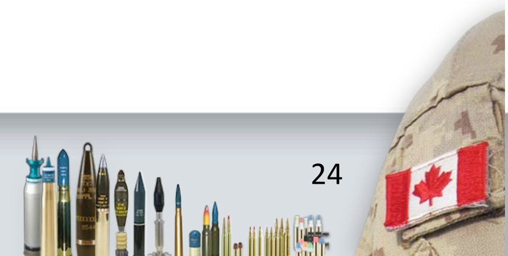
Gas density obtained through EOS: $\rho_{gas} = \frac{PM_w}{RT}$



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Gas density obtained through EOS: $\rho_{gas} = \frac{P M_w}{R T}$

Here, the mass generation rate can be approximated by:

$$\dot{m}_{gen} = \frac{m}{t_{max} - t_{ind}}$$

Numerical model

Volume (m^3)	Min. density (kg/m^3)	Max. Temperature (K)
0.06	0.74	452
1.8	0.48	823
100	0.18	1798

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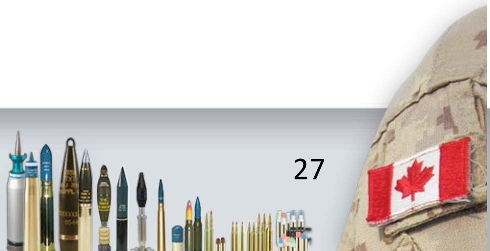
The gas density is estimated as

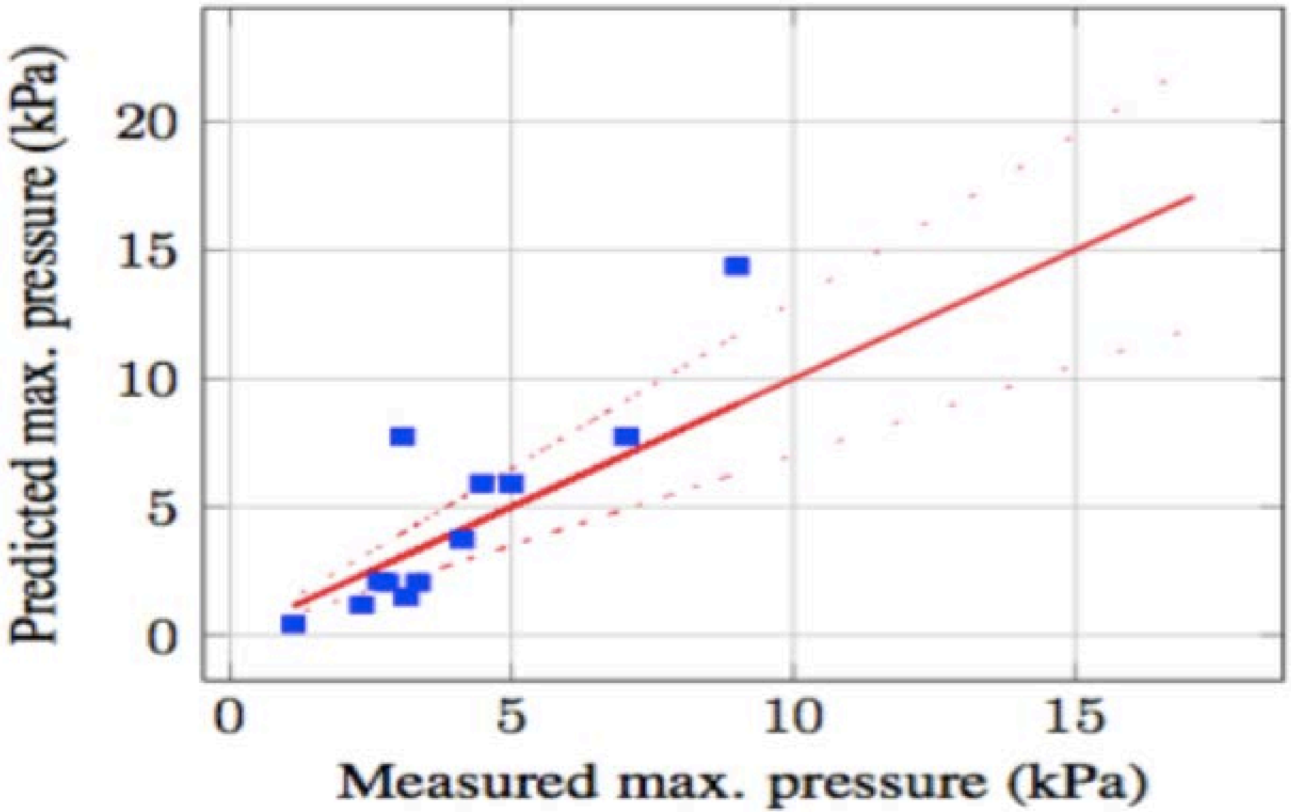
$$\rho_{gas} = 0.47\,V^{-0.19}$$

Subst. in theoretical model

$$\text{e.g. } P_{max} = \frac{1.06\,\dot{m}^2\,V^{0.19}}{A^{2.66}}$$



Comparing the scale dependent model and measured results:



→ Loss in quality due to the uncertainty in estimating $\dot{m}_{gen}$.

Future work

- Application to safety aspects
  - Quantities - distances relations, uniforms, building - process design, ...

- Better estimate of the mass combustion rate

- Application to "non dry" (or green) product

- Application to stick geometries (e.g. rocket motors)

- Application to cases at higher densities (higher pressures)

Acknowledgements

- General Dynamics OTS Canada - Valleyfield
  - ▸ Use of their burning ground and equipments
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