Explosion hazard mitigation by venting
The development of the Rhino HySafe explosion relief panel

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MADE IN BRITAIN

Overview

- Brief introduction & background
- Anatomy of an explosion
- Factors affecting explosion severity
- Consequence mitigation – the role of venting
- Summary of the development of the Rhino HySafe Vertex explosion relief panel
- Concluding remarks

Introduction & background

Rhino Engineering Group

- Over forty years' experience in the design, manufacture and installation of portals and barriers for the protection of assets from hazardous environments.
- Responsible for the development and full-scale experimental validation of the HySafe Vertex panel.

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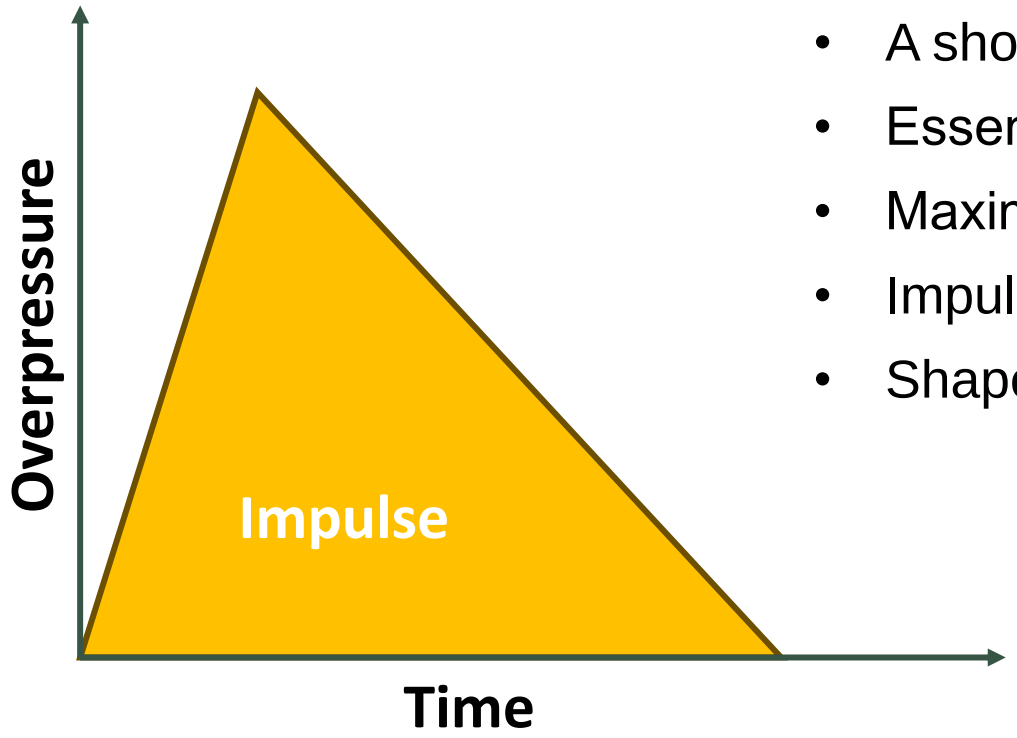
- Design & fabrication of blast resistant structures. Deflagration & detonation hazards.
- CUTE Hornchurch, BP/BOC/Linde H_2 fuelling installations, BP decarbonised fuels projects, CCS+H_2 syngas projects.

Anatomy of an explosion (“a flammable gas deflagration”)



- A short-lived, dynamic load – potentially very damaging
- Essential parameters include…
- Maximum overpressure (the “slap”)
- Impulse (the ability to overcome inertia – the “shove”)
- Shape of the overall overpressure pulse (e.g. rise time)

Factors affecting explosion severity

- The “Three Cs”…
- Chemistry – reactivity & combustion characteristics of the gas(es) involved.
- Congestion – the density of equipment & piping is proportional to combustion intensity.
- Confinement – the extent to which expanding combustion products are pent up.

- **Prompt reduction of confinement** is the essence of explosion relief venting.

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Factors affecting explosion severity – hydrogen context

PARAMETER	HYDROGEN	NATURAL GAS (85% CH_4)
Minimum ignition energy in air (mJ)	0.017	0.31
Flammable limits in air (%)	4–75	5–15
Energy density LHV (MJ/kg)	120	50
Laminar burning velocity (cm/s)	265–325	38

* Standard temperature & pressure, as defined by NIST (293.15 K / 101.325 kPa)

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Consequence mitigation – the role of venting

- Prompt reduction in confinement.
- Escape path for combustion products.
- Consequent reduction in build-up of overpressure (and impulse) inside enclosures.

- Long history of venting as a means of mitigation (bulk handling, oil & gas, nuclear).
- Codes & standards go back to at least 1945 (USA).
- Noteworthy that the 2023 edition of NFPA 68 includes an Annex dedicated to H_2 venting.
- **Venting must be viewed as part of an overall strategy – integrity, ventilation, detection**

The development of the Rhino HySafe Vertex relief panel

- Key design drivers included…
- Speed & predictability of operation (low inertia, rapid delivery of “vented area”).
- Avoid reliance of complex release mechanisms.
- Ease of manufacture & installation.
- Provide specifiers with full characterisation of panel response (pressure **and** impulse).
- Underpin the entire design via full-scale experimental testing.

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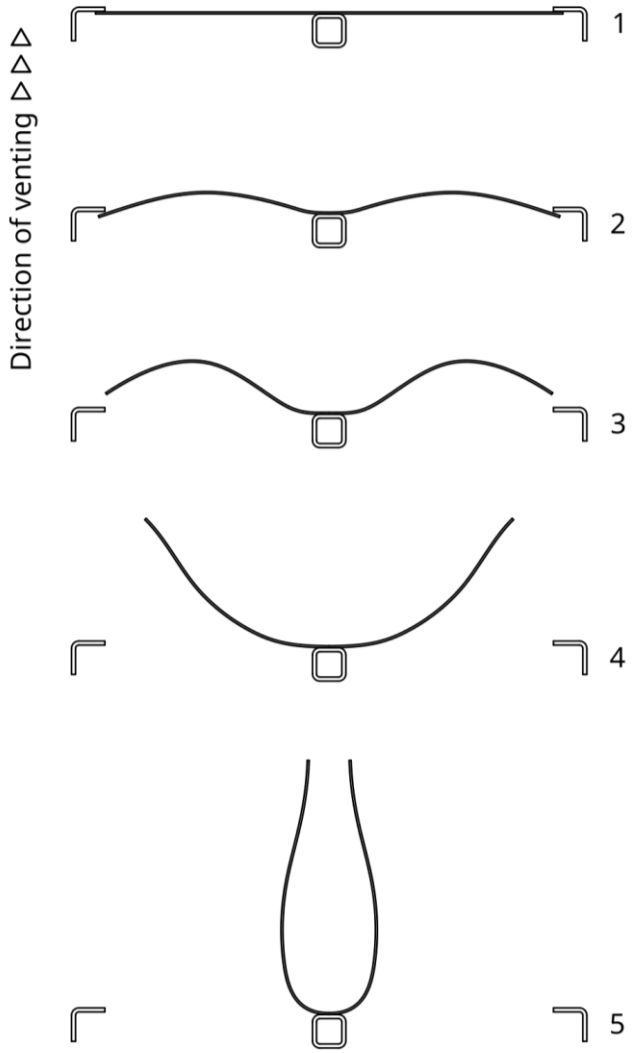
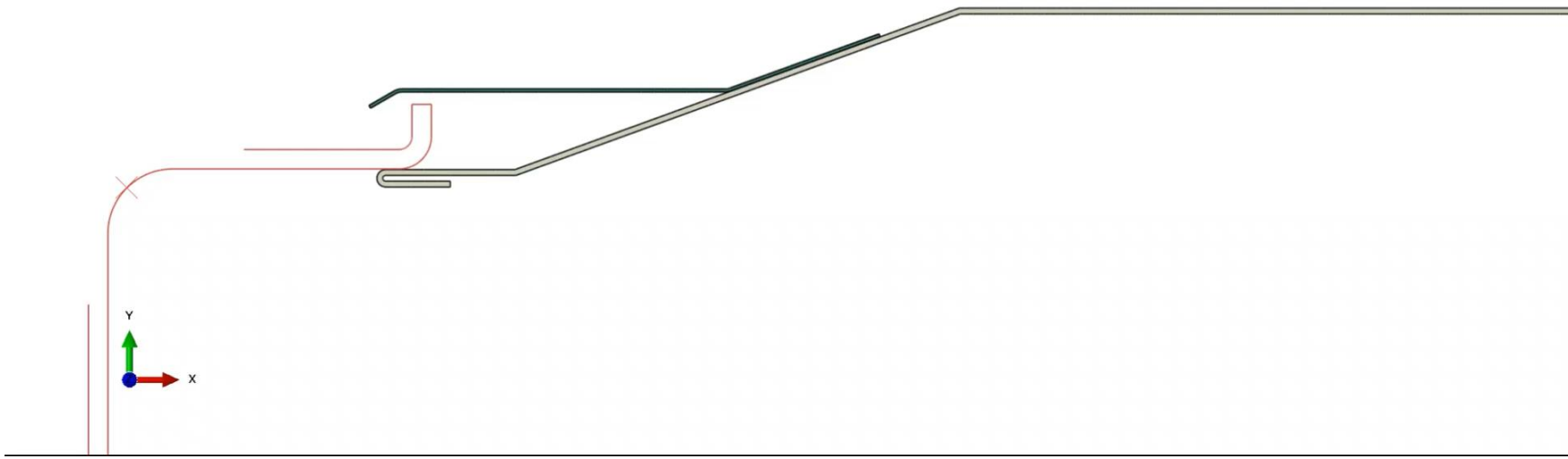
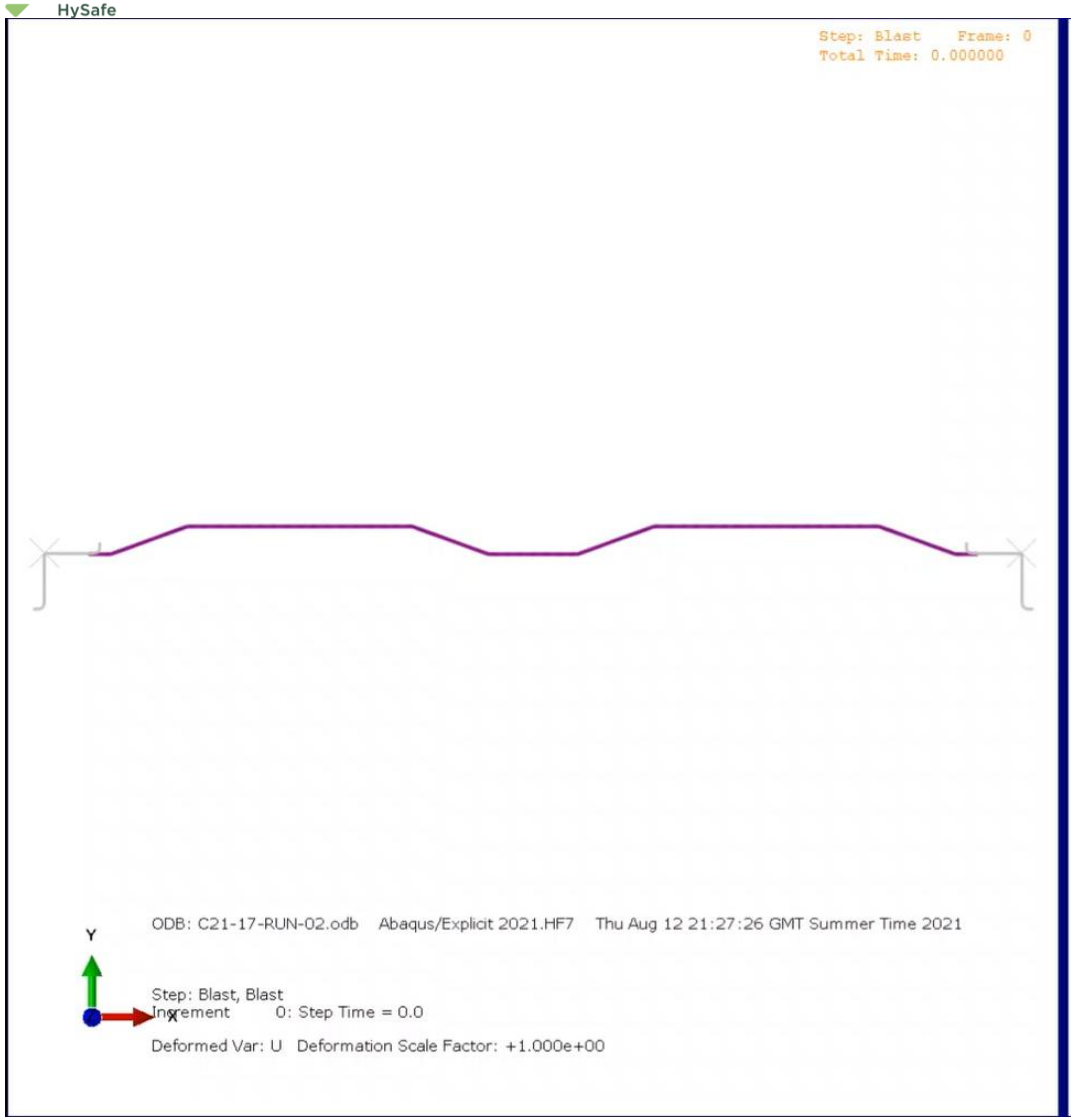
Reliance on geometry instead of material non-linearity



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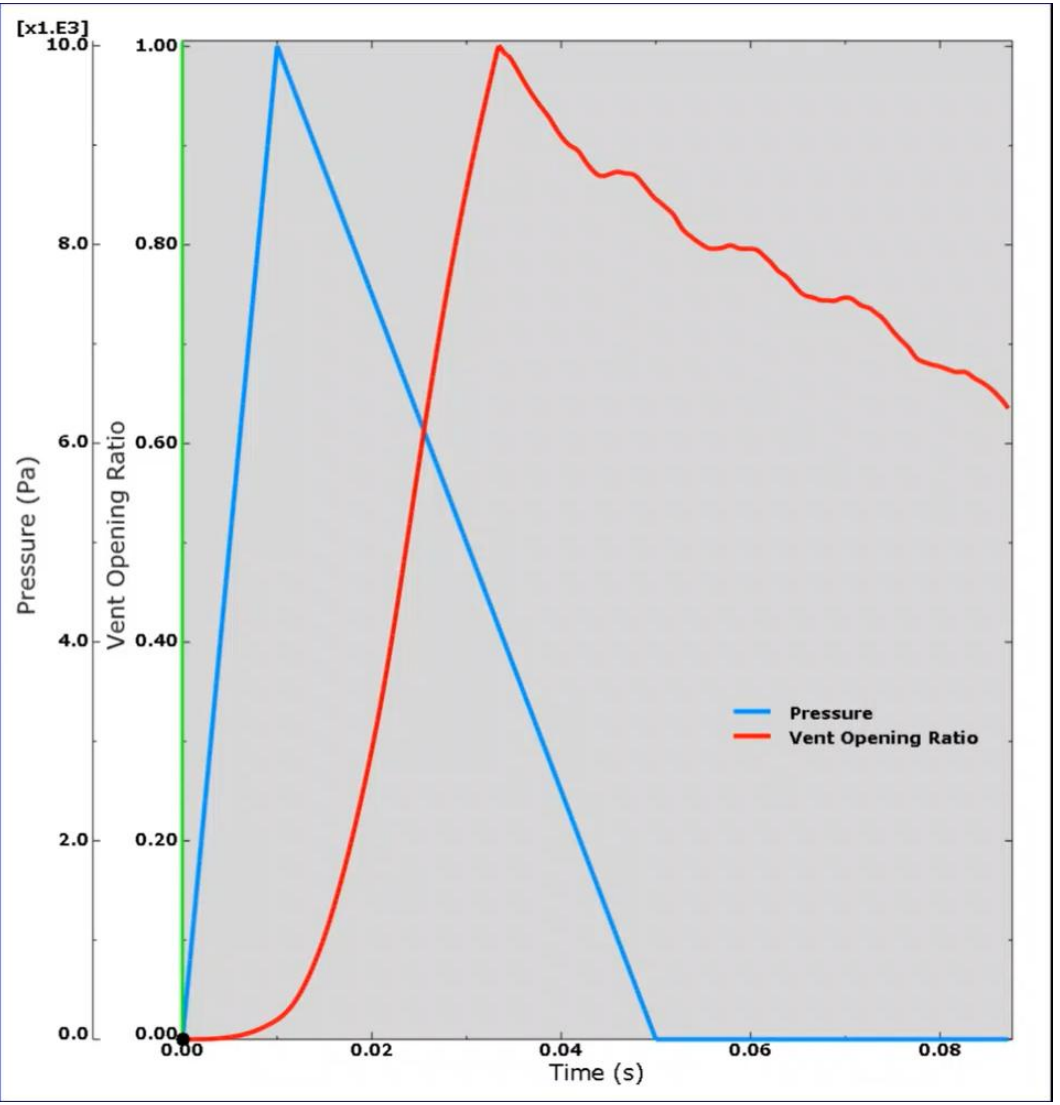
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8.0
6.0
4.0
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Pressure (Pa)
1.00
0.80
0.60
0.40
0.20
0.00
Vent Opening Ratio
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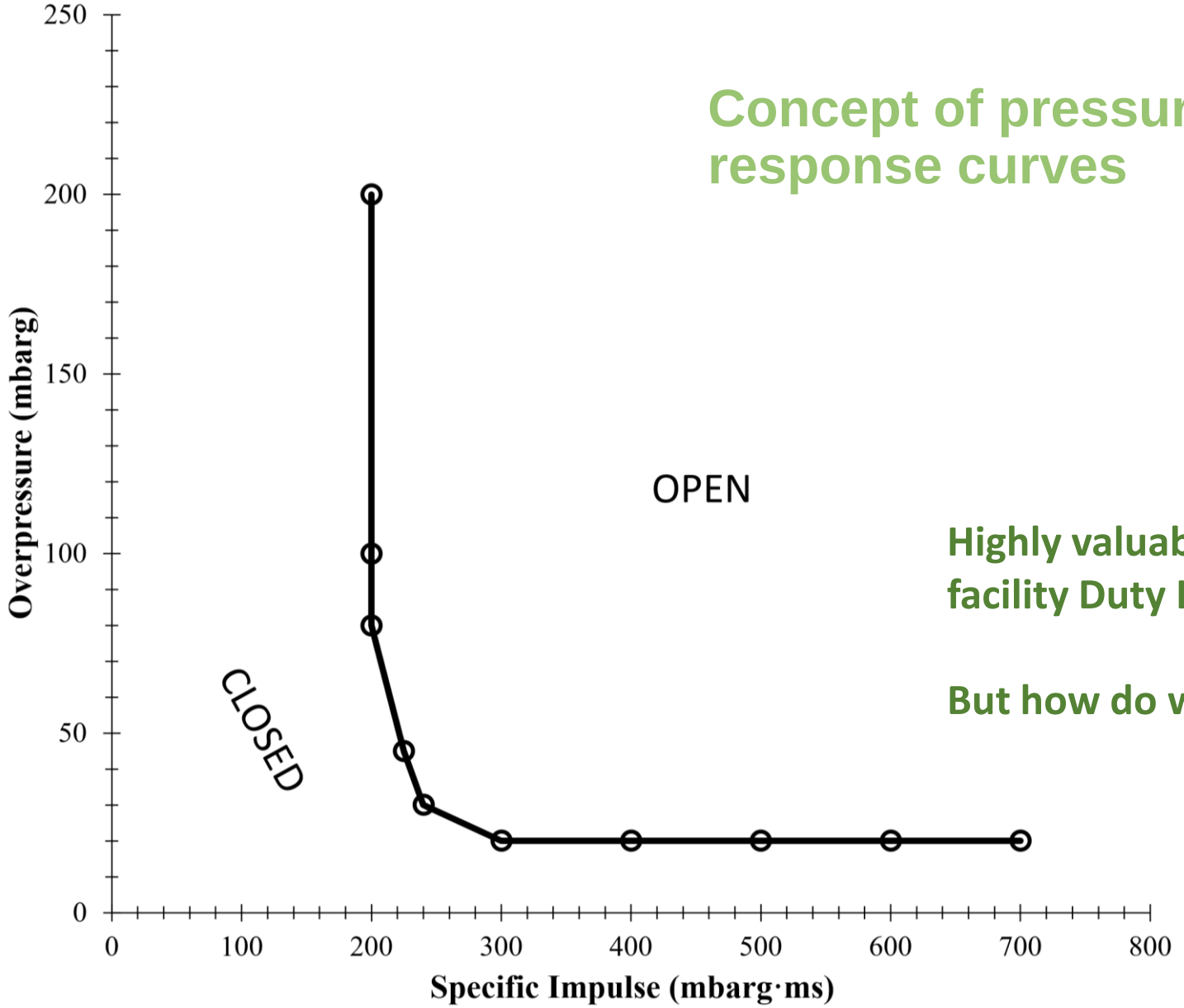
0.02
0.04
0.06
0.08
Time (s)
Pressure
Vent Opening Ratio

Concept of pressure-impulse response curves



Highly valuable for specifiers and facility Duty Holders.

But how do we arrive here? 🤔

Bringing experimental data to bear

$data_{Test\_03} := \text{READEXCEL}(\text{".\C21-17-XLS-01.xlsx"}, \text{"DNV Test Data!J3:K10003"})$

$data_{Test\_04} := \text{READEXCEL}(\text{".\C21-17-XLS-01.xlsx"}, \text{"DNV Test Data!M3:N10003"})$

$t_3 := data_{Test\_03}^{\langle 0 \rangle}$ $P_3 := data_{Test\_03}^{\langle 1 \rangle}$ $t := 0, 0.5 .. 60$

$t_4 := data_{Test\_04}^{\langle 0 \rangle}$ $P_4 := data_{Test\_04}^{\langle 1 \rangle}$ $mbarg := bar \cdot 0.001$

$\beta_3 := \text{expfit}(t_3, P_3)$ $\beta_4 := \text{expfit}(t_4, P_4)$

$$\beta_3 = \begin{bmatrix} 6.96 \\ 0.0554 \\ -8.0227 \end{bmatrix} \text{ Test 03} \qquad \beta_4 = \begin{bmatrix} 4.6925 \\ 0.1053 \\ -6.0535 \end{bmatrix} \text{ Test 04}$$

$P_{P3}(t) := \beta_{3_0} \cdot e^{\beta_{3_1} \cdot t} + \beta_{3_2}$ $P_{P3}(0) = -1.063$

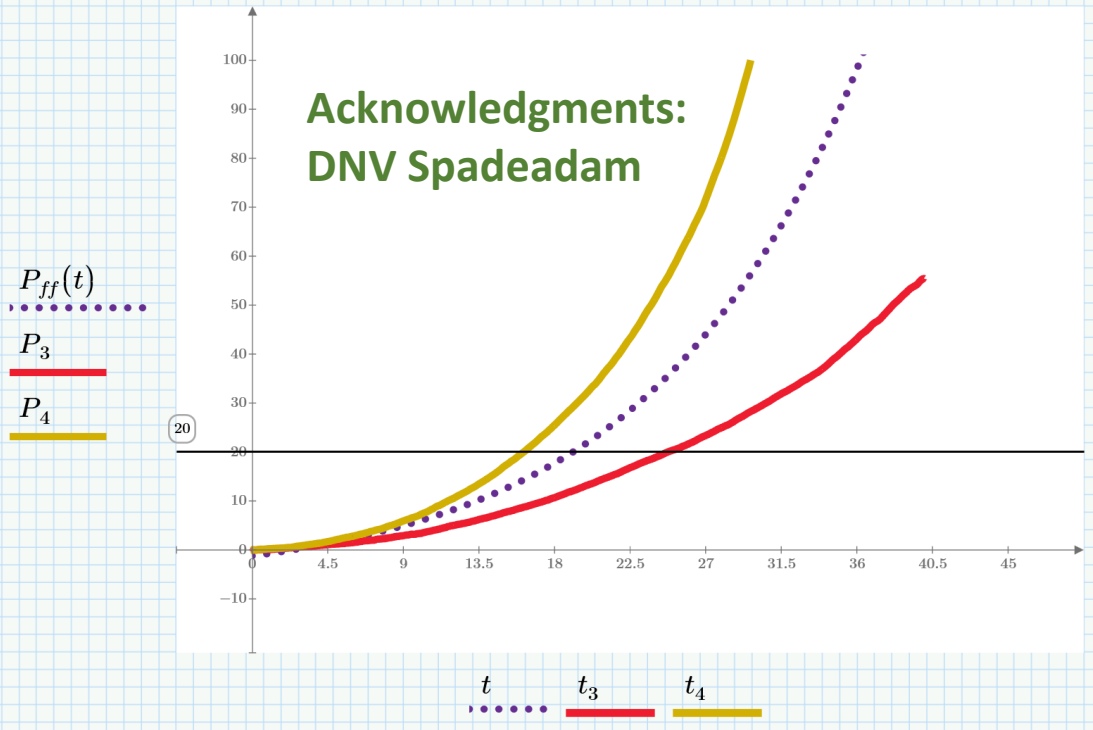
$P_{P4}(t) := \beta_{4_0} \cdot e^{\beta_{4_1} \cdot t} + \beta_{4_2}$ $P_{P4}(0) = -1.361$

$\varphi := 0.5$ Interpolation factor

$$\beta_{ff} := \begin{bmatrix} \beta_{3_0} - \left(\varphi \cdot \left|\beta_{4_0} - \beta_{3_0}\right|\right) \\ \beta_{3_1} + \left(\varphi \cdot \left|\beta_{4_1} - \beta_{3_1}\right|\right) \\ \beta_{3_2} + \left(\varphi \cdot \left|\beta_{4_2} - \beta_{3_2}\right|\right) \end{bmatrix} = \begin{bmatrix} 5.82628 \\ 0.08039 \\ -7.03813 \end{bmatrix}$$

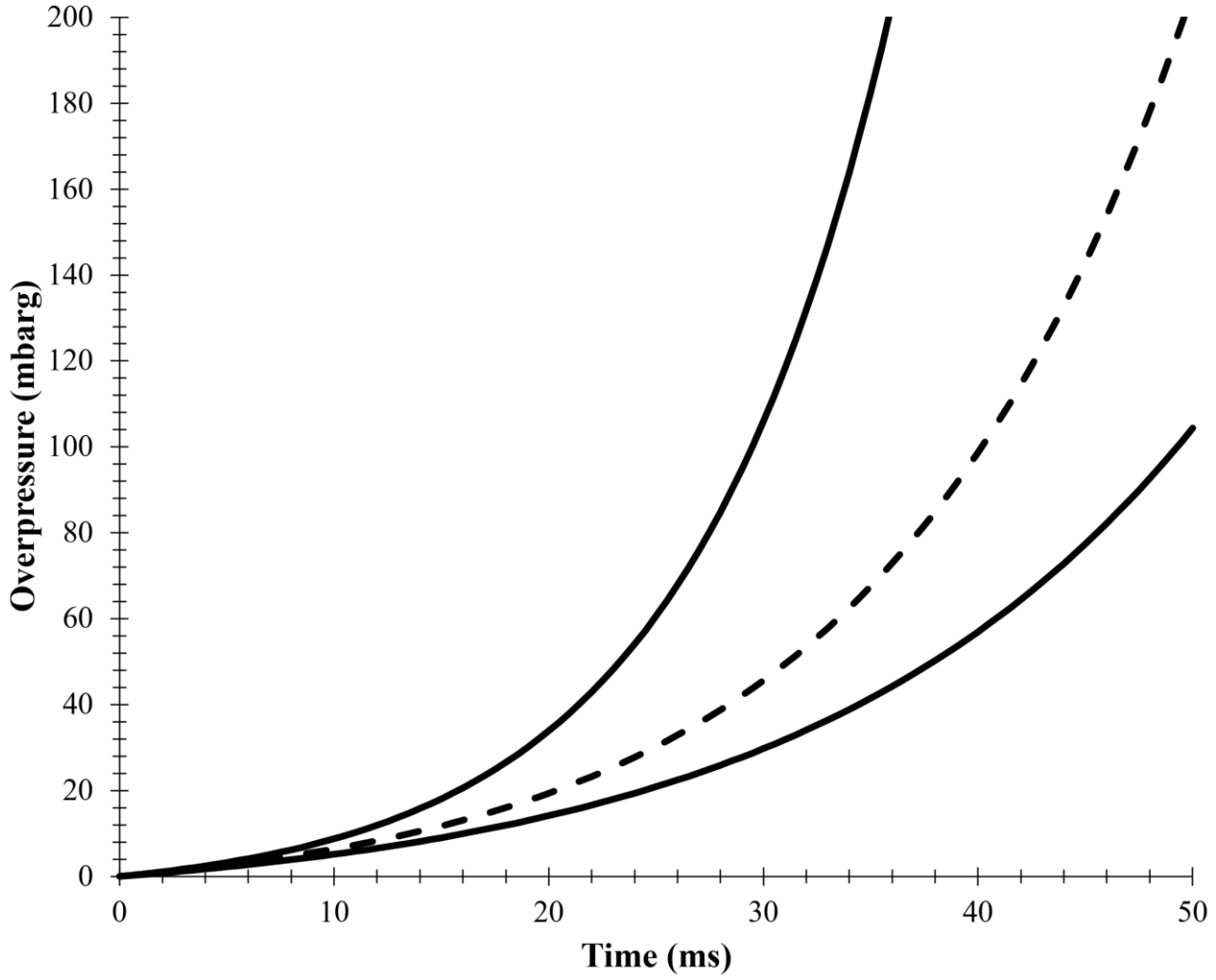
$P_{ff}(t) := \beta_{ff_0} \cdot e^{\beta_{ff_1} \cdot t} + \beta_{ff_2}$

$P_{ff}(0) = -1.212$

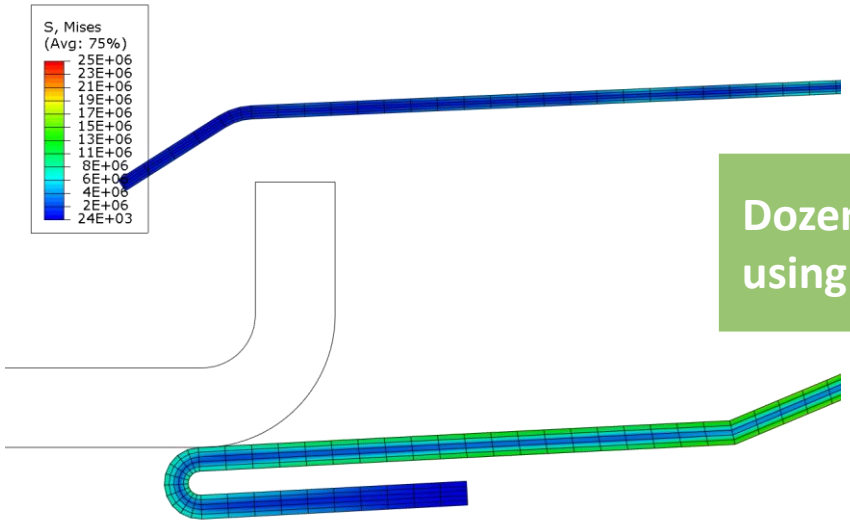


Acknowledgments:
DNV Spadeadam

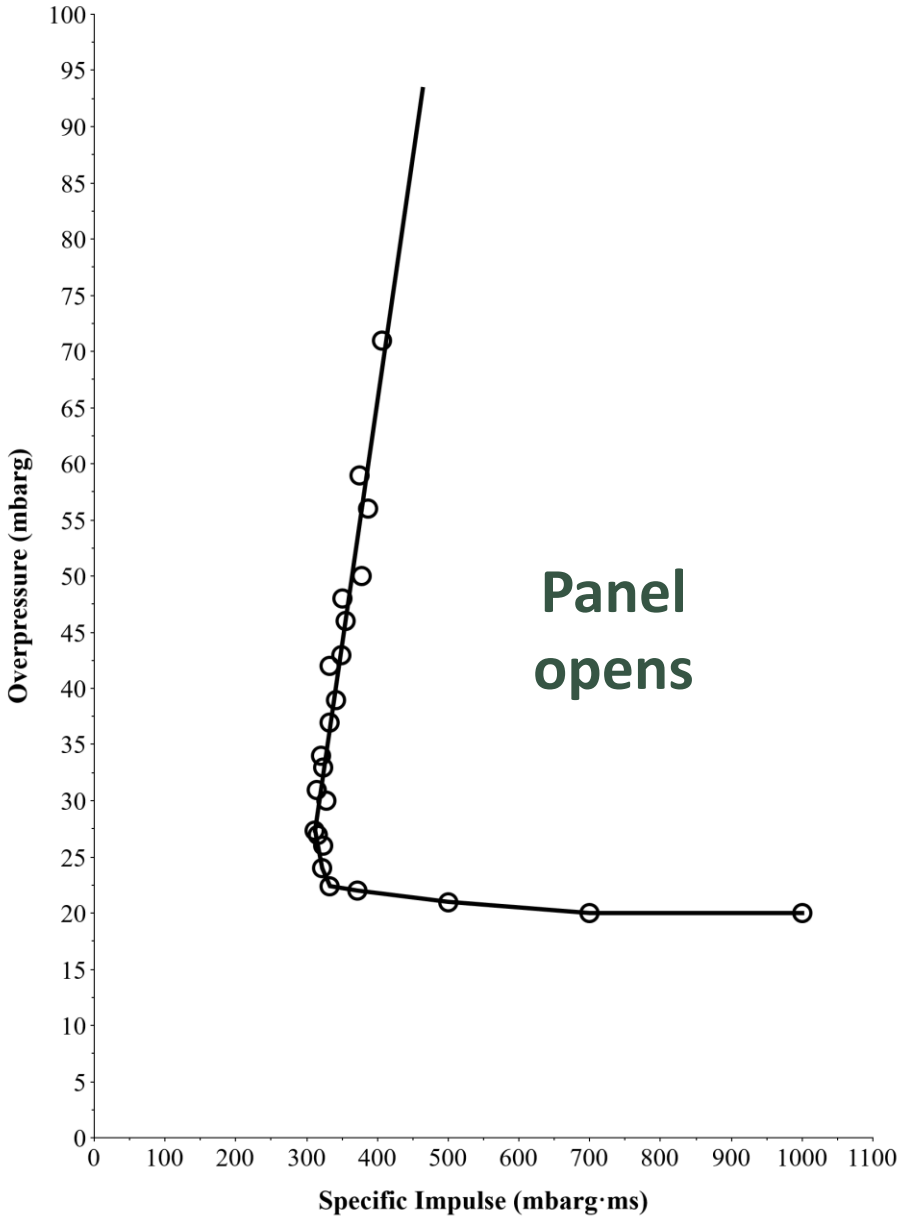
Family of synthetic early hydrogen explosion pressure curves, derived from testing



Definition of Vertex panel “Iso-opening” curve



Dozens of simulations using synthetic curves



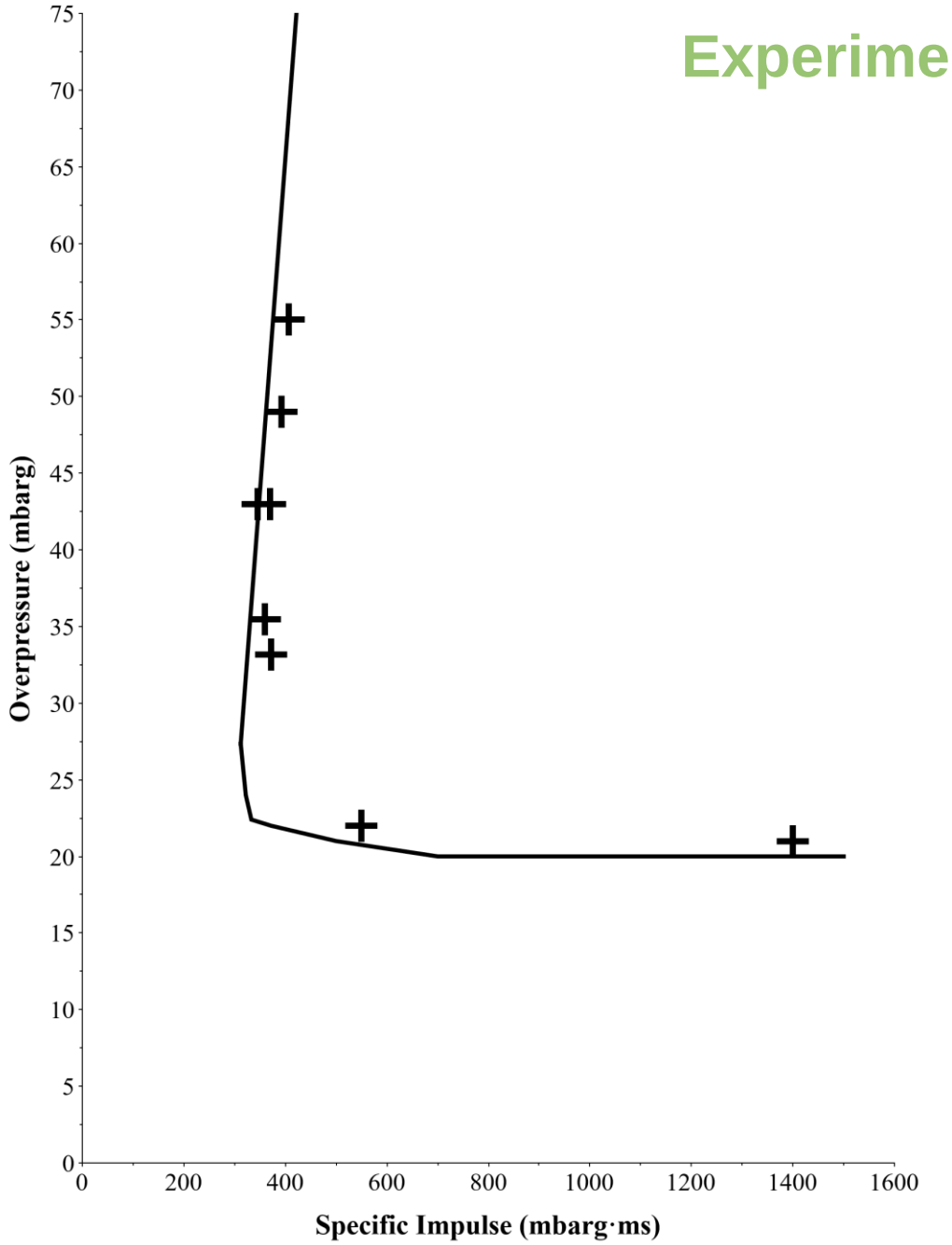
Panel opens

Experimental validation

- A range of hydrogen deflagration tests.
- Diverse overpressure & impulse combinations.
- Extreme, “beyond design” scenario included in testing.
- Close correspondence between design analyses and experimental results.
- Very high level of technical support from DNV Spadeadam throughout test programme.

Experimental validation

- Close correspondence between design analyses & experimental results.
- Very low static opening pressure ≈ 20 mbarg.
- Robust design information for specifiers, hazard analysis specialists & facility Duty Holders.



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Concluding remarks

- Relief venting is a long-established & essential aspect of explosion hazard mitigation
- It must be viewed as **part of an overall strategy** (ventilation, integrity, leak detection, etc.)
- The Rhino Vertex vent panel modular system offers predictable, low-inertia operation, underpinned by full-scale experimental testing. Full response envelope defined.

- Hydrogen explosion hazards can safely be managed, but detailed understanding of the deflagration characteristics of hydrogen is essential.
- We must remain mindful of complicating phenomena, such as rapid deflagration & transition to detonation.

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Thank you & best wishes for your future projects