Conference or Workshop Item:
Rigby, S. (2021) Near-field blast loading : challenges, unknowns, and opportunities. In: Fire and Blast Information Group Webinar 028.

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FIRE AND BLAST INFORMATION GROUP

WEBINAR 028 PROCEEDINGS

NEAR-FIELD BLAST LOADING: CHALLENGES, UNKNOWNS AND OPPORTUNITIES

7th July 2021

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The University of Sheffield

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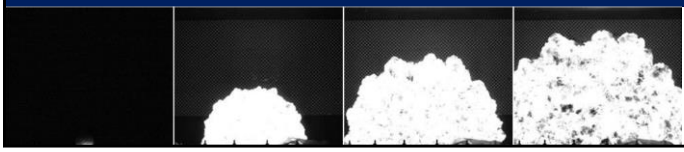
Near-field blast loading:

Challenges, unknowns, and opportunities



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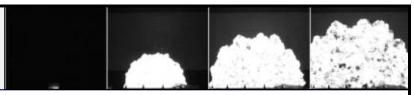

Overview and purpose of talk

- Understanding and predicting near-field blast loading is a significant challenge to the blast protection engineering community
- This talk is focussed on my work in three main areas:
- **Challenges**
  - How do we study near-field explosions in a scientific sense? How do we measure them?
- **Unknowns**
  - What is it that we cannot yet do, or account for? Why not?
- **Opportunities**
  - What can we do about it? What emerging tools can we use?

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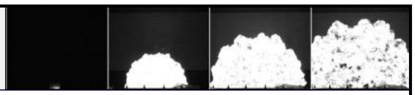

Motivation

https://abcnews.go.com/Lifestyle/wireStory/oklahoma-city-bombing-survivor-tree-dna-live-62500453

https://www.independent.co.uk/news/uk/unseen-photographs-capture-the-devastating-and-emotional-aftermath-of-the-1996-ira-bomb-in-9538378.html

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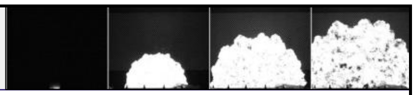
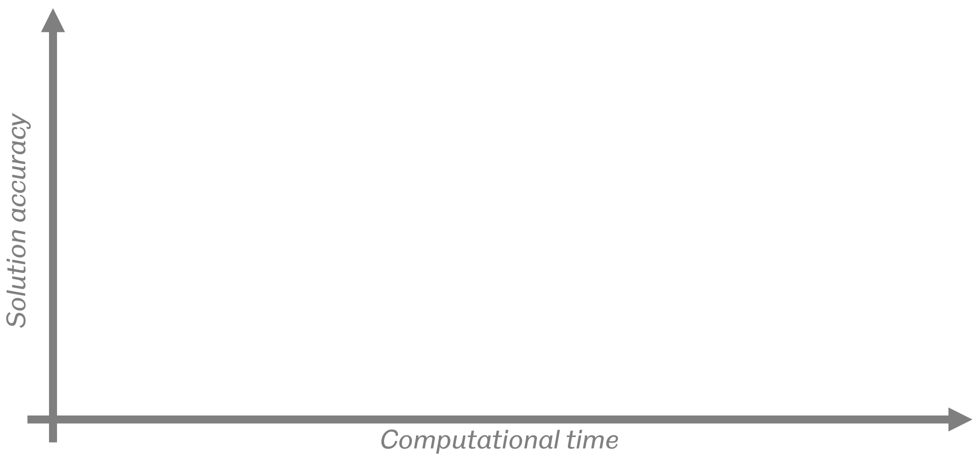
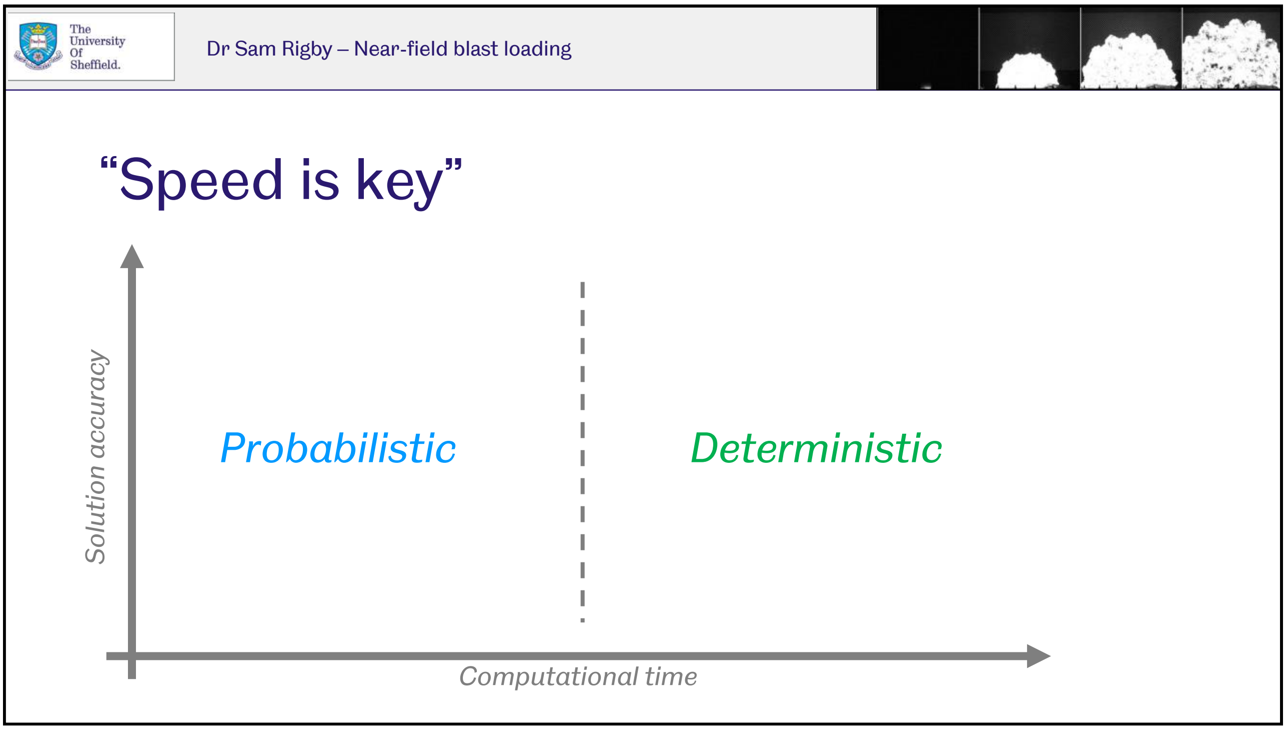


“Speed is key”

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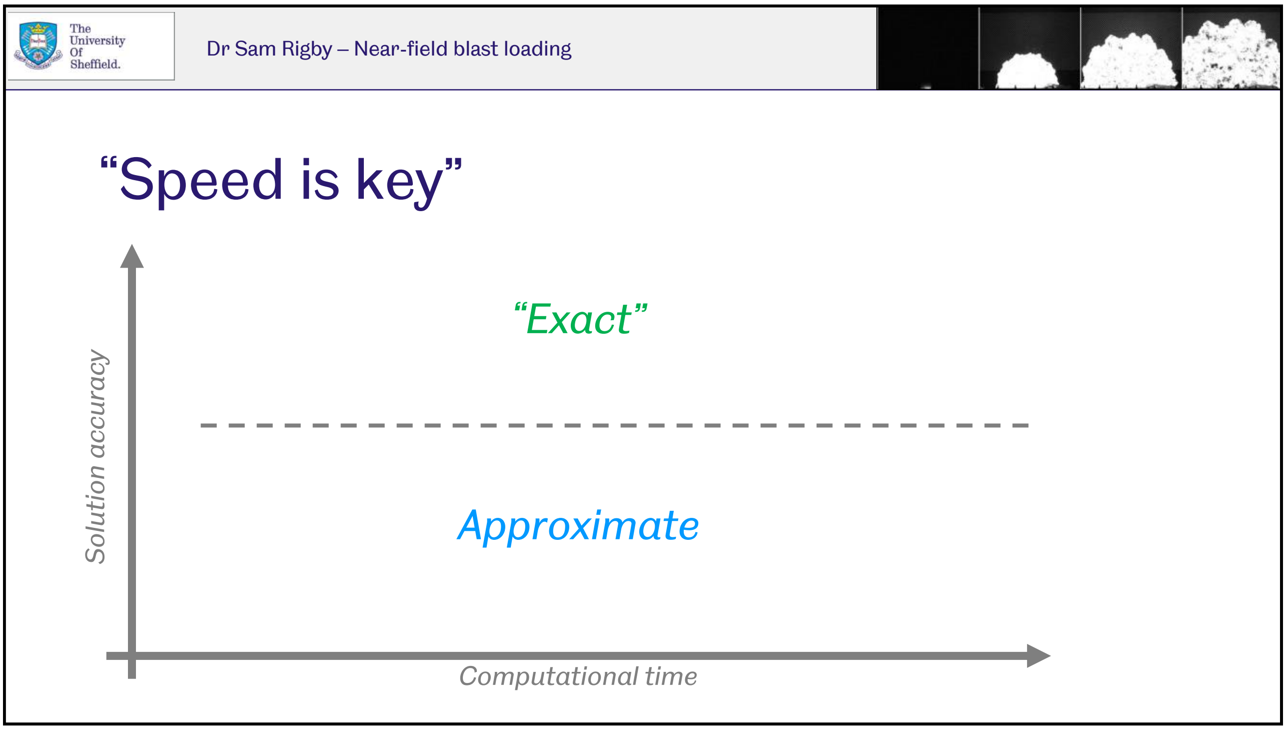
"Speed is key"
Solution accuracy
Probabilistic
Deterministic
Computational time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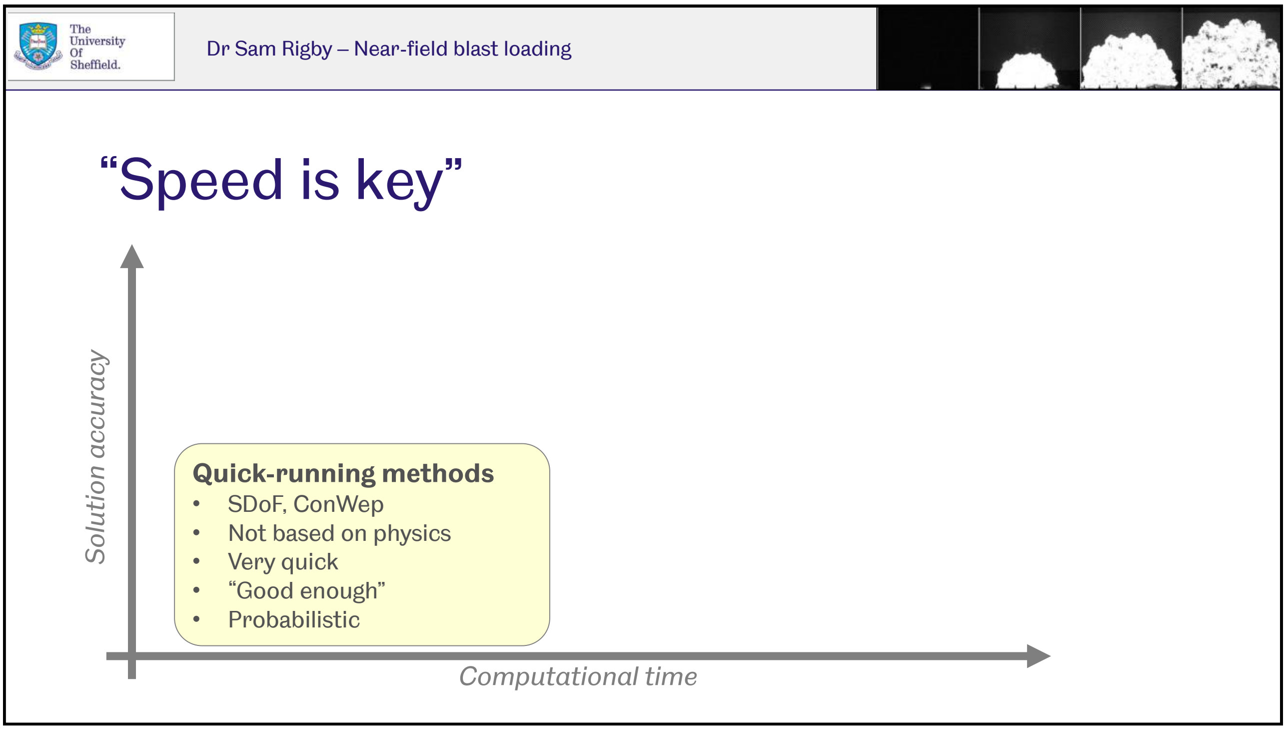
"Speed is key"
Solution accuracy
"Exact"
Approximate
Computational time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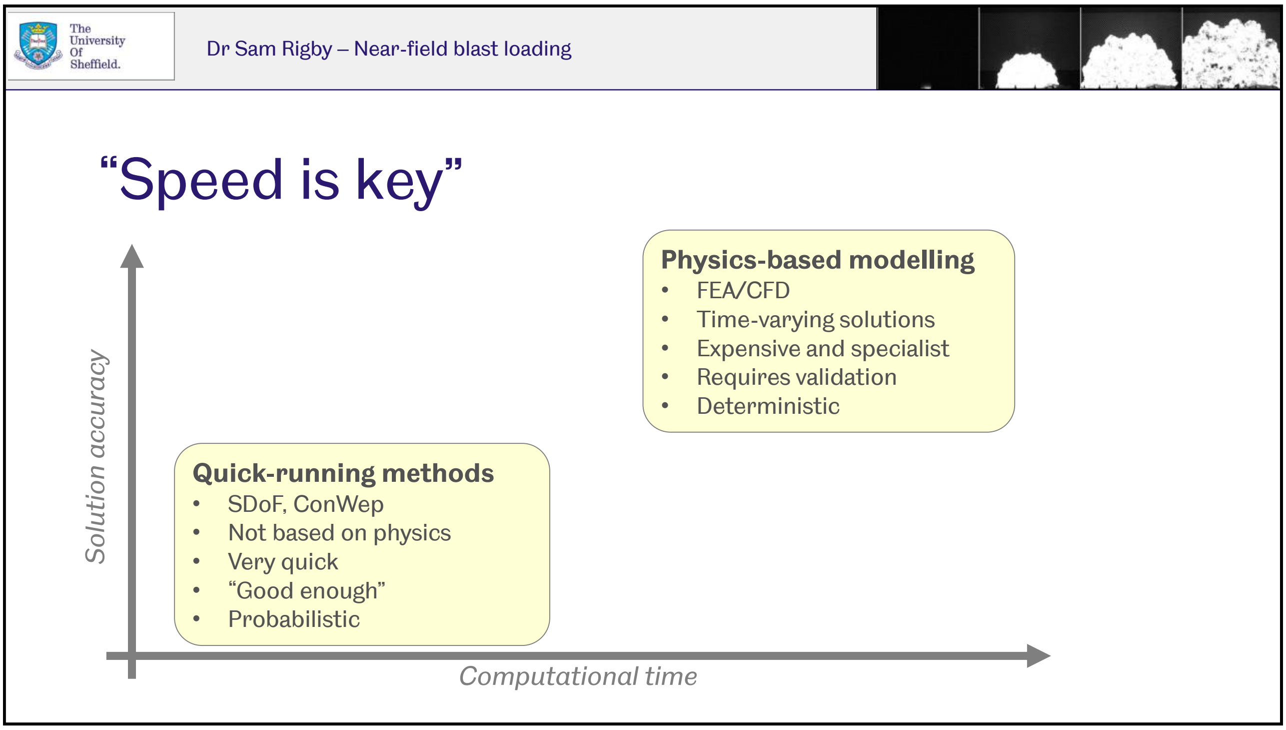
"Speed is key"
Solution accuracy
Quick-running methods
• SDoF, ConWep
• Not based on physics
• Very quick
• "Good enough"
• Probabilistic
Computational time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"Speed is key"
Physics-based modelling
• FEA/CFD
• Time-varying solutions
• Expensive and specialist
• Requires validation
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Solution accuracy
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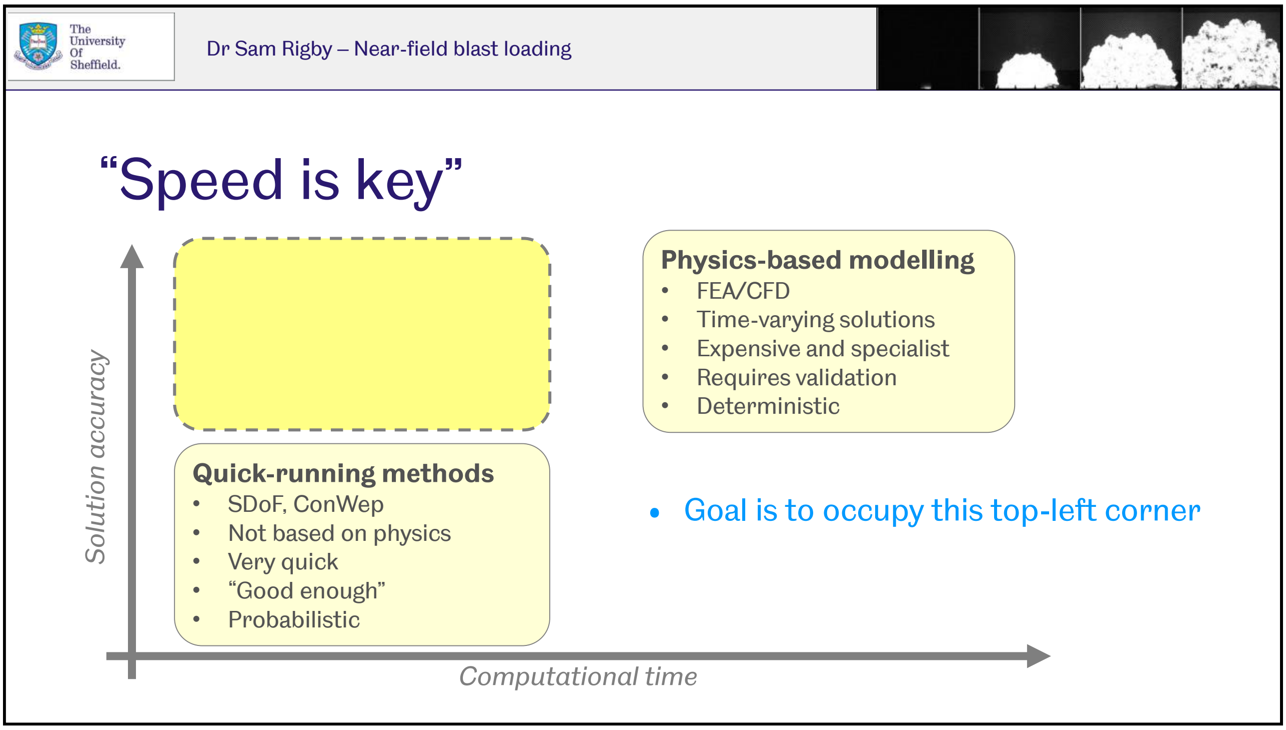
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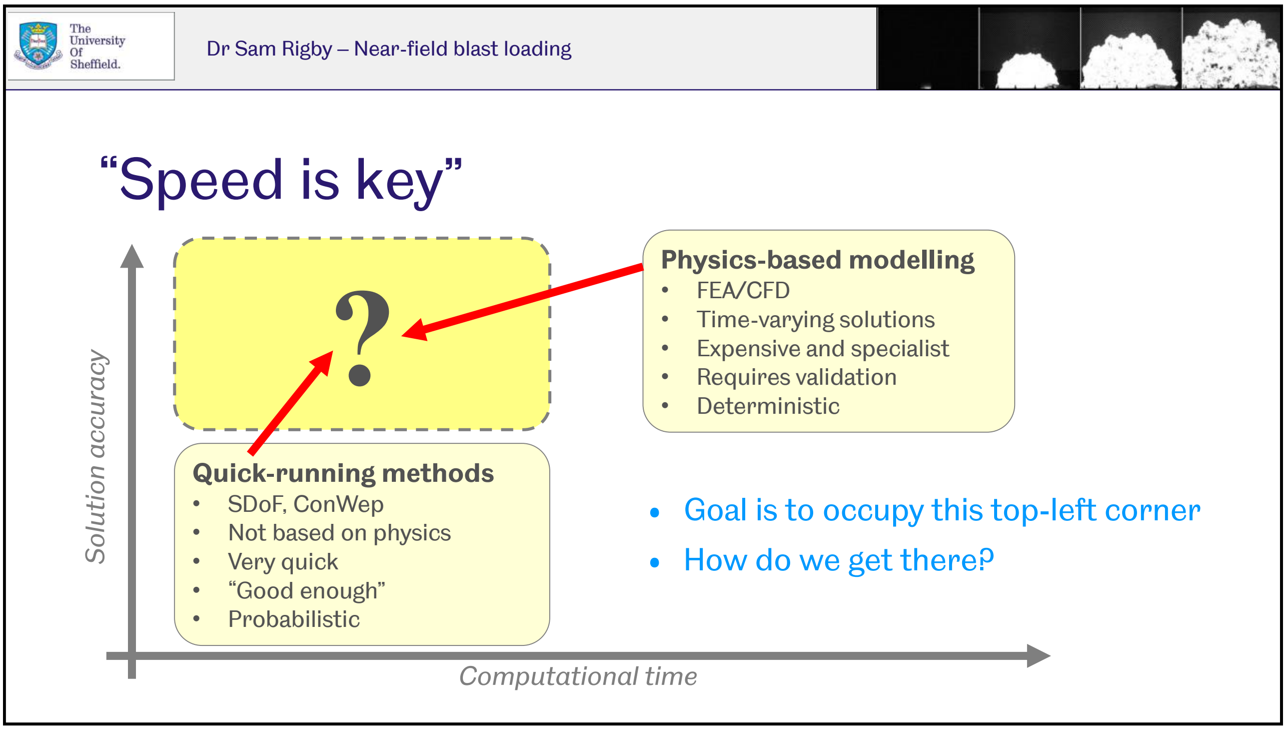
Probabilistic
Goal is to occupy this top-left corner
Solution accuracy
Computational time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"Speed is key"
?
Physics-based modelling
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Deterministic
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"Good enough"
Probabilistic
Goal is to occupy this top-left corner
How do we get there?
Solution accuracy
Computational time

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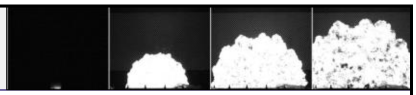
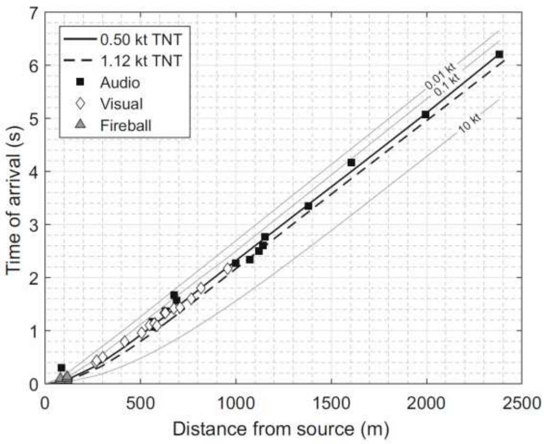


Practical use of FREMs

- Estimated the yield of the 2020 Beirut explosion using existing FREMs
- Initial results widely reported in the media within 24hrs of the explosion

Rigby et al. *Shock Waves* 2020;**30**:671-675



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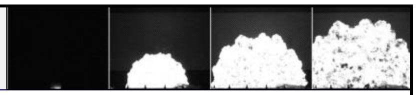

Research approach

- To develop experimental approaches to **measure** loading in the near-field
- To better understand the underlying physical mechanisms: **origin** and **significance**
- To devise ways to augment existing quick-running tools with **knowledge** of these mechanisms, and **data** from validated numerical models

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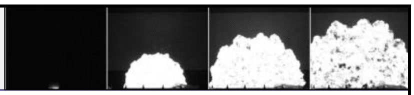

Research approach

- To develop experimental approaches to **measure** loading in the near-field
  [Challenges]
- To better understand the underlying physical mechanisms: **origin** and **significance**
  [Unknowns]
- To devise ways to augment existing quick-running tools with **knowledge** of these mechanisms, and **data** from validated numerical models
  [Opportunities]

Challenges:

Experimental measurements of near-field blast loading

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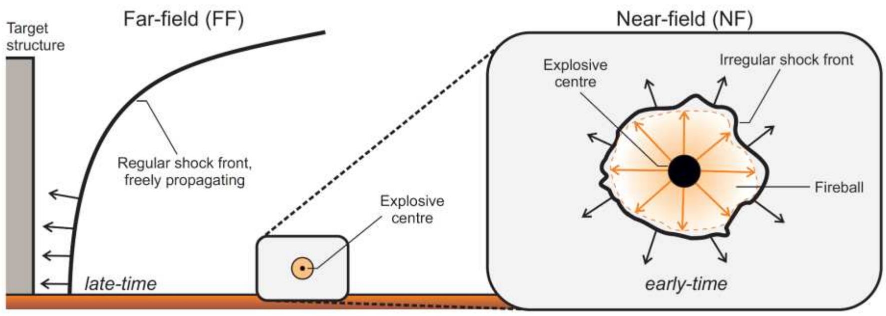
Near-field loading

- Combined loading from (entrained) shock wave and fireball impingement
- Pressures in 100s MPa, microsecond durations, 1000s °K temperatures



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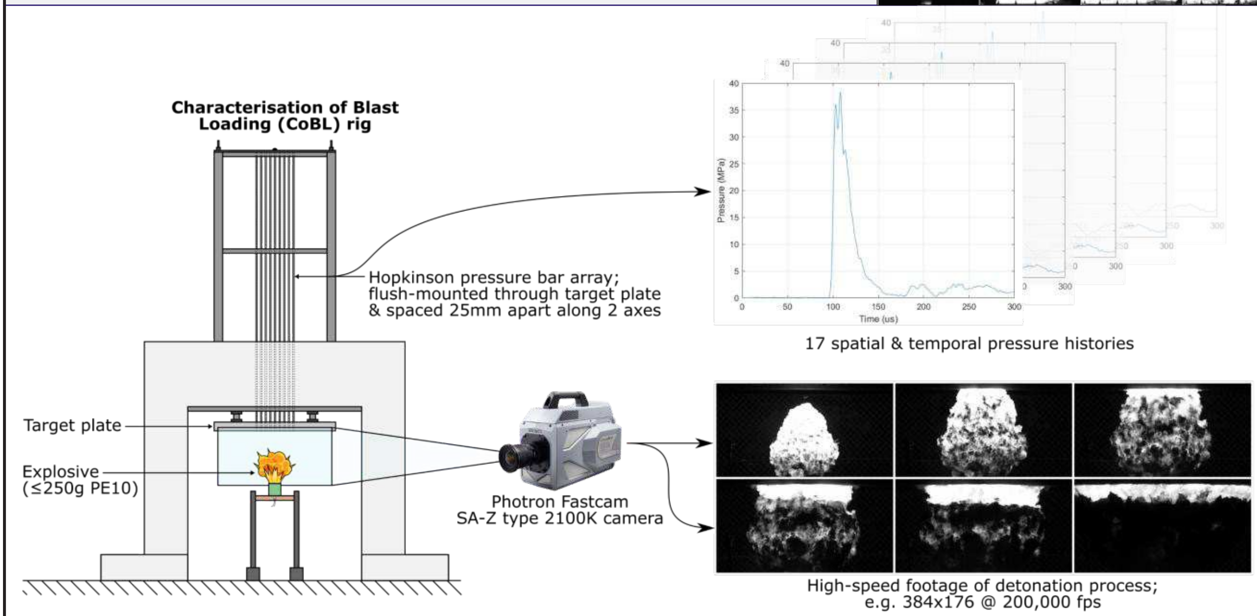

Adapted from Clarke et al. *Measurement Science and Technology* 2015;**26**:015001

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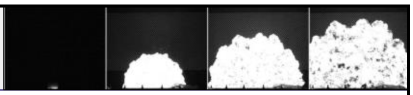

Data capture

- Pressure measured using flush-mounted HPBs (~GPa range, MHz frequency)
- Data processing routines to "step-through" from local to global parameters

1. Individual pressure/impulse histories
2. Peak pressure/impulse distributions
3. Total impulse
   [integrated over instrumented region]
4. High speed video

Local → Global

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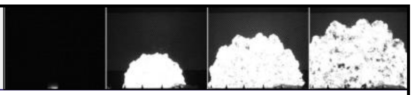
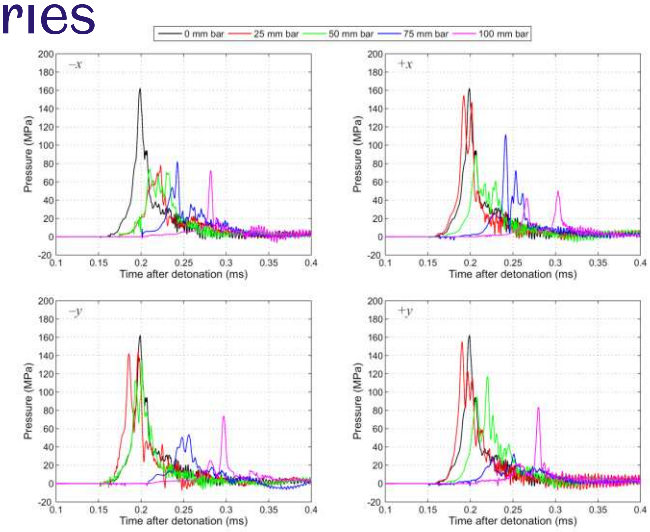


1. Individual histories



Rigby et al. *International Journal of Impact Engineering* 2016;**96**:89-104

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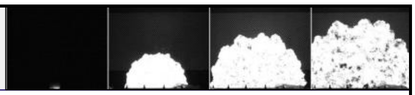
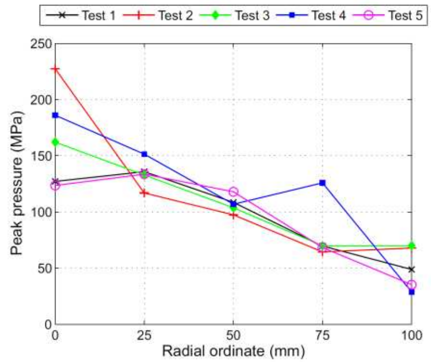
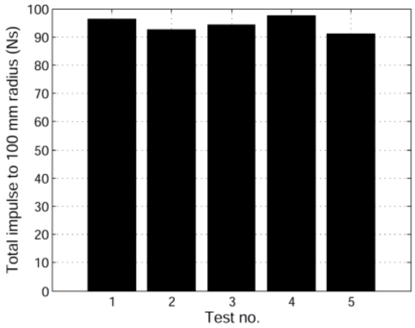


2. Peak distributions



Rigby et al. *International Journal of Impact Engineering* 2016;**96**:89-104



Rigby et al. *International Journal of Impact Engineering* 2016;**96**:89-104

3. Total impulse

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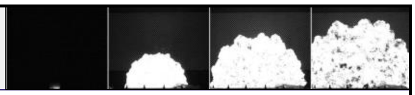
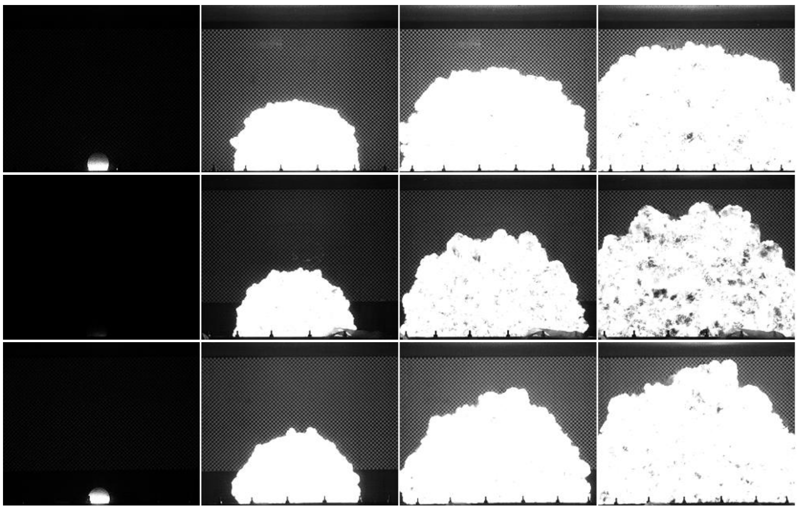


4. High speed video

Rigby et al. *Experimental Mechanics* 2020;**60**:875-888



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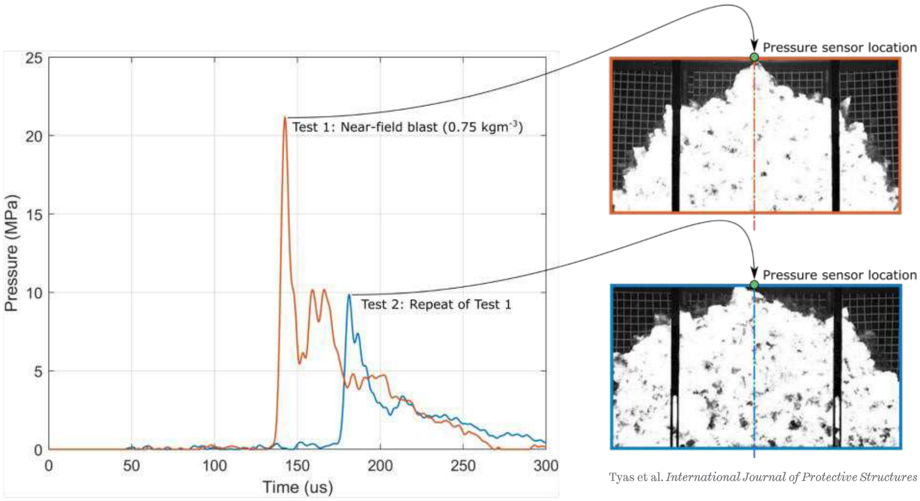
Instabilities and localised variations



Tyas et al. *International Journal of Protective Structures* 2016;7(3):456-465

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Not a scaling issue...

- Left: ~0.1 **kg** TNTe
- Right: ~4.5 **kt** TNTe
  (“Minor Scale”, 1985)

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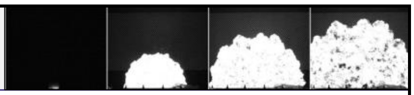
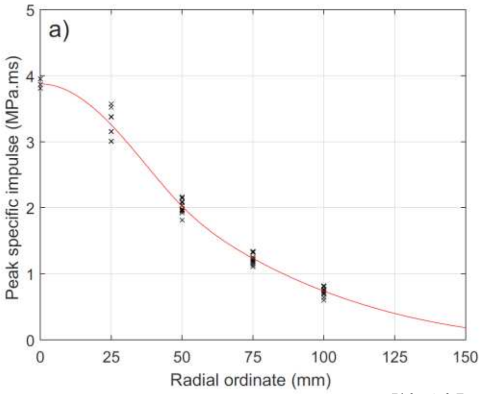
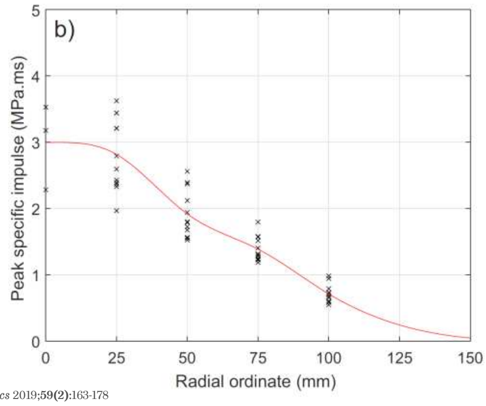


Effect of charge shape

(a) 100g PE4 sphere @55mm clear



(b) 78g PE4 cylinder @168mm clear



Rigby et al. *Experimental Mechanics* 2019;**59(2)**:163-178

Observations

- Localised variations in loading appear significant
- Do not appear to be scale-dependent
- Variations appear to increase with scaled distance

  … to a certain point, because we know far-field loading is highly repeatable

  Rigby et al. *In: PSHI4* 2014. Tianjin, China

- Some charge shapes produce more variable loading

Questions

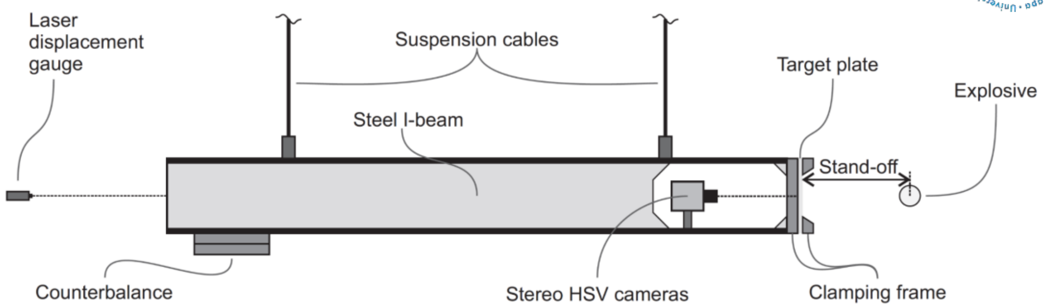
- How does this influence plate deformation?
- Are structures sensitive to these localised variations?

Unknowns:

Understanding the significance of loading features

Measuring plate deformation

- Steel *I*-beam suspended from ceiling of blast chamber
- Part of web removed to house 2× HSV cameras @30,000 fps



Rigby et al. *Experimental Mechanics* 2019;**59(2)**:163-178

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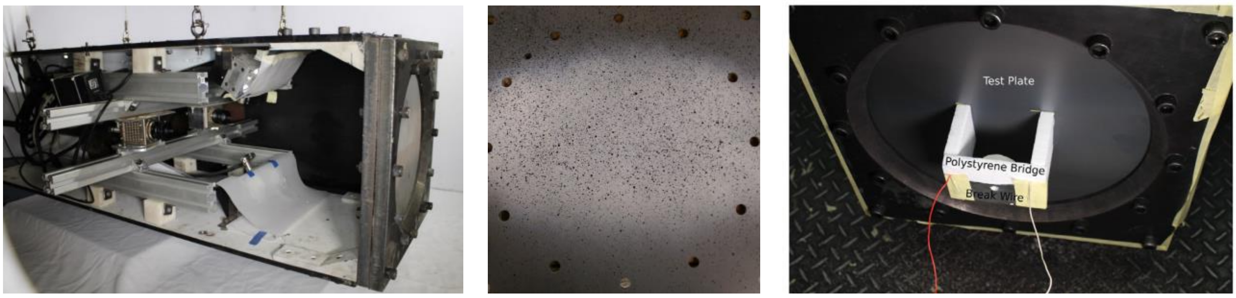
Digital image correlation

- Speckle pattern applied to rear face of plate
- Individual pixels are tracked by the cameras, and the relative movement in each field-of-view is used to calculate displacement (towards the cameras)



Curry & Langdon. *International Journal of Impact Engineering* 2017:**102**:102–116

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Experimental study

- Load measurement tests previously conducted at Sheffield were repeated
- Scaled equivalent of 100g sphere and 78g cylinder tests
- This time, target deformation was measured using DIC

- Specific impulse can be inferred from plate's initial velocity profile:

$$v(x) = \frac{i(x)}{\rho t}$$

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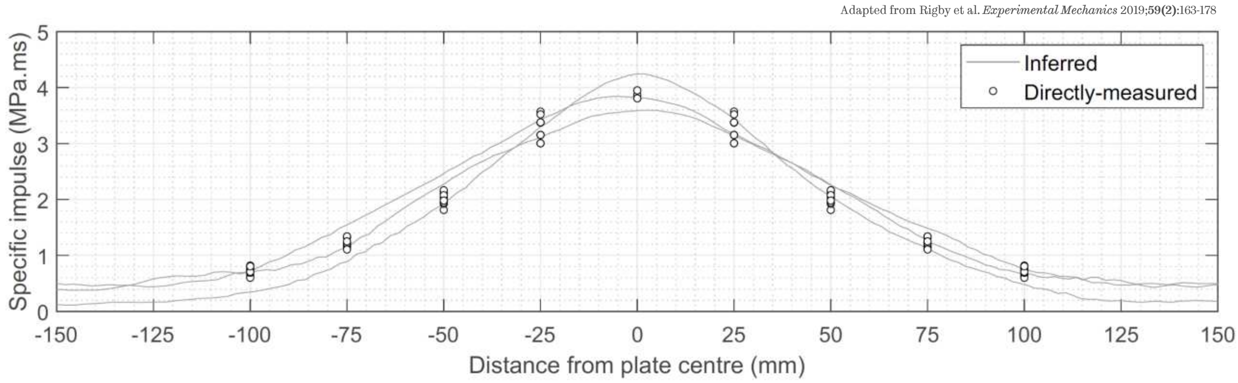
Results [spheres]

Adapted from Rigby et al. *Experimental Mechanics* 2019;**59**(**2**):163-178



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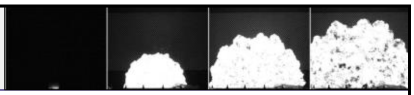
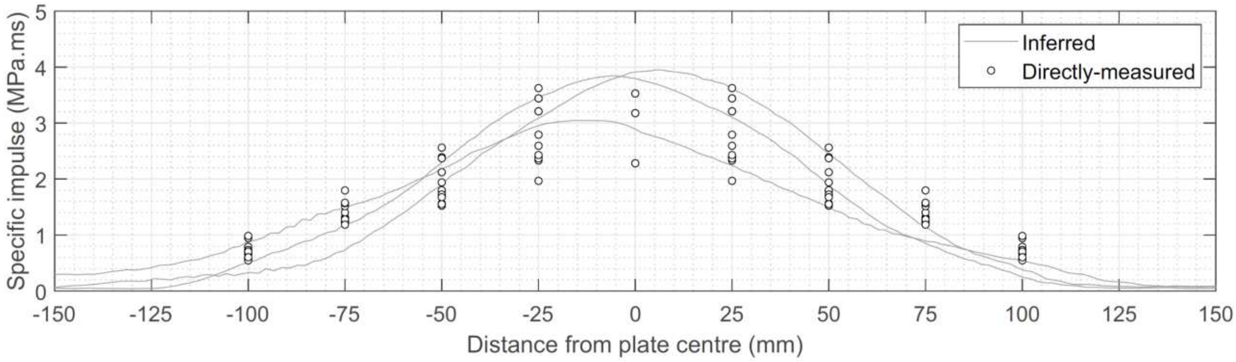


Results [cylinders]

Adapted from Rigby et al. *Experimental Mechanics* 2019;59(2):163-178



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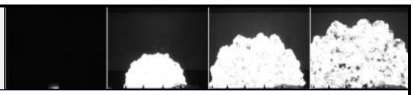

Significance

- Application of a specific impulse causes a *directly proportional* velocity uptake in the plate
- Velocity → kinetic energy → plate deformation
- Therefore, we cannot accurately predict plate response with *global* measures, we need to know *local* loading distributions
- Variations in loading lead to commensurate variations in plate response

Plates are sensitive to the stochastic nature of blast loading

Plates are sensitive to the stochastic nature of blast loading

therefore...

...we need to treat the load and response in a probabilistic sense

Opportunities:

Improving quick-running methods, and new approaches

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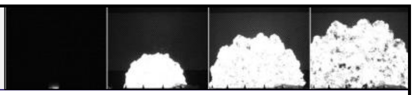
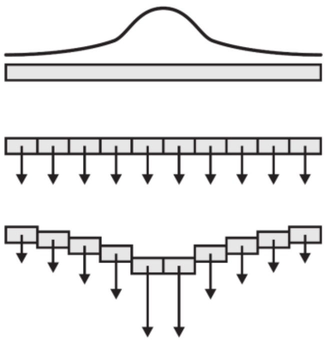


Energy equivalent impulse



Take a non-uniform load,

Applying this load uniformly, leads to: $E_{k,l} = \dfrac{\left(\int_A i \,\mathrm{d}A\right)^2}{2\rho t A}$

Whereas true initial velocity, leads to: $E_{k,u} = \dfrac{1}{2\rho t}\int_A \dfrac{(i\,\mathrm{d}A)^2}{\mathrm{d}A}$

Rigby et al. *International Journal of Impact Engineering* 2019;128:24-36

We can define a uniform load that imparts the same KE as the distributed load

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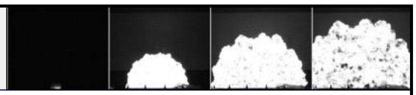
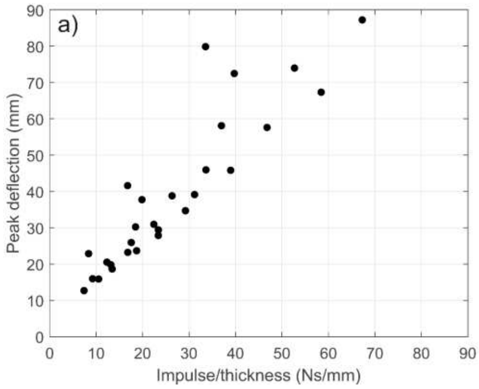


Energy equivalent impulse

- Finite element parametric study undertaken
- Variety of loading distributions and plate properties

- Results show weak positive correlation when plotted as total impulse (averaged over area)
- Some loadings are much more effective at producing deformation, for a given total load (more concentrated)



Rigby et al. *International Journal of Impact Engineering* 2019;**128**:24-36

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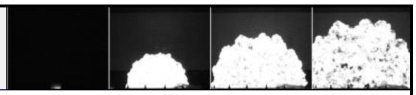
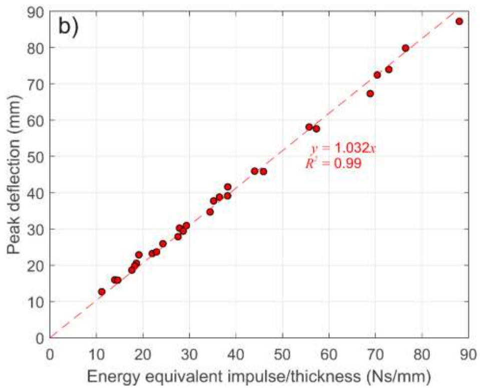


Energy equivalent impulse

- Finite element parametric study undertaken
- Variety of loading distributions and plate properties

- But near-perfect correlation when plotted as energy equivalent impulse
- Shows that incorporation of non-uniform loading into existing FREMs should be possible



Rigby et al. *International Journal of Impact Engineering* 2019;**128**:24-36

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What if we don't know the loading?

- Previous work has assumed that the loading is known *a priori*
  - Experiment measurements, modelling, existing predictive methods…
- What if this isn't the case?
- Do we have tools available to rapidly generate loading predictions for unknown cases?
- Machine learning is an option…

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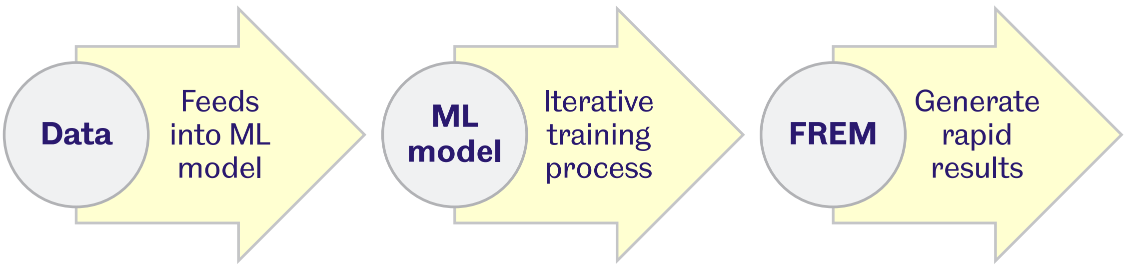
Machine learning



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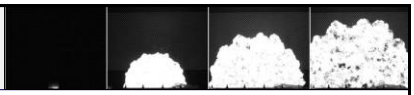
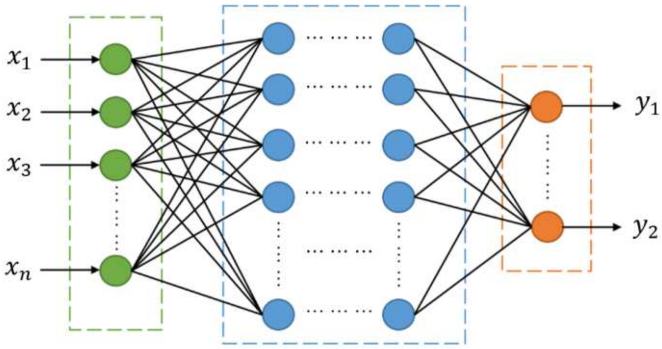


Artificial Neural Networks (ANNs)

- Made up of three groupings of neurons
- Information flows left to right
- Connections between neurons strengthen based on positive results
- Allows the computer to learn patterns in the data and links between input/output



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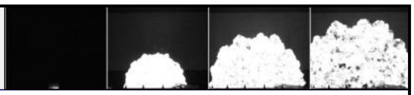
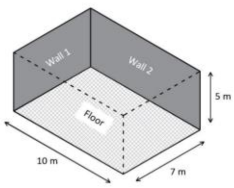
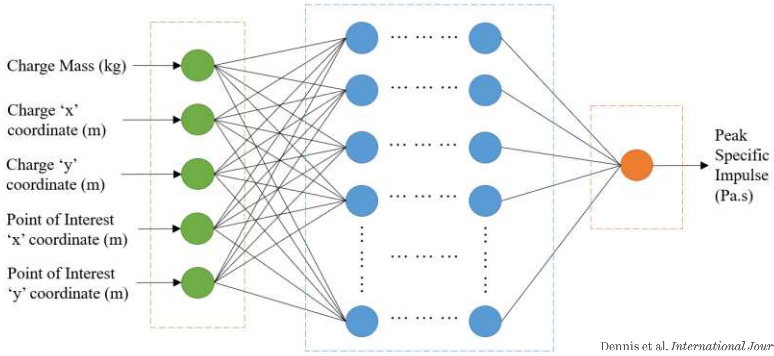


Prediction of complex blast using ANNs

- CFD used to generate blast loading in a semi-confined room
- Over 20,000 data points from 72 different model configurations





Dennis et al. *International Journal of Protective Structures* 2020 [in press]

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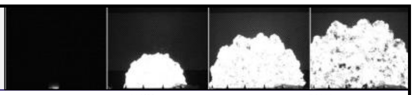
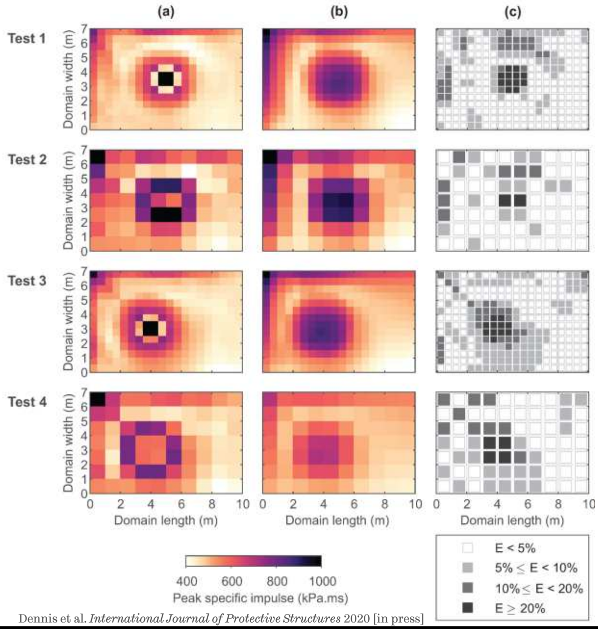
Dr Sam Rigby – Near-field blast loading



Results

- Once trained, the model was able to match blind CFD results, generally to within 10%
- Could populate predictions for the entire domain in less than 4 minutes
- Compared to ~2 hours for the CFD model
- Complex features (e.g. pressure build up in corners) learned well



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Outlook

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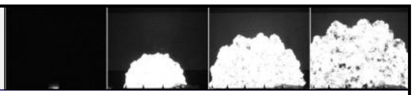

Outlook

- Near-field blast loading is highly complex, and our work has only scratched the surface
- Here, the blast load is extremely high in magnitude, and governed by several complex mechanisms that we don't yet understand
- We need to be able to predict this loading accurately and quickly
- Experiments, modelling, analytical and ML tools have been used to enhance existing FREMS with some success…
- … but there is still a lot more work to do!

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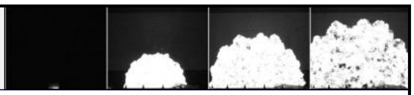

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Preliminary yield estimation of the 2020 Beirut explosion using video footage from social media

S. E. Rigby, T. J. Lodge, S. Alotaibi, A. D. Barr, S. D. Clarke, G. S. Langdon & A. Tyas

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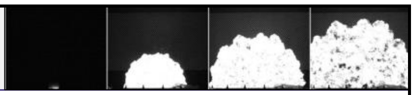

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