FABIG

Fire and Blast Information Group

UK Technical Meeting: New Insights into Risk Assessment

Democratisation of the probabilistic methodology for determining structural design loads for blast

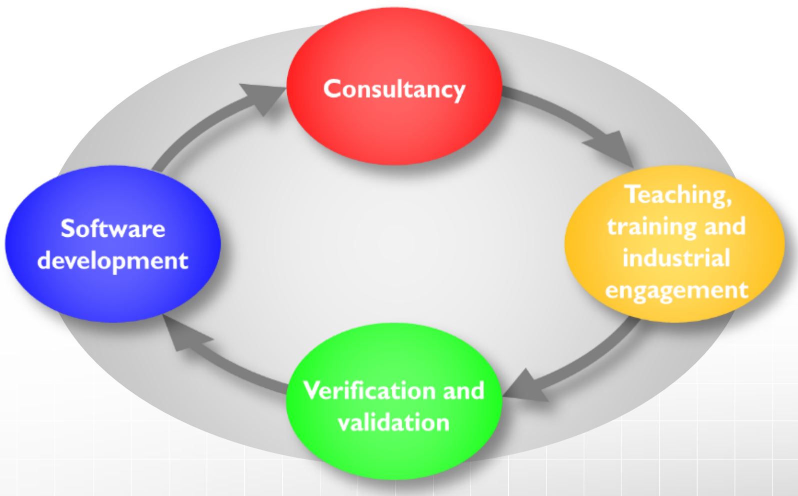
Steve Howell and Prankul Middha

30th November (Aberdeen) and 1st December 2016 (London)

abercus

Abercus

Abercus is an independent, privately-owned consultancy specialising in advanced engineering simulation within the energy sector – computational fluid dynamics (CFD), finite element analysis (FEA), the development of bespoke software tools and teaching/training.



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FABIG Fire and Blast Information Group

NAFEMS

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Summary

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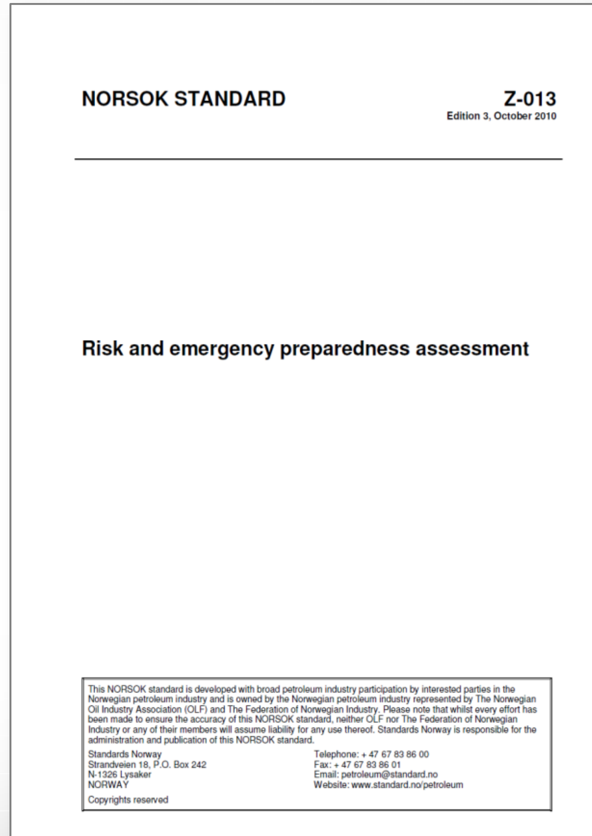
Introduction

Since the conception of the **NORSOK Z013 standard** in the late 1990's, the industry has steadily moved towards a **probabilistic approach for modelling explosion risk** (the recommended procedure outlined in Annex F).


NORSOK STANDARD

Z-013
Edition 3, October 2010

Risk and emergency preparedness assessment

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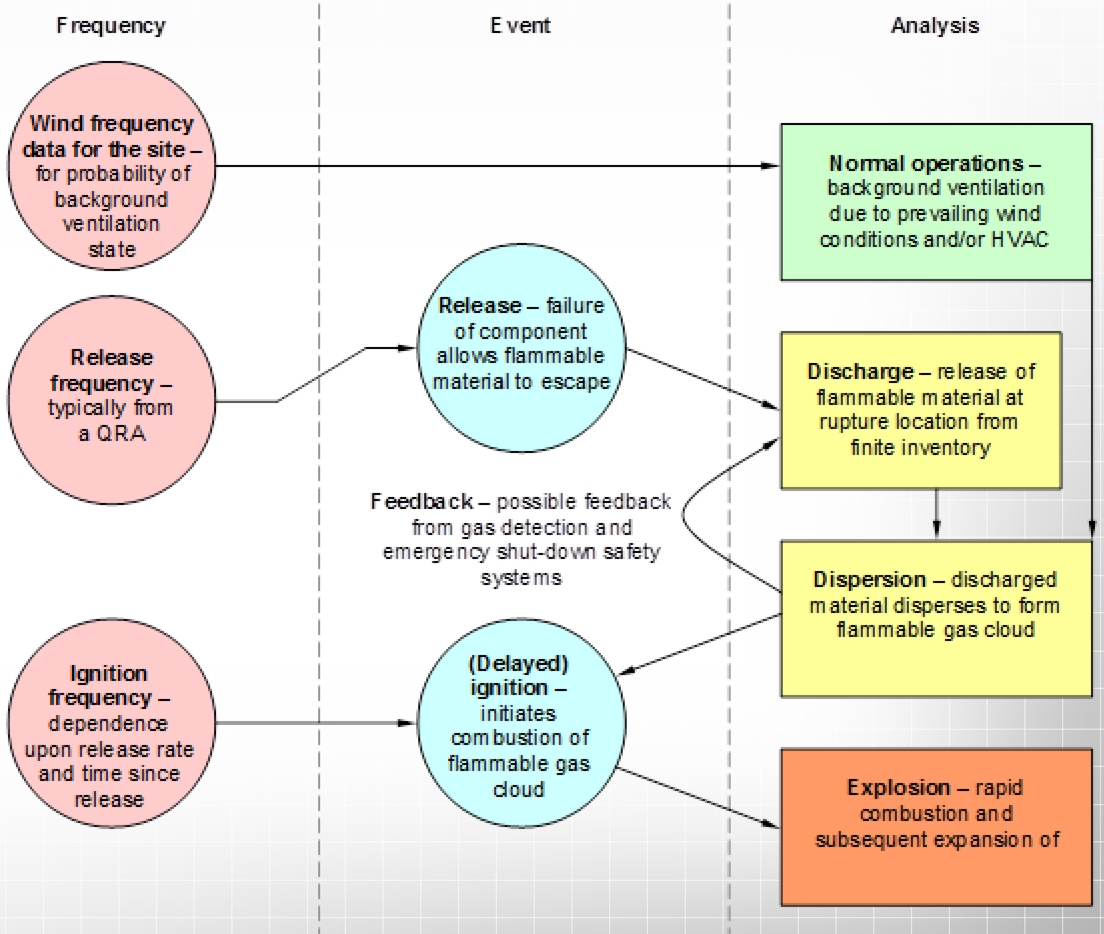
Introduction

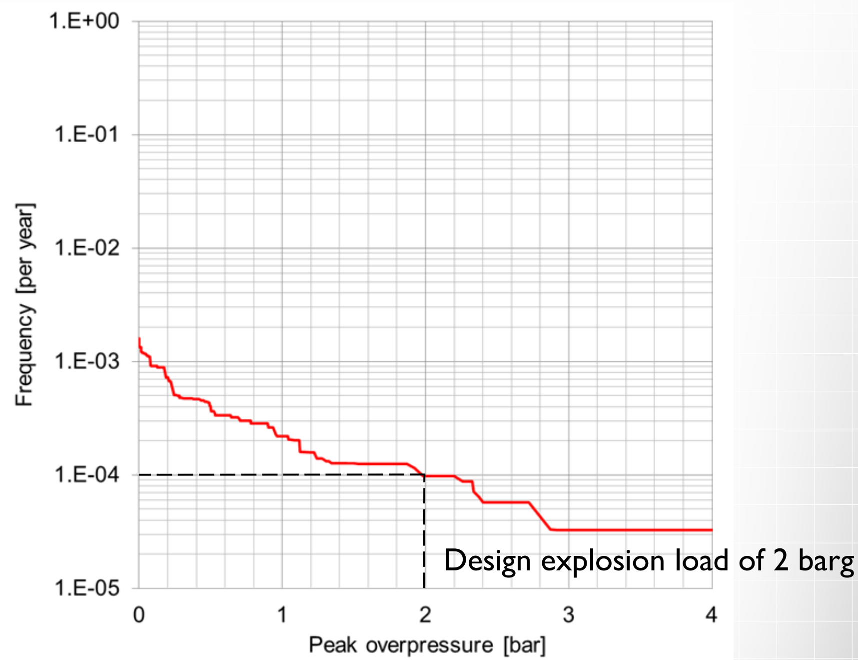
Simulating a large dataset of scenarios, with an understanding the frequencies of occurrence at each stage, allows **exceedance curves** for the explosion load to be constructed.



Introduction

Exceedance curves show the predicted frequency for explosion loading at a target of interest

For a specified allowable frequency, the design load is read from the curve and can be used as the basis of the structural design.



Introduction

Normal operations	• Wind speed • Wind direction
Discharge	• Pressure and temperature of the contained material • Magnitude of the inventory of the contained material • Composition of the contained material • Release hole size
Dispersion	• Location of release • Direction of release
Explosion	• Time of ignition following the release • Ignition location

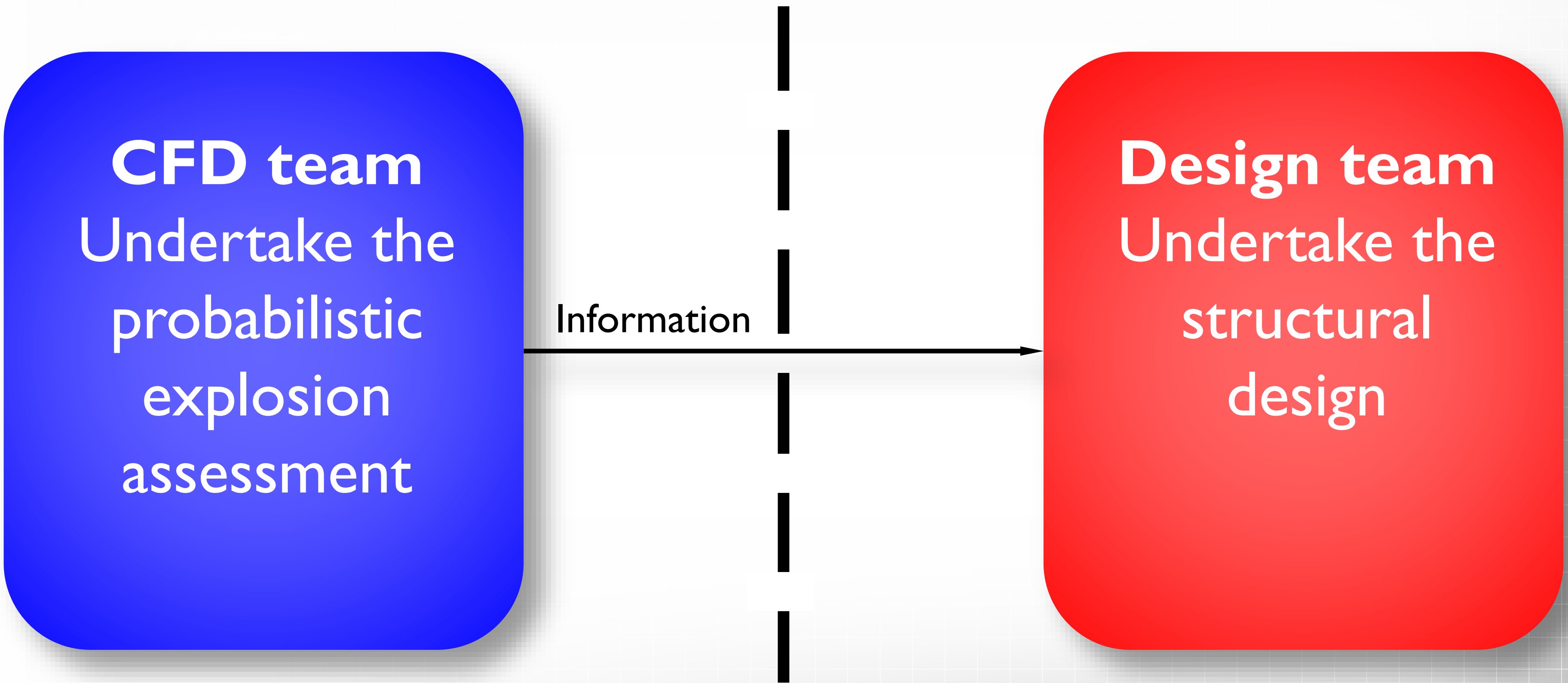
Introduction

- Typically a probabilistic explosion assessment may comprise the following CFD simulations:
  - Twelve for ventilation behaviour
  - A few hundred/couple of thousand for transient dispersion
  - A couple of hundred for explosion dynamics
- The associated duration for the assessment may be:
  - Around one month for the dispersion scope
  - A few days for the explosion scope
  - Typically a couple of months in total.

Introduction

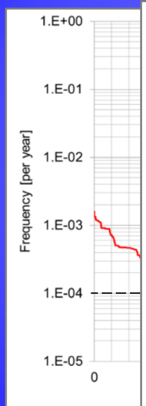
- A probabilistic explosion assessment is a substantial undertaking and is often performed by a **CFD team** that is entirely **separate** to the **structural design team** that will use the modelling outputs.

Introduction



Introduction

CFD team



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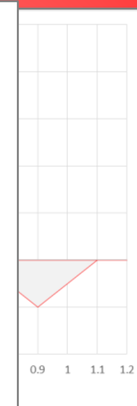
Design team

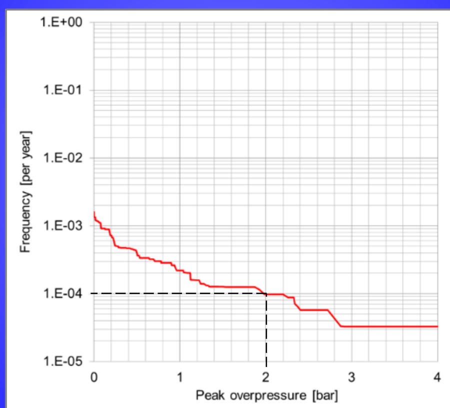


sion

The interface between the parties generally comprises the transfer of a single DAL for each target of interest, typically the 10^{-4}/yr DAL derived from exceedence curves, comprising the 10^{-4}/yr peak overpressure and an associated measure of the duration of the 10^{-4}/yr blast

Introduction

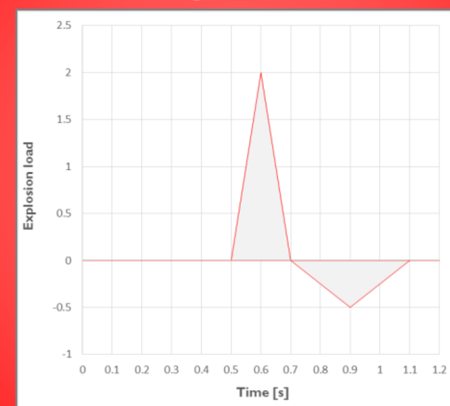
CFD team



Exceedence curves

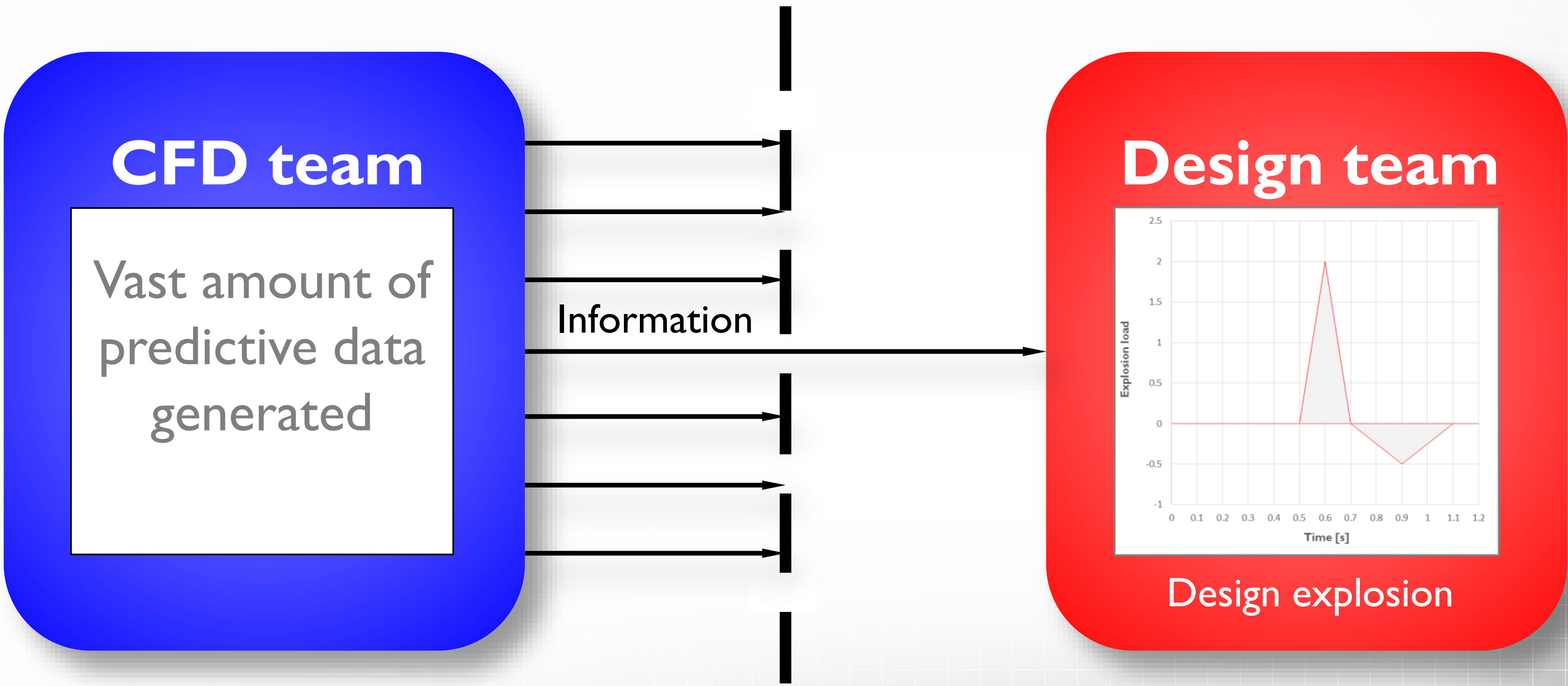
Information

Design team

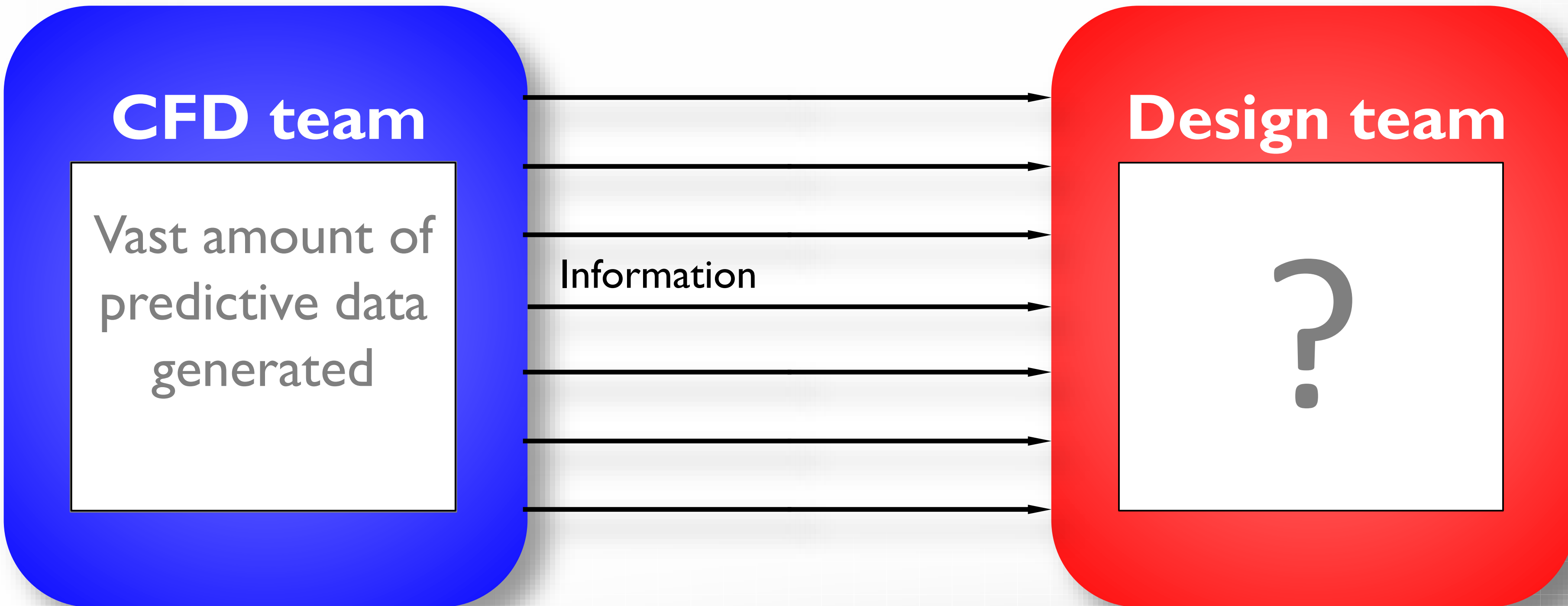


Design explosion

Introduction



Introduction



Introduction

- With such a large number of individual simulations, the success of an assessment can be ensured through the use of **simulation data management (SDM)**
- Effective SDM tools can also allow:
  - The sharing of predictive data with the design team, thus democratising the analysis data and the general approach
  - The automatic compilation of predictive data to provide new insight and new opportunities for analysis (3D risk assessment and one-to-one CFD-NLFEA coupling).

Introduction

- The more you investigate something, very often it yields further questions that had not been previously apparent
- As new methods are enabled though SDM tools, there may be a need for updated guidance to minimise inconsistency across our industry – perhaps some FABIG technical guidance?

Agenda

Introduction

Simulation data management

Sensitivity to assumptions

3D risk assessment

Probabilistic structural response

Consistency across the industry

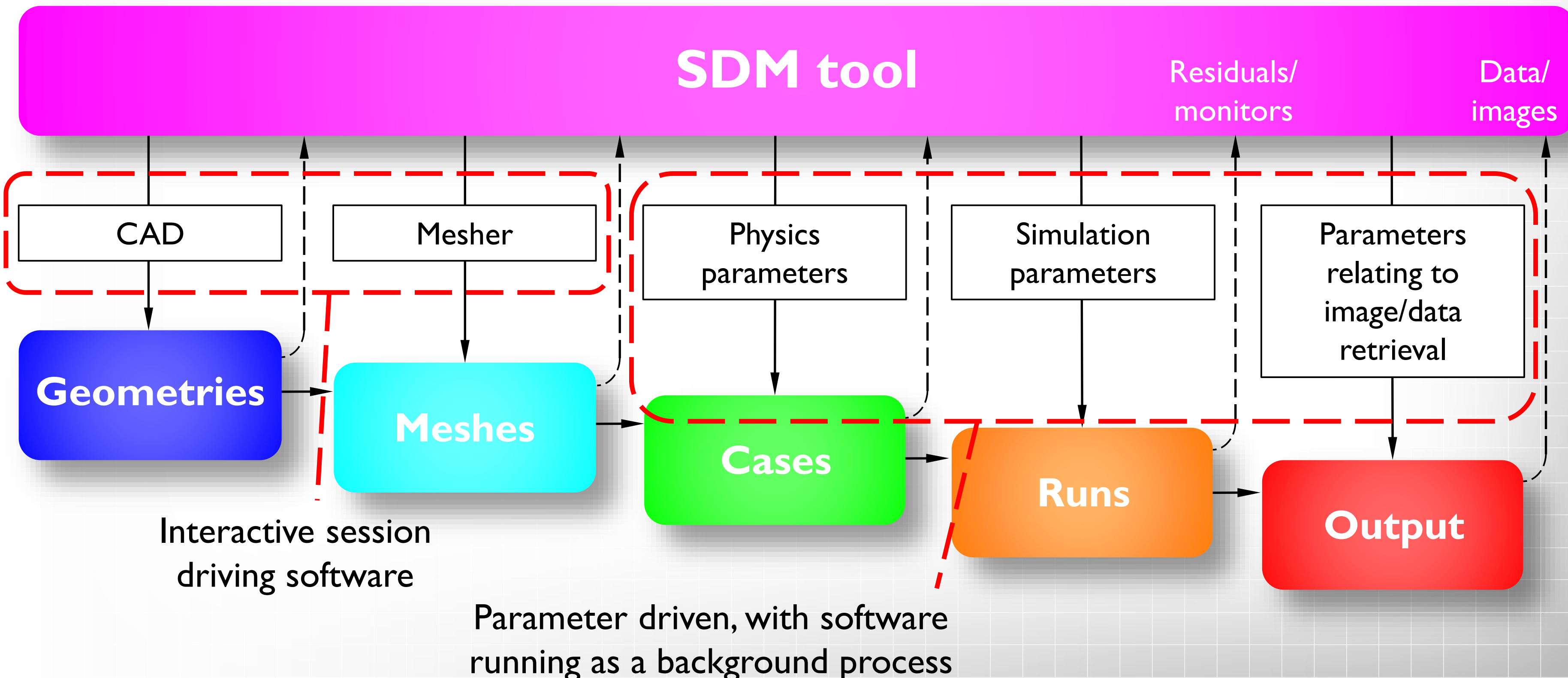
Summary

Simulation data management

- **Every simulation** undertaken at Abercus is **scripted** so that a precise record of the simulation is stored, in line with our QMS/ISO 9001 requirements
- Abercus uses SDM tools to manage it's work – effectively the SDM tool is a **database** of all of the relevant information which describes each simulation.

Simulation data management

Generic CFD/FEA analysis

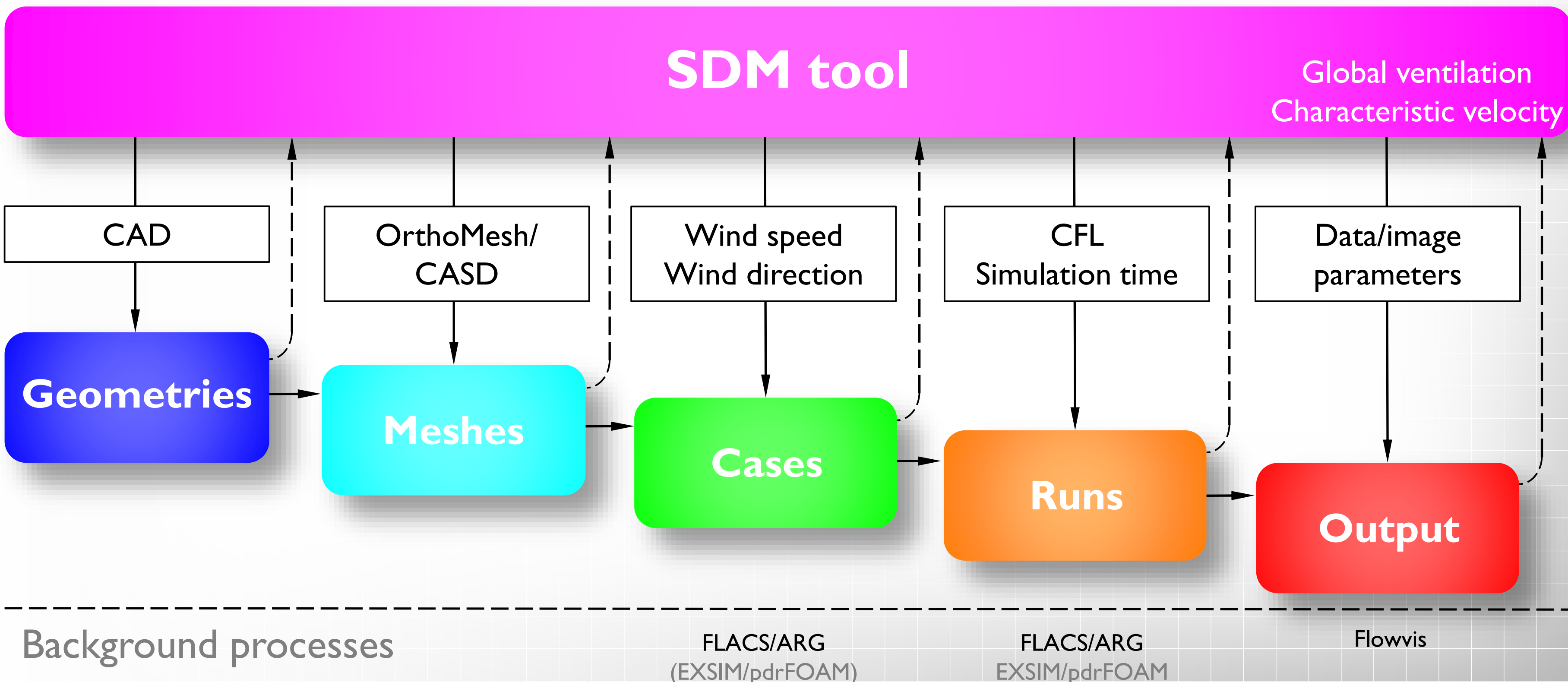


Simulation data management

- The application of SDM to a probabilistic explosion workflow essentially integrates the three stages of analysis (ventilation/dispersion/explosion)

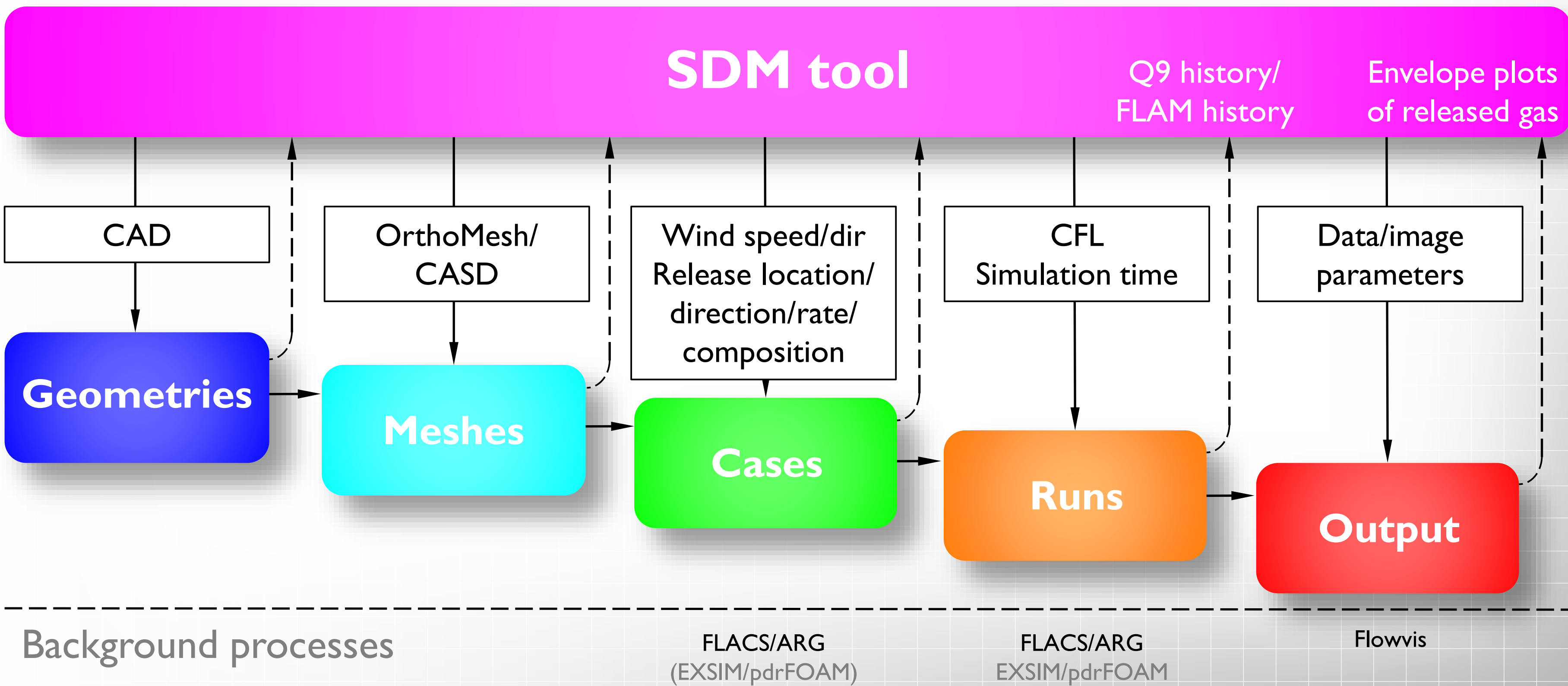
Simulation data management

Background ventilation



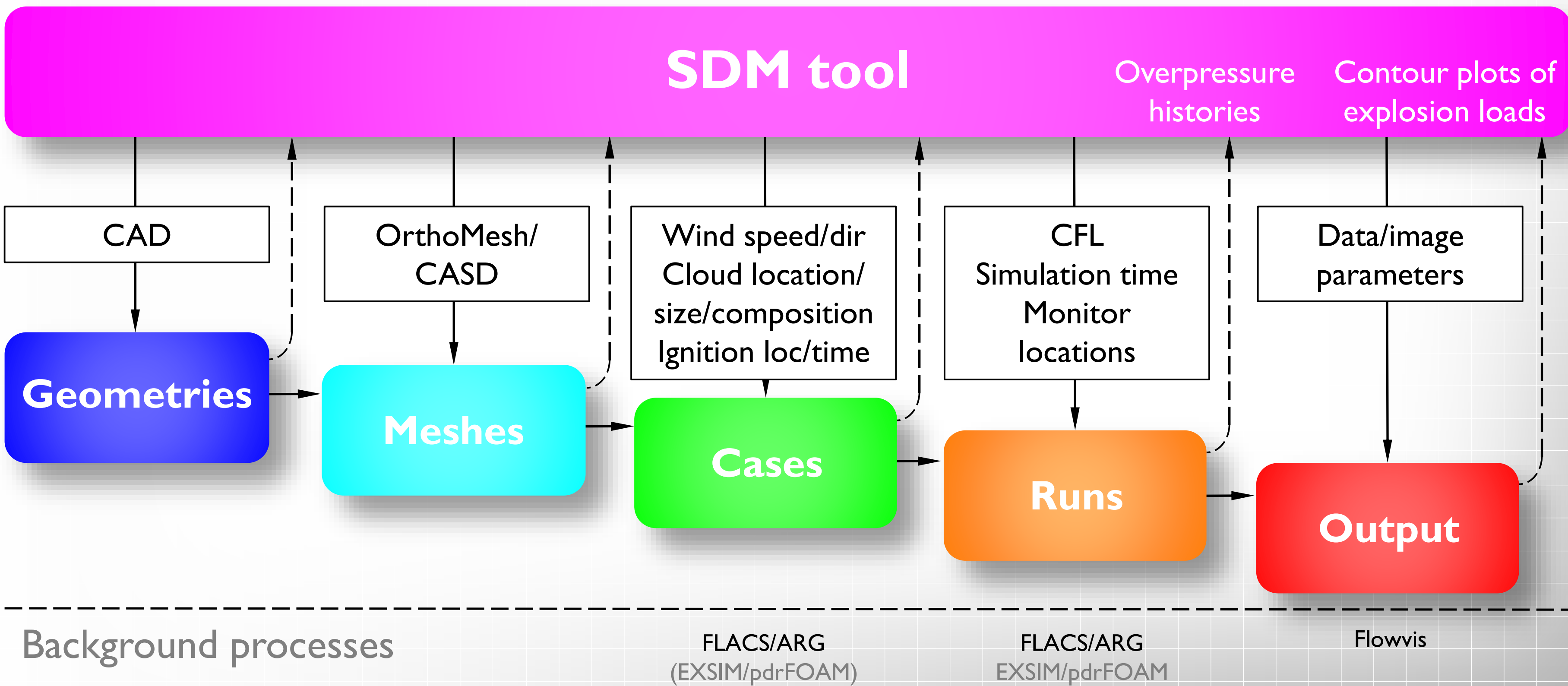
Simulation data management

Dispersion



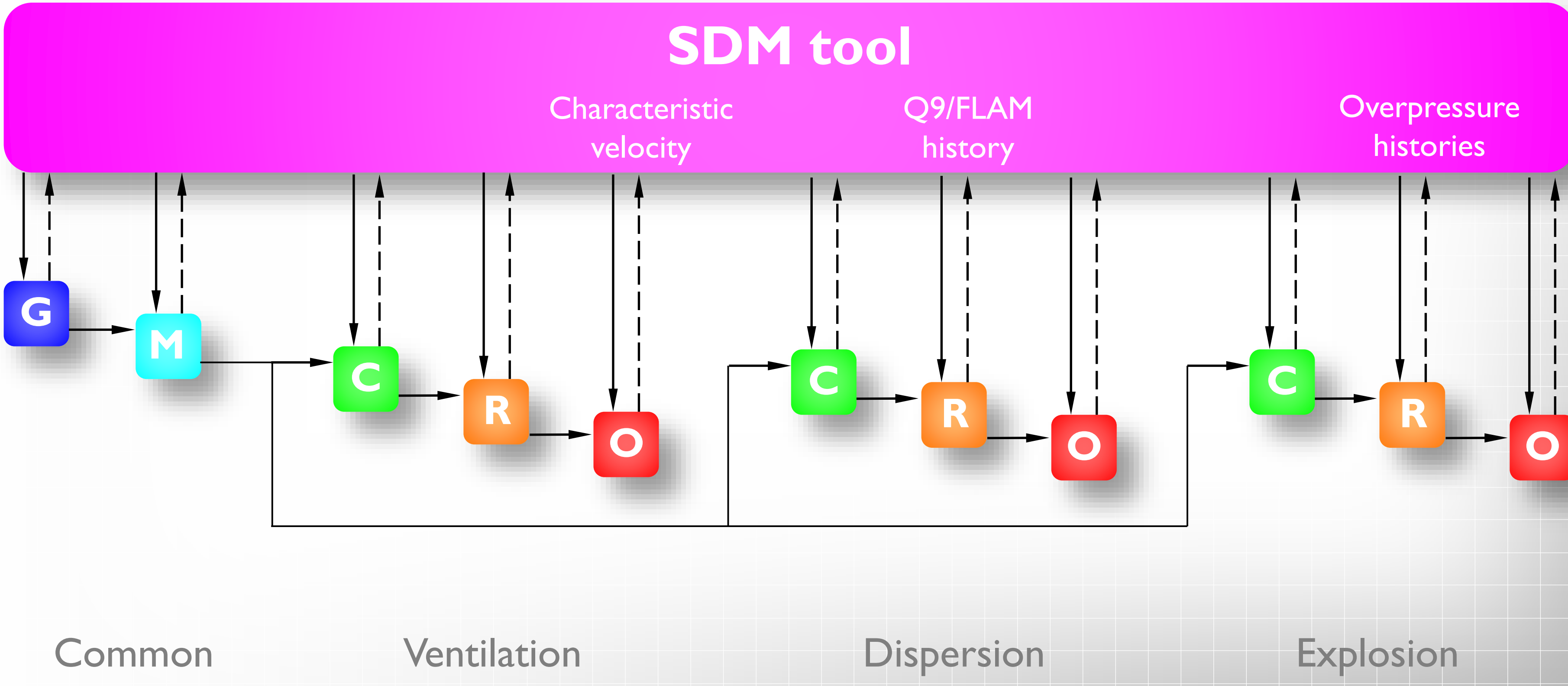
Simulation data management

Explosion



Simulation data management

Probabilistic explosion assessment

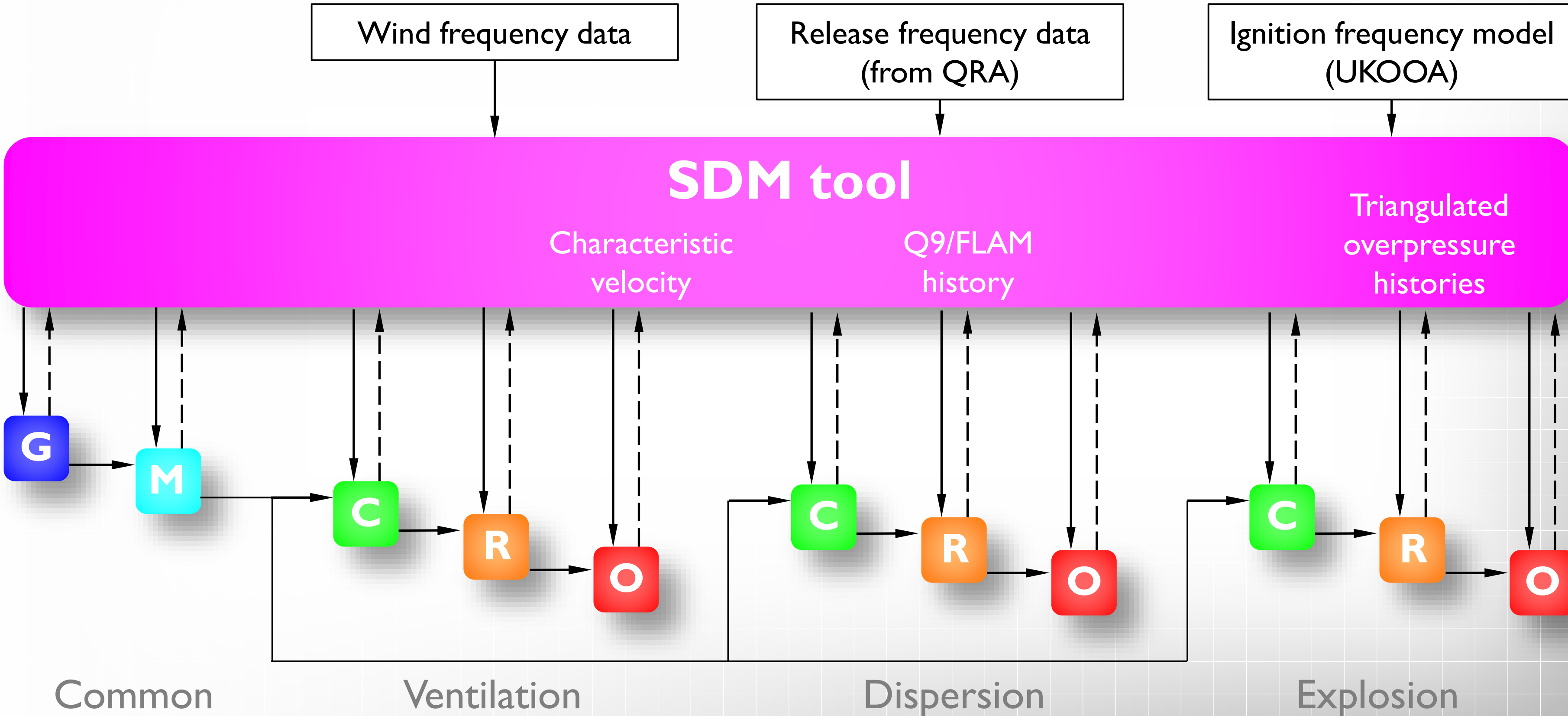


Simulation data management

- The application of SDM to a probabilistic explosion workflow essentially integrates the three stages of analysis (ventilation/dispersion/explosion)
- And with a little additional functionality it allows the output from each study to be automatically processed to construct the required exceedence data.

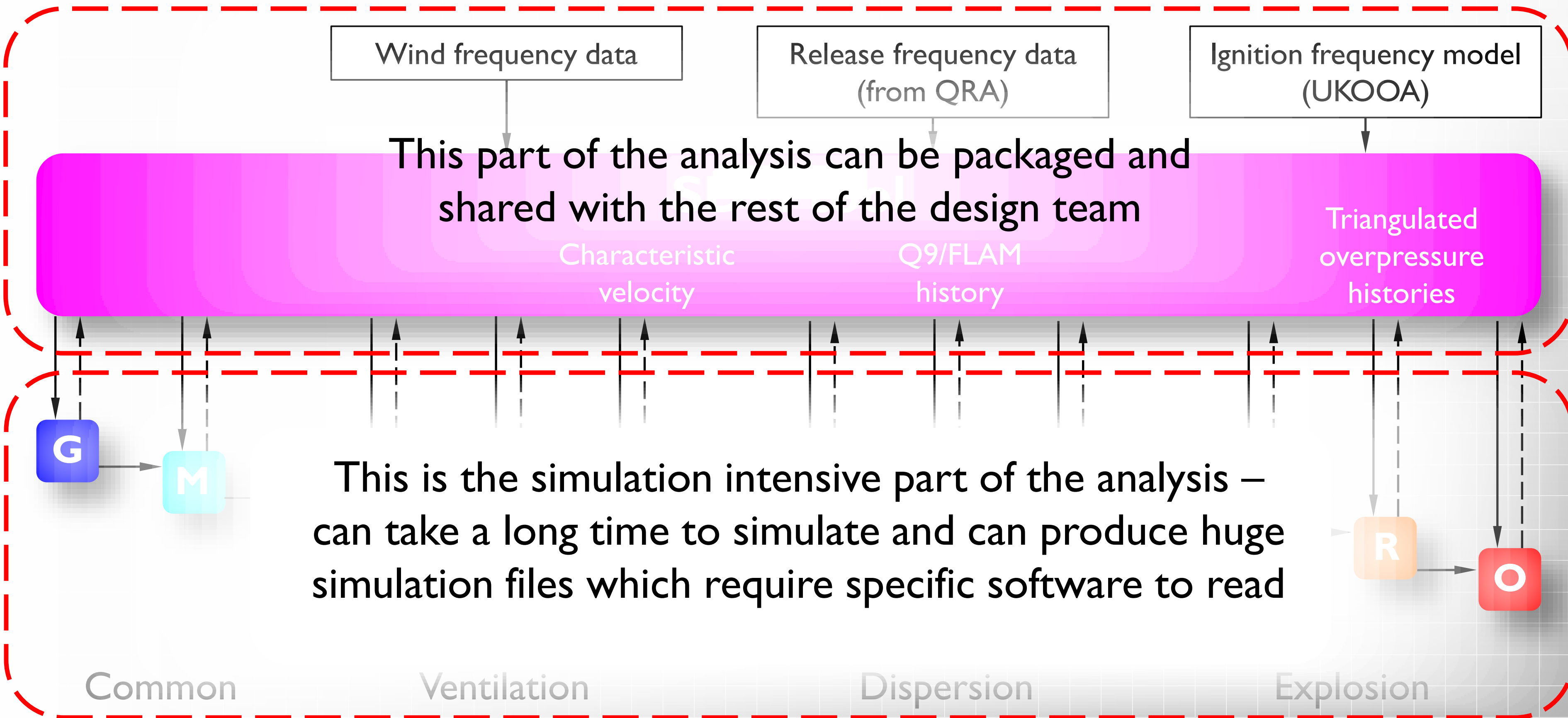
Simulation data management

Probabilistic explosion assessment



Simulation data management

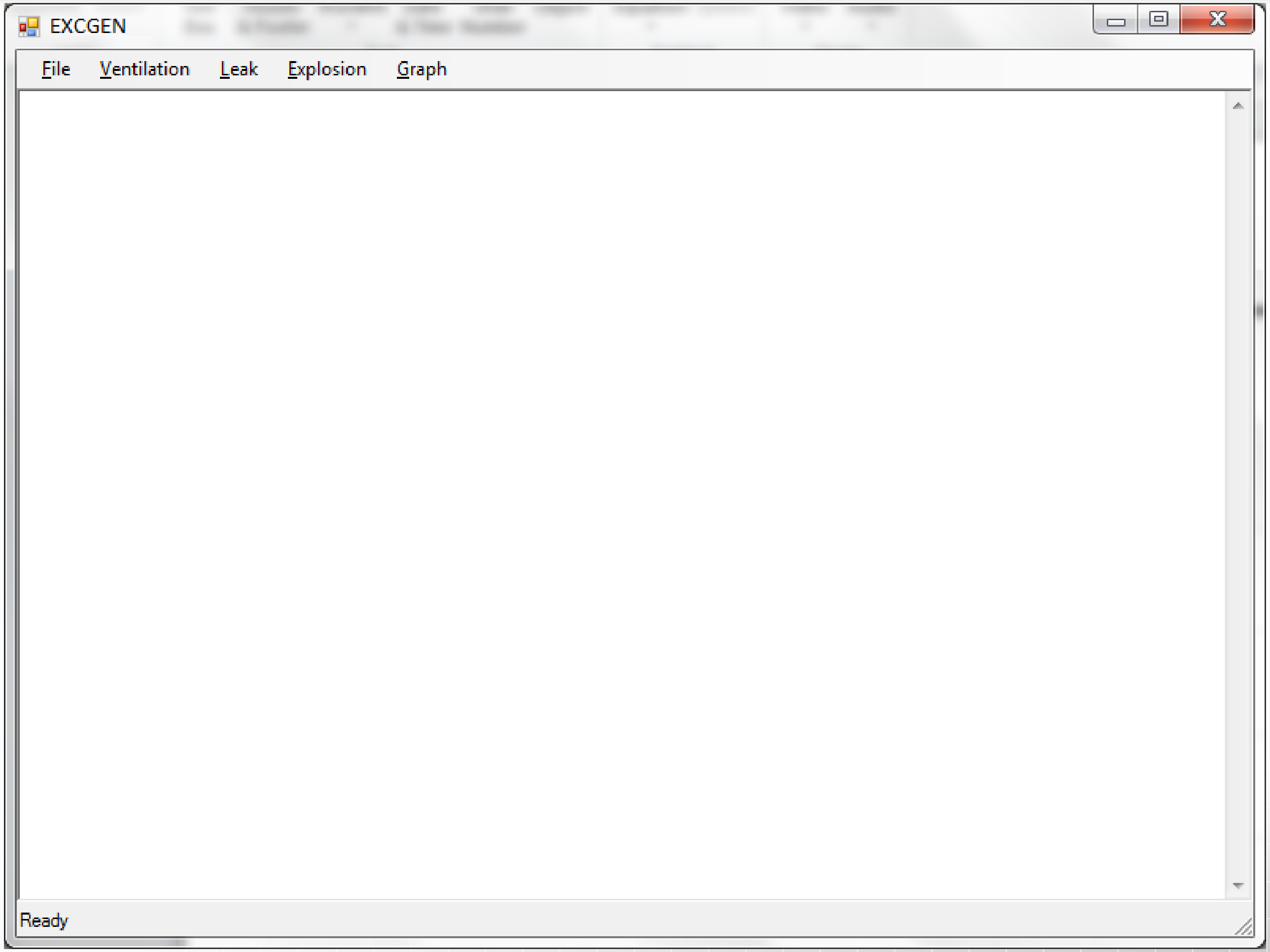
Probabilistic explosion assessment



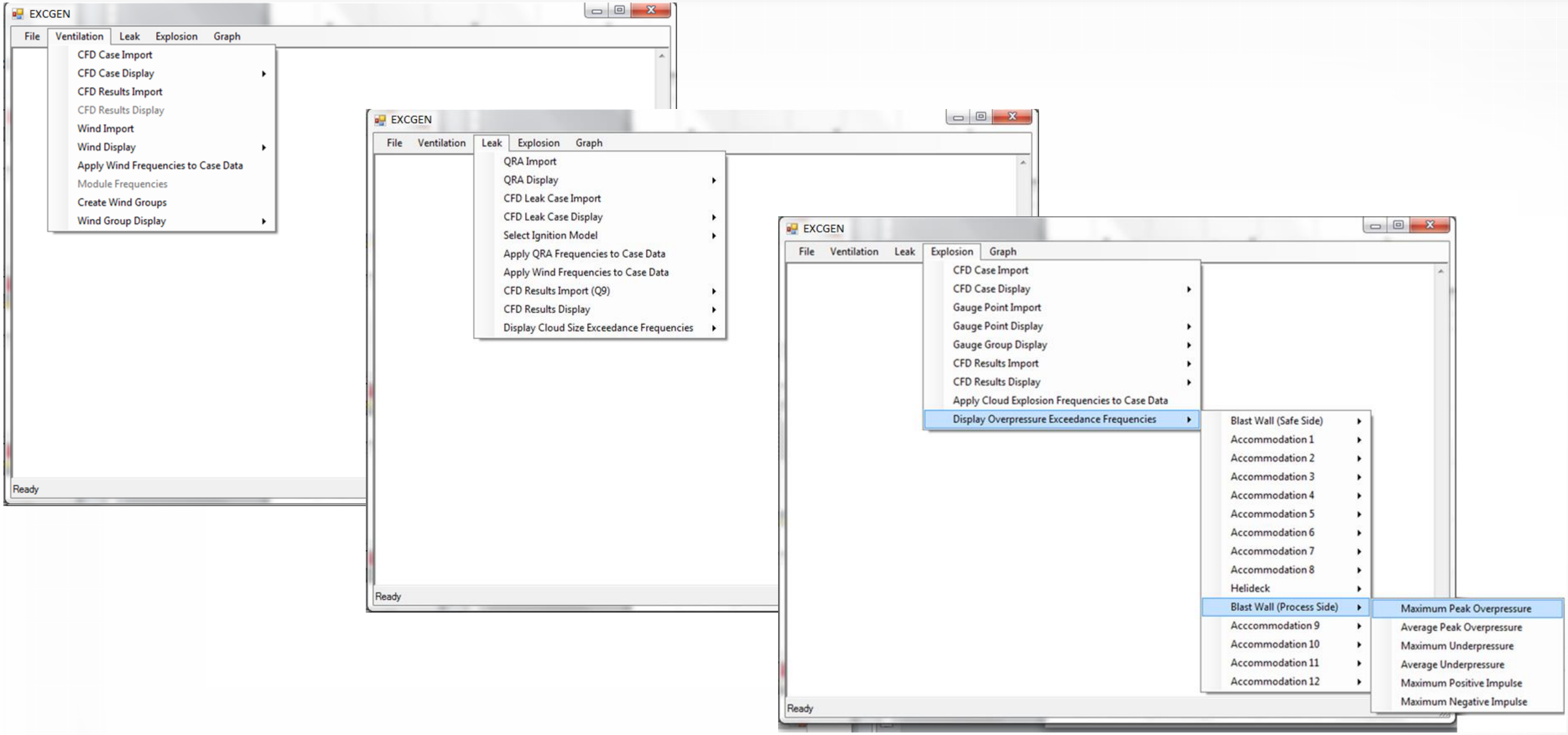
Simulation data management

- The packaged tool/data can be easily shared with the design team, thus **democratising the approach**
- This can improve the interaction between the structural engineer and explosion analyst, which should lead to **better, safer design**
- Abercus has developed EXCGEN for this purpose

Simulation data management



Simulation data management



Simulation data management

- The packaged tool/data can be easily shared with the design team, thus **democratising the approach**
- This can improve the interaction between the structural engineer and explosion analyst, which should lead to **better, safer design**
- Abercus has developed EXCGEN for this purpose
- Gexcon is developing RISK and it is likely that other parties will also develop similar tools – it is hoped that these too will allow the easy sharing of data.

Simulation data management

Some major benefits of an automated SDM approach:

1. Can provide a robust, **consistent method** for the implementation of the NORSOK Standard Z-013, provided the underlying implementation is openly documented
2. **Sharing and democratisation** of analysis data, allowing the **sensitivity** of the exceedence data to many of the probabilistic assumptions **to be investigated** on-the-fly, in the company of the wider design team

Simulation data management

Some major benefits of an automated SDM approach:

3. Automatic compilation of **3D risk assessment** information where, for example, the **spatial variation** of an explosion load can be presented across a structural target of interest, rather than just a single worst-case load that is read from a traditional exceedence curve
4. Automatic mapping of CFD explosion loads on to an FEA model so that the associated structural response can be simulated using **one-to-one coupling** between explosion **CFD and NLFEA**.

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Introduction

Simulation data management

Sensitivity to assumptions

3D risk assessment

Probabilistic structural response

Consistency across the industry

Summary

Sensitivity to assumptions

- Sensitivities to (some of) the probabilistic assumptions can be investigated on-the-fly, with the design team
  - Ignition methodology
  - Underlying wind conditions
  - Flammable volume methodology (Q9 vs FLAM)
  - Release frequencies from the QRA
- Typically these sensitivities might not be explored (at least, so interactively, with the rest of the team).

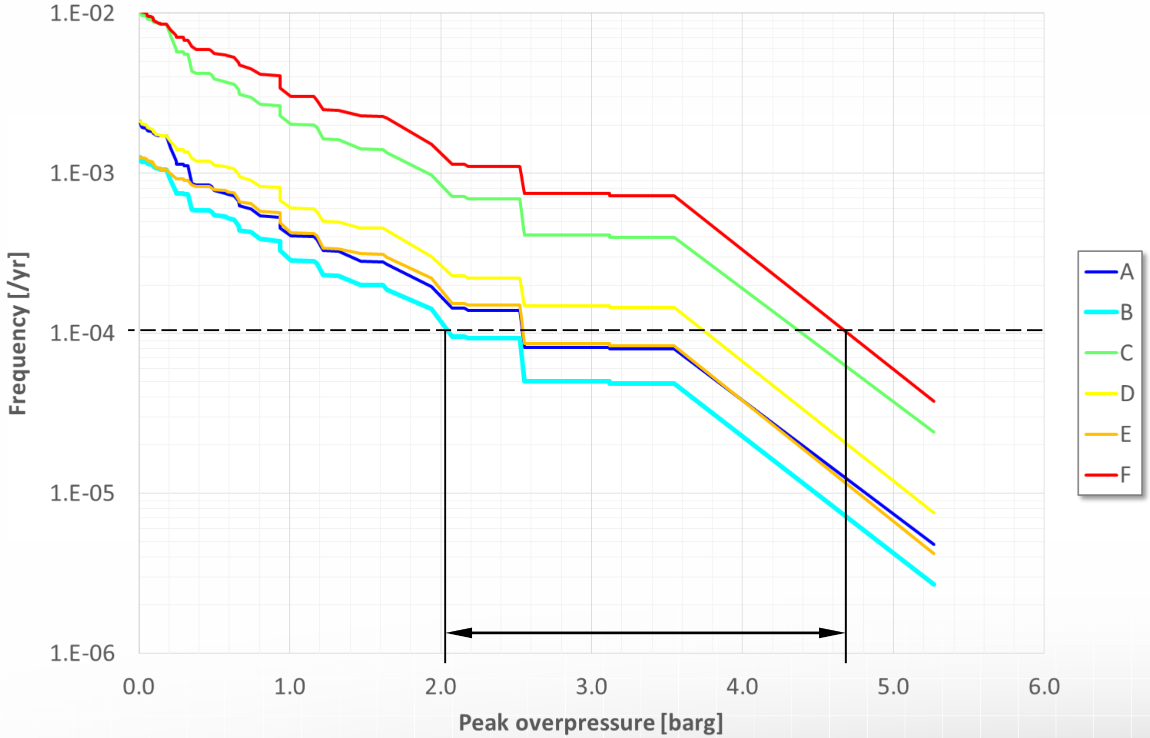
Sensitivity to assumptions

Ignition methodology

Ignition methodology	Probability of ignition	Probability of explosion given ignition	Time dependence
A	UKOOA 25	Fixed at 20%	UKOOA
B	UKOOA 25	Cox, Lees and Ang	UKOOA
C	UKOOA 25	Ignored	UKOOA
D	UKOOA 25	Fixed at 20%	Ignored
E	UKOOA 25	Cox, Lees and Ang	Ignored
F	UKOOA 25	Ignored	Ignored

Sensitivity to assumptions

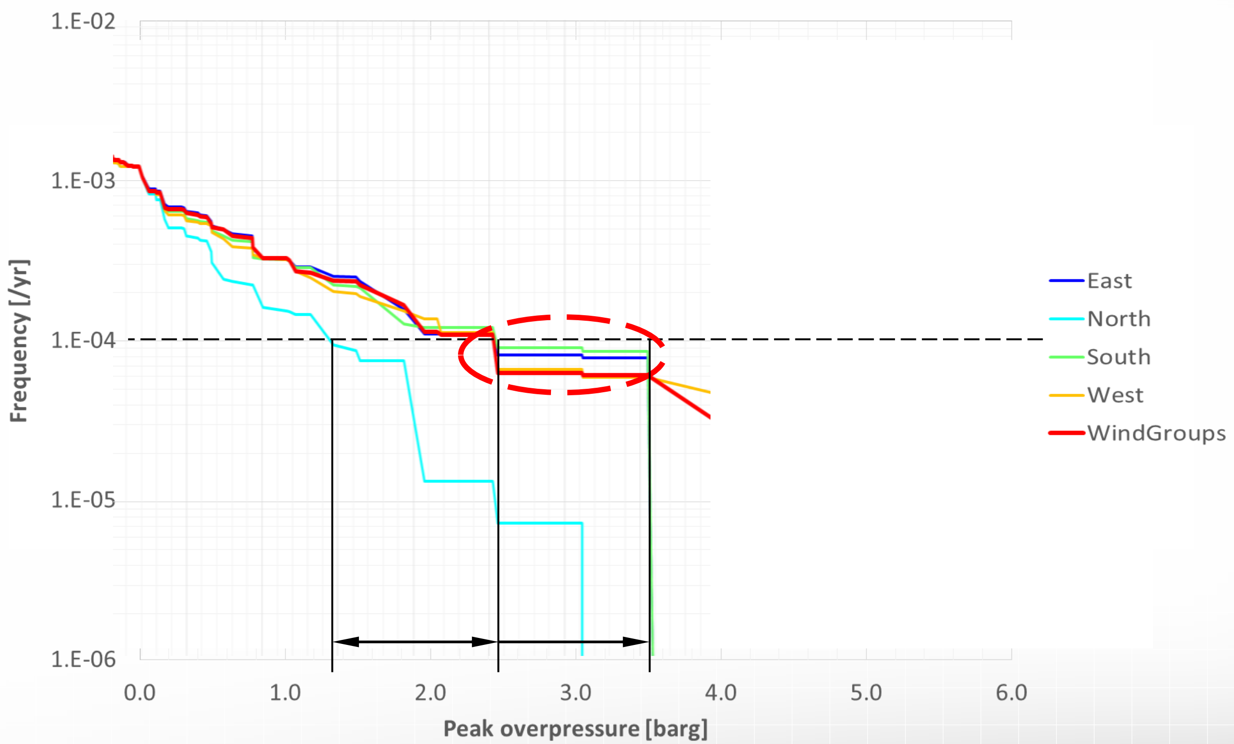
Ignition methodology



Exceedance curves for peak overpressure

Sensitivity to assumptions

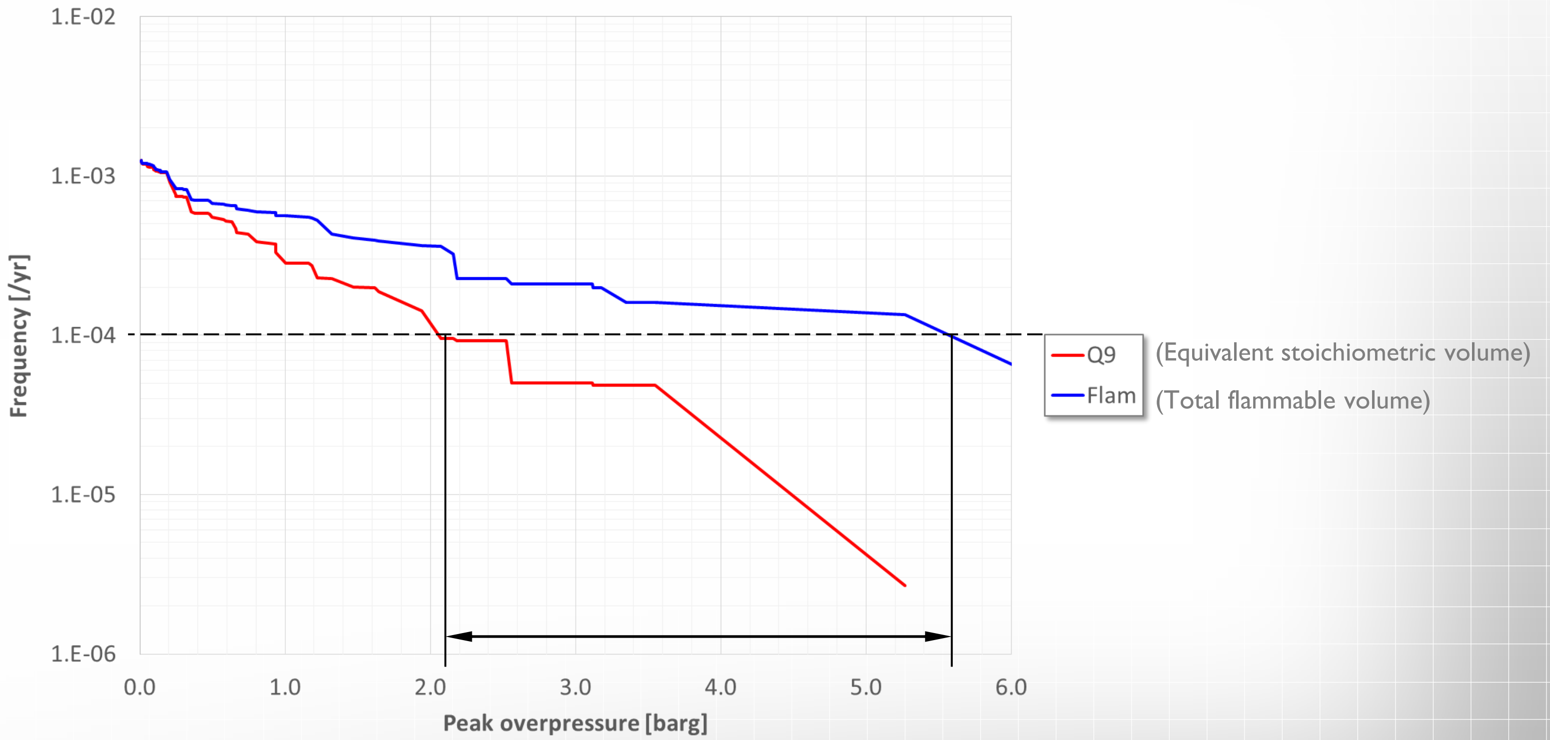
Wind direction



Exceedance curves for peak overpressure

Sensitivity to assumptions

Flammable volume methodology



Exceedance curves for peak overpressure

Sensitivity to assumptions

- The more you investigate something, very often it yields further questions that had not been previously apparent
- Exploring sensitivities on the fly provides an opportunity to discuss some of the uncertainties associated within the probabilistic approach with the design team.

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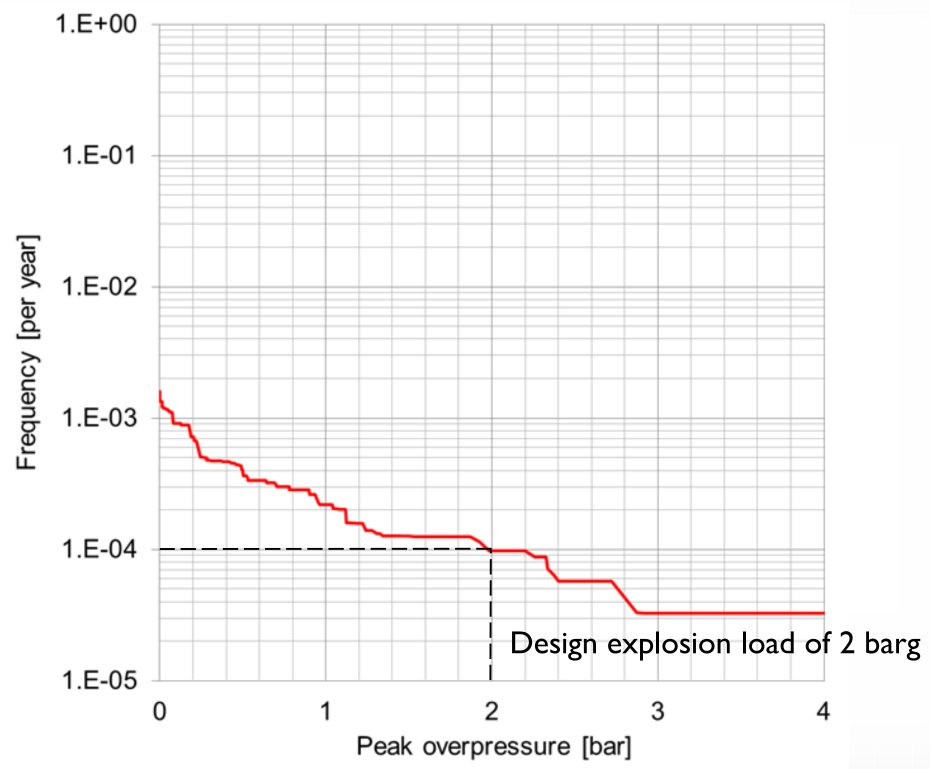
3D risk assessment

The explosion loads, particularly for **large targets** such as blast walls, may **vary spatially** so providing a single value for the design load may be **overly conservative**.

3D risk assessment

For this exceedence curve, the 10^{-4}/yr peak overpressure for the blast wall is 2 barg



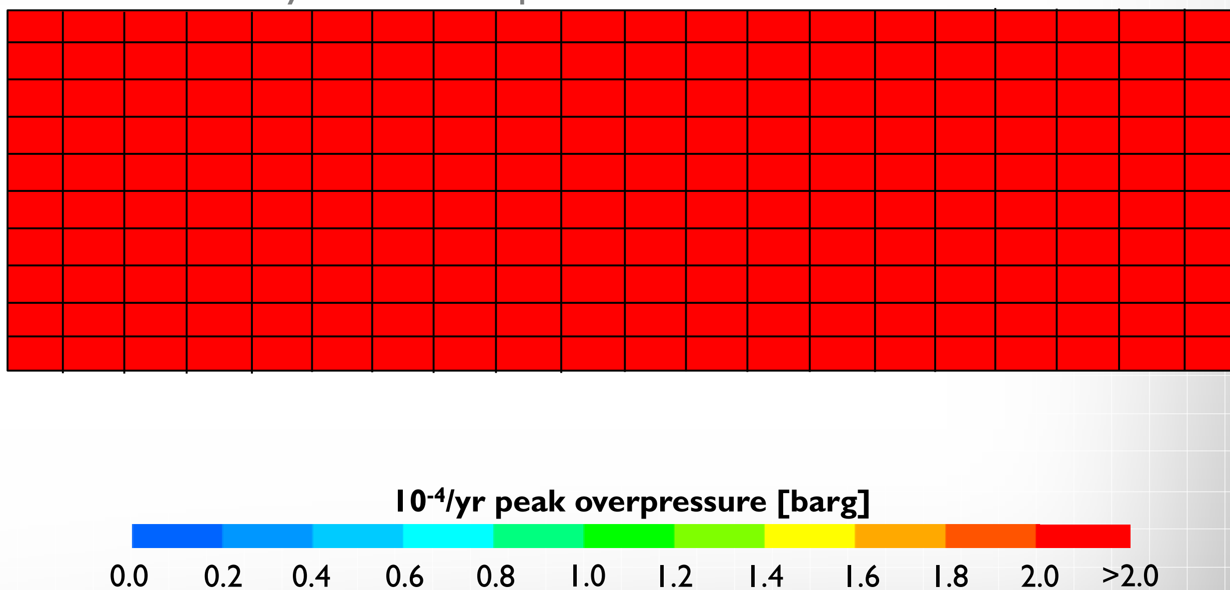
3D risk assessment

For this exceedence curve, the 10^{-4}/yr peak overpressure for the blast wall is 2 barg

Typically this would be applied uniformly across a large object, such as a blast wall.

Contours of 10^{-4}/yr peak overpressure

Large objects are typically represented by a discretised array of monitor panels within the CFD model



3D risk assessment

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Contours of 10^{-4}/yr peak overpressure

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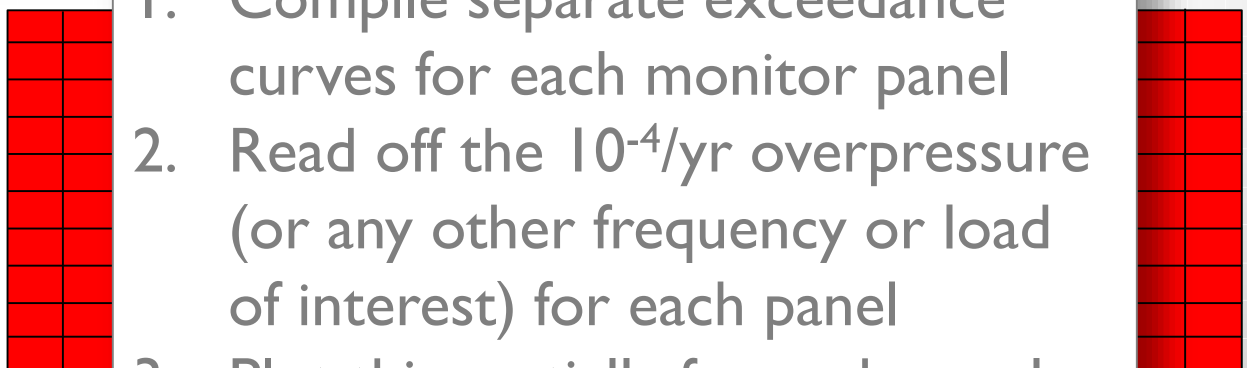
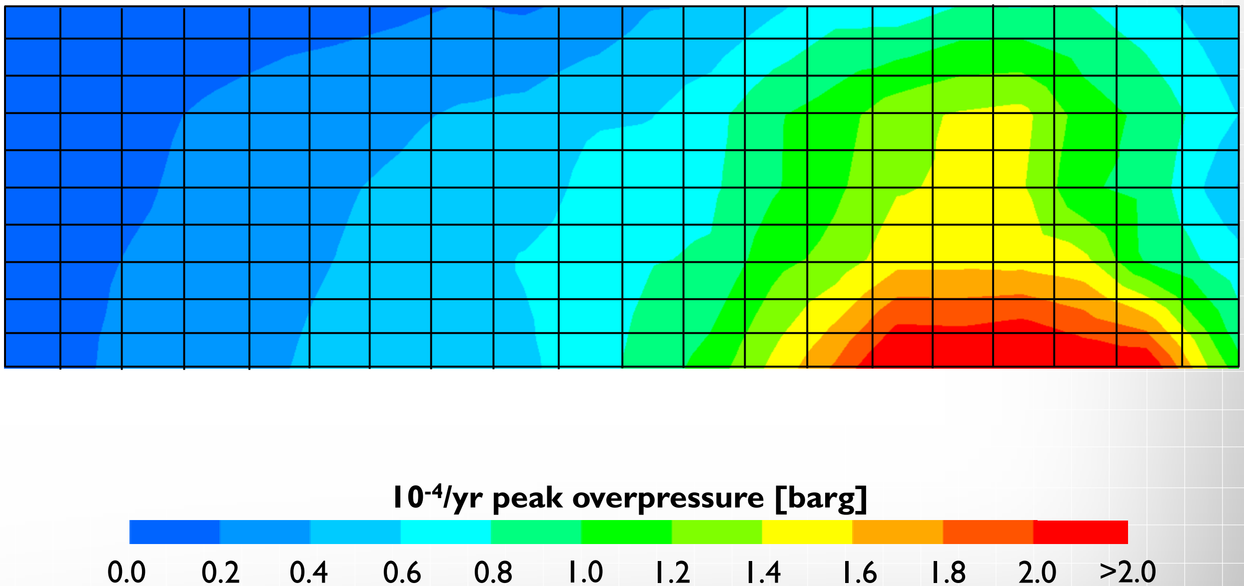


1. Compile separate exceedance curves for each monitor panel
2. Read off the 10^{-4}/yr overpressure (or any other frequency or load of interest) for each panel
3. Plot this spatially for each panel

3D risk assessment

If exceedence curves are constructed separately for each panel, the spatial variation of the 10^{-4}/yr peak overpressure can be considered

Contours of 10^{-4}/yr peak overpressure

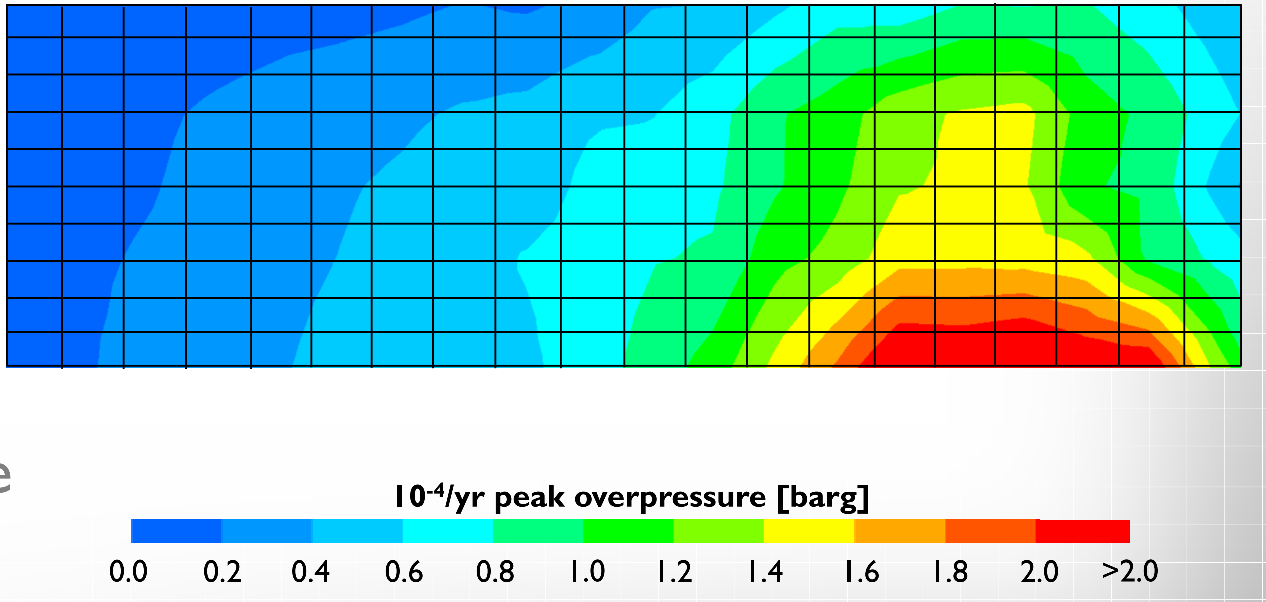


3D risk assessment

The 10^{-4}/yr peak overpressure for the majority of the blast wall is significantly less than 2 barg in this example

This can have a significant impact upon the structural response of the blast wall under DAL loading.

Contours of 10^{-4}/yr peak overpressure

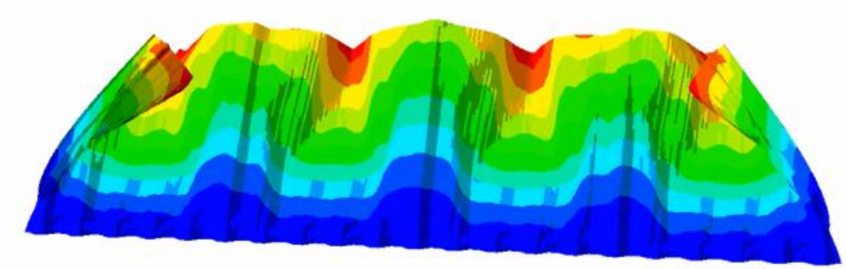


3D risk assessment

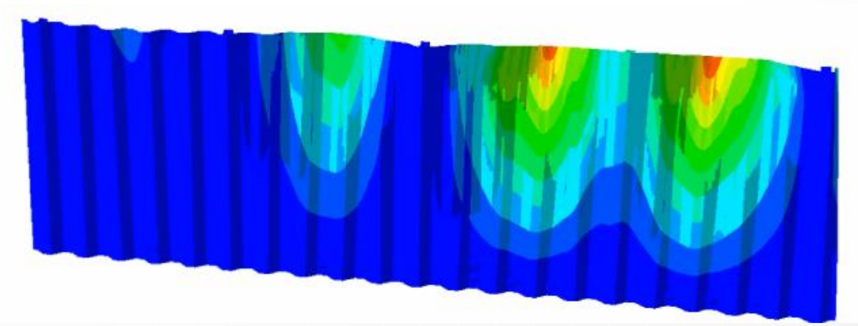
The 10^{-4}/yr peak overpressure for the majority of the blast wall is significantly less than 2 barg in this example

This can have a significant impact upon the structural response of the blast wall under DAL loading.

Contour plot of normalised deflection

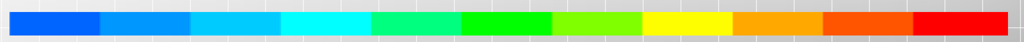


2 bar overpressure uniformly applied



Contours of overpressure for 10^{-4}/yr pseudo-event

Normalised deflection

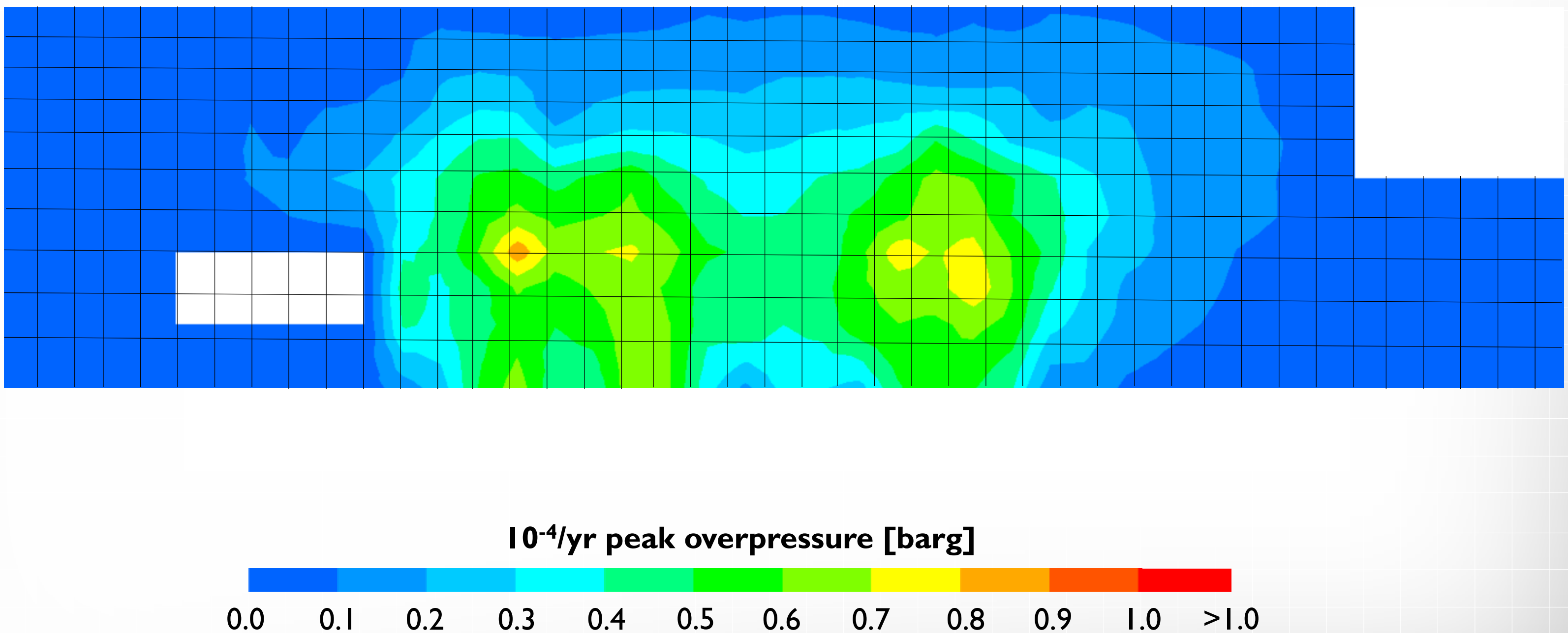


3D risk assessment

- The more you investigate something, very often it yields further questions that had not been previously apparent
- Open questions:
  - What is the correct way/order to average explosion loads over the surface of a large object?
  - Is it possible to find representative 10^{-4}/yr explosion events from those simulated for the purpose of structural design?

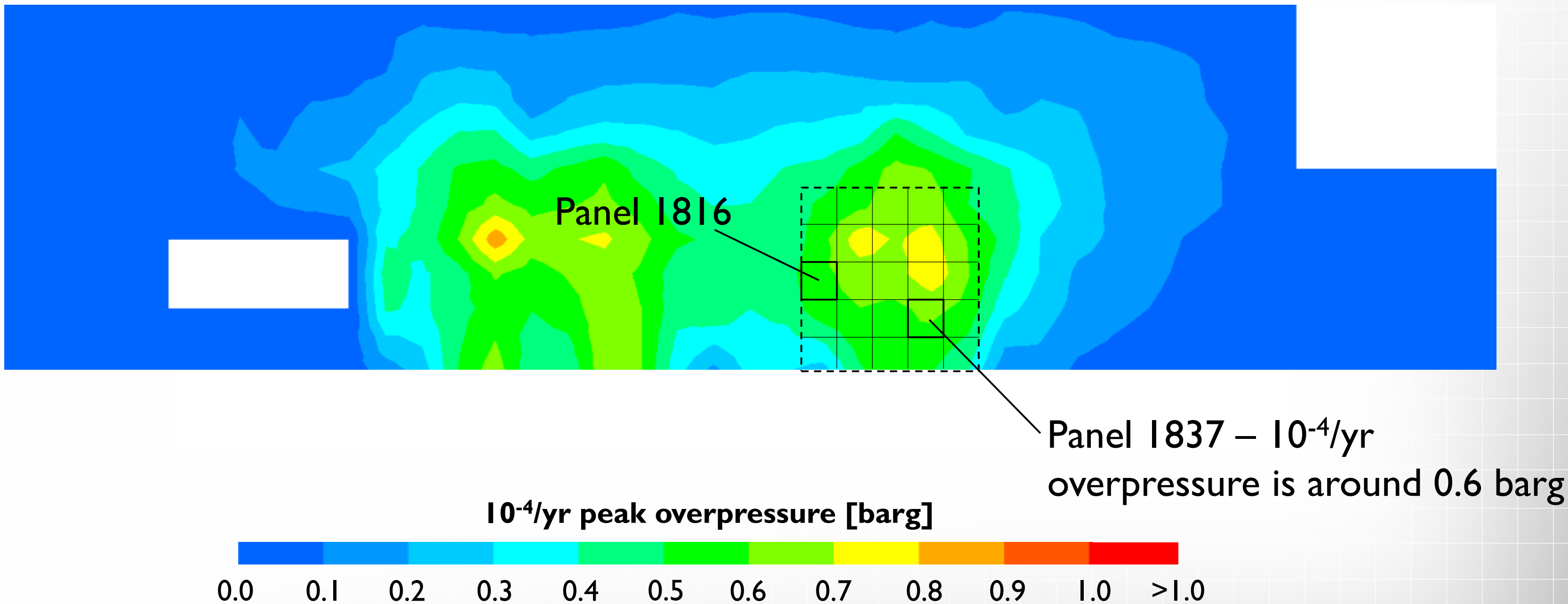
3D risk assessment (representative 10^{-4}/yr events)

Contours of 10^{-4}/yr peak overpressure



3D risk assessment (representative 10^{-4}/yr events)

Contours of 10^{-4}/yr peak overpressure



3D risk assessment (representative 10^{-4}/yr events)

- At panel 1837, the 10^{-4}/yr peak overpressure is 0.6 barg

3D risk assessment (representative 10^{-4}/yr events)

Event indices for the 10^{-4}/yr event at each panel

171	172	32	36	114	169	168	113	34	113	121	121	121	121	148	122	166	154	145	79	153	105	70	114	158	177	174	144	33	33	144	144	61	164	61						
122	32	114	104	169	168	121	168	113	168	168	169	171	169	112	122	155	159	145	104	59	105	59	59	172	151	60	70	33	33	61	144	144	159	35						
122	122	32	169	114	168	164	121	113	113	33	169	171	31	164	80	170	170	112	154	59	152	158	81	158	168	159	70	35	61	144	144	144	61	61						
168	114	114	168	168	104	81	81	168	164	36	169	32	169	112	122	61	161	160	112	166	71	172	158	151	159	159	144	144	144	168	168	61	61	36						
168	114	34	34	121	121	121	113	114	32	35	114	114	33	32	169	170	123	123	104	105	144	153	35	144	35	144	71	150	150	144	168	168	168	61						
164	171	171	34	113	81	113	164	168	34	114	33	30	169	36	34	111	111	111	167	154	154	154	34	158	164	159	36	71	150	150	168	168	168	168	168	168	150	165	81	129
104	164	122	171	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	110	110	176	162	104	144	172	61	157	61	164	71	36	35	164	34	144	81	81	168	168	70	150	165	69	150
104	169	164	113	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	170	176	110	123	34	157	81	71	31	145	147	31	161	36	160	160	144	144	60	70	70	81	60	165	69	150
81	61	122	121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	170	31	164	161	104	166	173	61	155	145	162	33	161	145	34	35	150	168	160	81	70	60	60	60	80	151
29	130	61	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	169	36	177	34	177	61	61	34	31	145	31	36	166	35	162	71	150	144	70	60	81	60	165	124	81	131

154	34	158	164	159
61	157	61	164	71
71	31	145	147	31
61	155	145	162	33
34	31	145	31	36

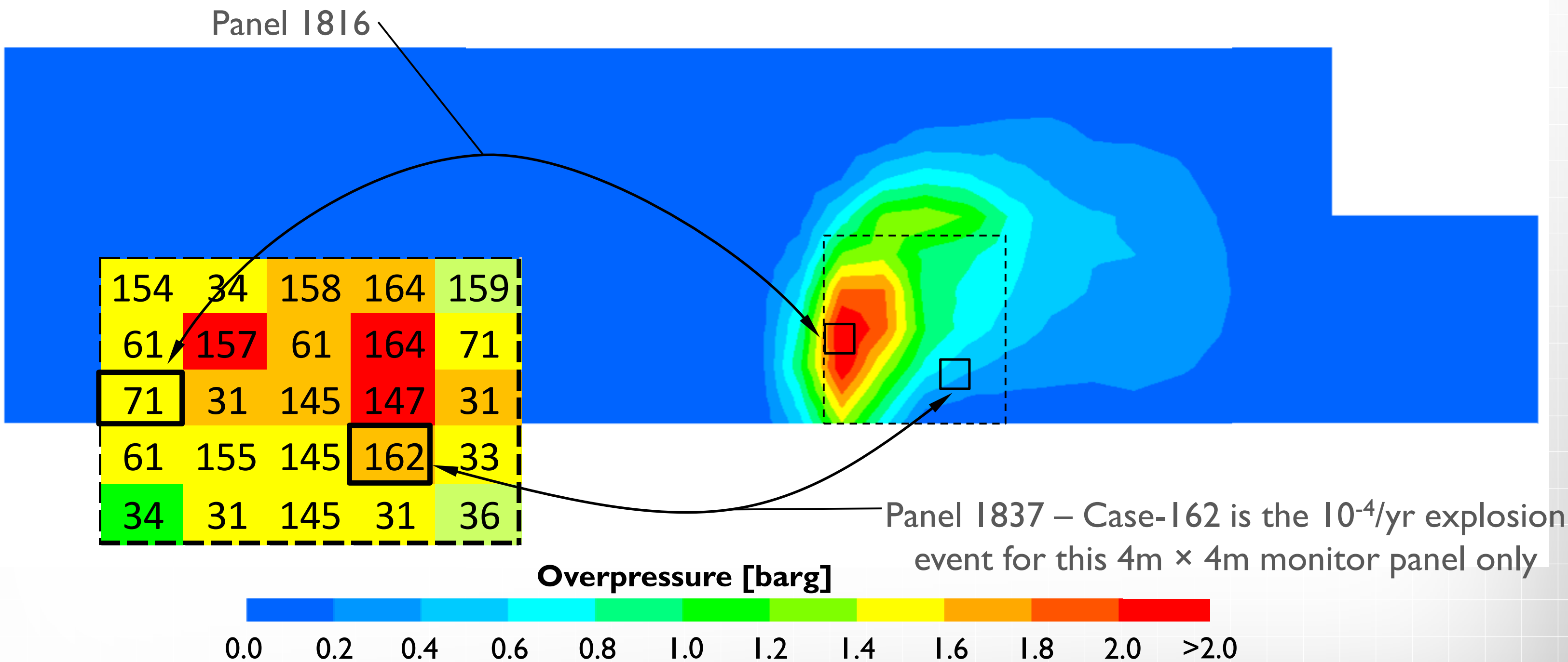
At panel 1837, the explosion event corresponding to the 10^{-4}/yr peak overpressure is event 162

3D risk assessment (representative 10^{-4}/yr events)

- At panel 1837, the 10^{-4}/yr peak overpressure is 0.6 barg
- The explosion event corresponding to this 10^{-4}/yr peak overpressure is event 162

3D risk assessment (representative 10^{-4}/yr events)

Maximum peak overpressure for explosion event 162

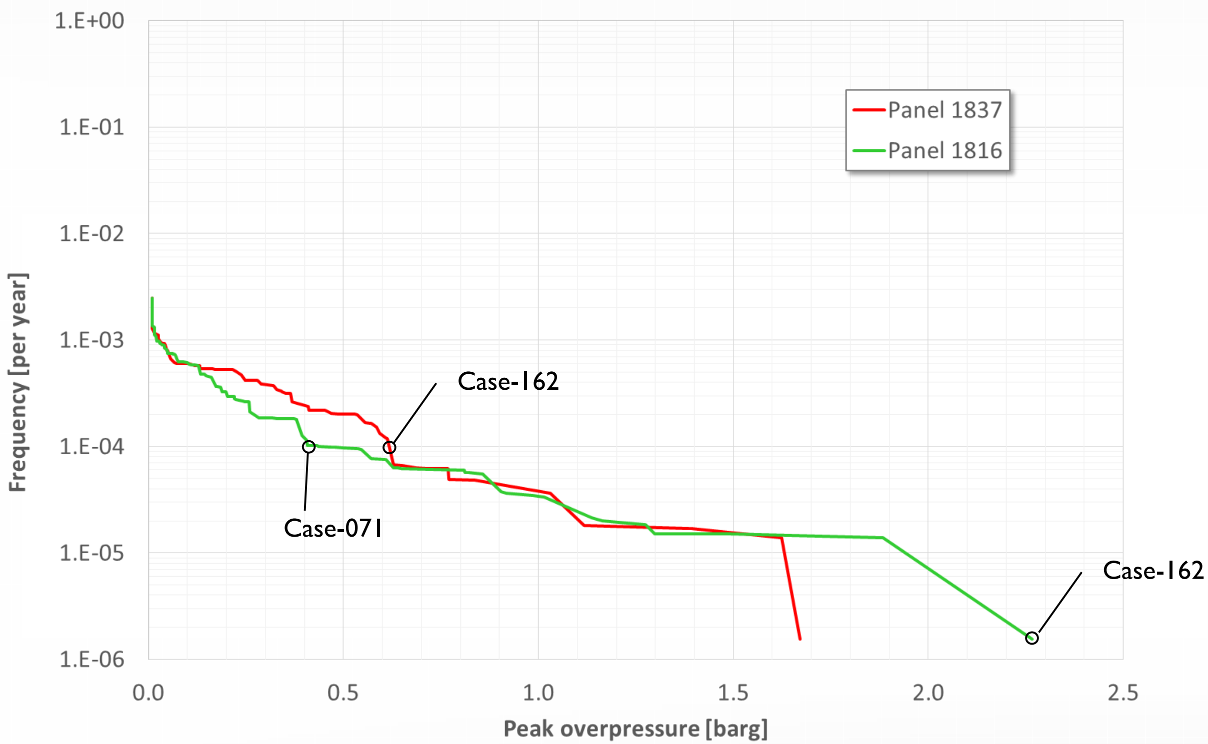


Maximum instantaneous overpressure (averaging area 4m × 4m)

3D risk assessment (representative 10^{-4}/yr events)

- At panel 1837, the 10^{-4}/yr peak overpressure is 0.6 barg
- The explosion event corresponding to this 10^{-4}/yr peak overpressure is event 162
- The peak overpressure for event 162 is over 2 barg, which is significantly higher than the 10^{-4}/yr overpressure but it occurs in a different location – at panel 1816
- At panel 1816, the 10^{-4}/yr overpressure corresponds to a different event – event 071.

3D risk assessment (representative 10^{-4}/yr events)



Exceedance curves for panels 1837 and 1816

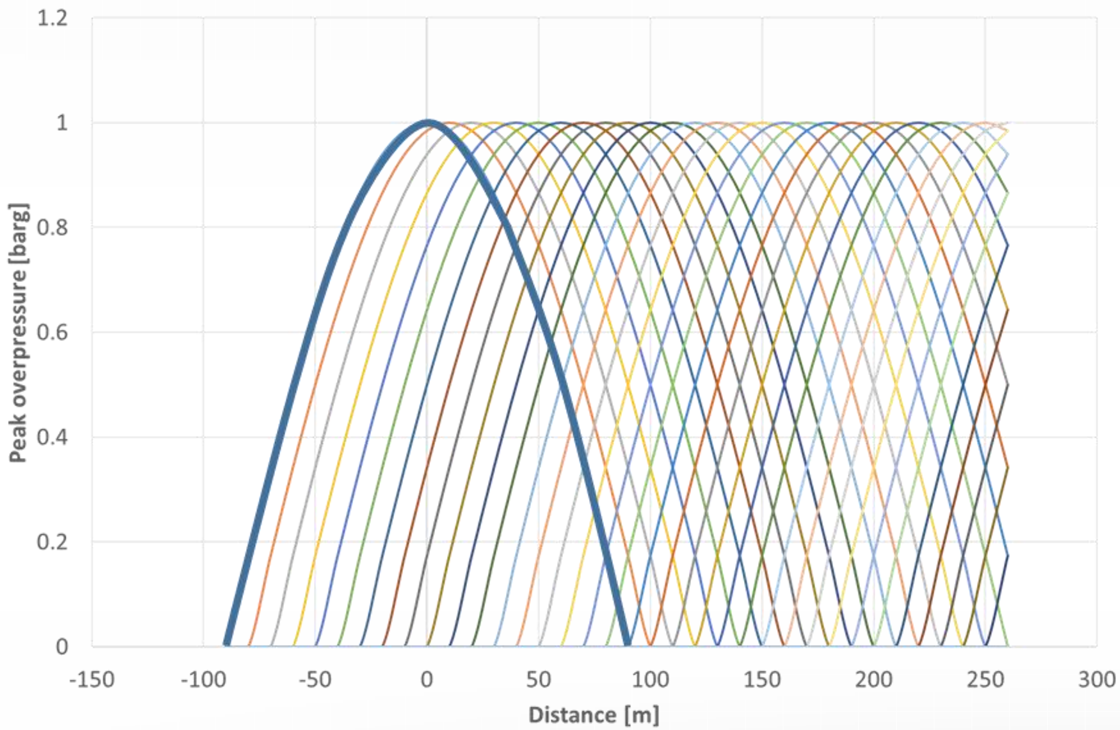
3D risk assessment (representative 10^{-4}/yr events)

- From the exceedance curves, event 162 represents a lower frequency of occurrence at panel 1816 and, therefore, this higher overpressure does not contribute to the 10^{-4}/yr overpressure reported on the contour plot – event 071 corresponds to the 10^{-4}/yr frequency
- The 10^{-4}/yr overpressure across a large surface will typically comprise contributions from many individual explosion events.

3D risk assessment (representative 10^{-4}/yr events)

- Imagine that we have simulated a series of identical blast events, such that the blast for each event is similar, but with the clouds displaced at 10m intervals
- Imagine that the variation of the peak overpressure with distance along a deck for the first event which has a **peak overpressure of 1 barg**
- If we then plot the peak overpressure for all of the blast events on the same plot, we have the same shaped curve but it is repeated at intervals of 10m.

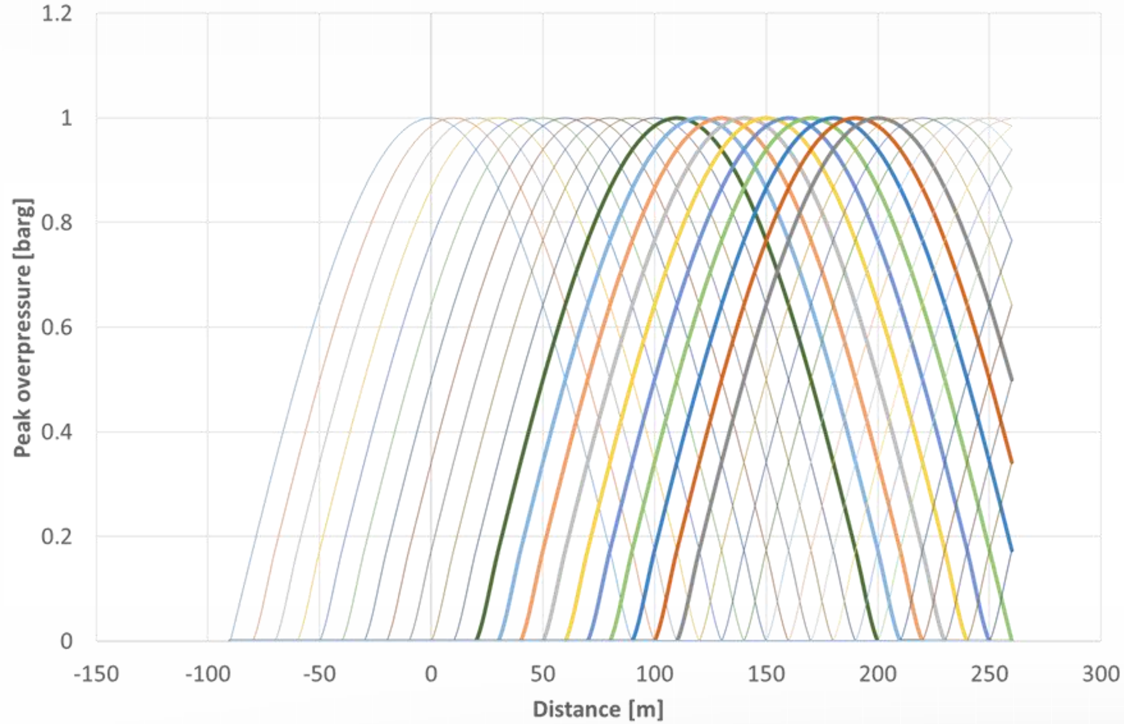
3D risk assessment (representative 10^{-4}/yr events)



3D risk assessment (representative 10^{-4}/yr events)

- Imagine that each blast event individually has a probability of occurrence of 10^{-5}/yr
- This means that to find the 10^{-4}/yr overpressure at any point along the deck there needs to be 10 of the curves which, at that point, has a higher local peak overpressure
- To illustrate this, 10 of the curves are identified in bold in the upper part of the figure.

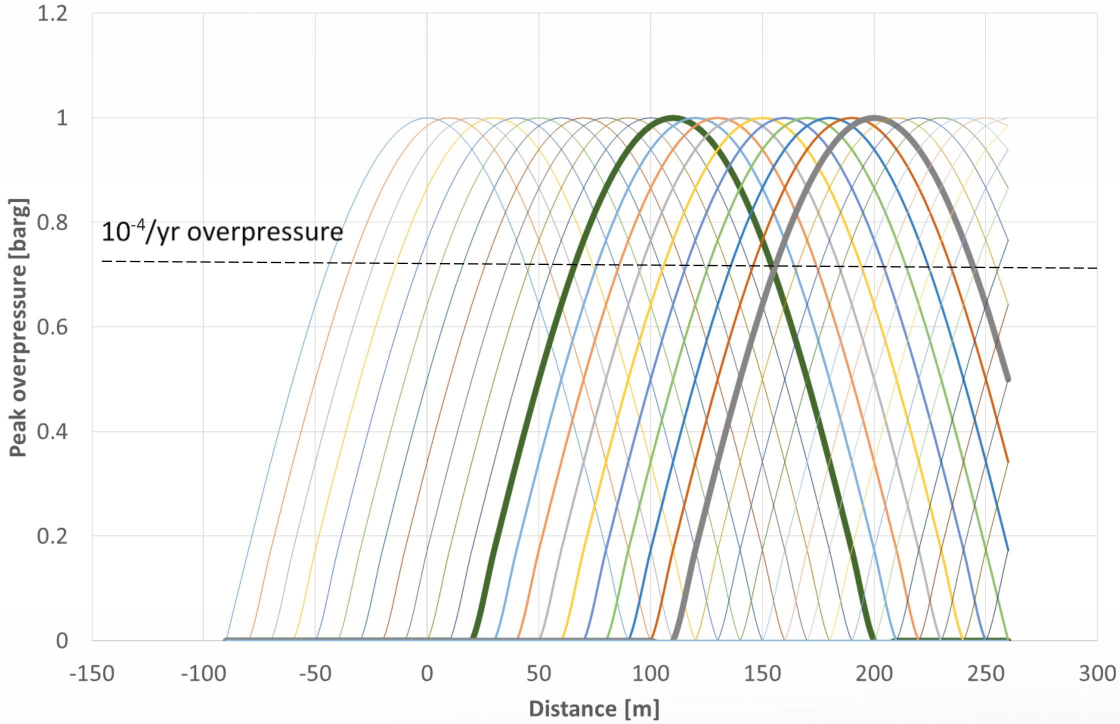
3D risk assessment (representative 10^{-4}/yr events)



3D risk assessment (representative 10^{-4}/yr events)

- If we then consider the 150m location, for example, the **10^{-4}/yr peak overpressure is 0.7 barg** – at this point, 10 of the curves have a peak overpressure in excess of 0.7 barg
- In this idealised example, the events represented by the dark green and dark grey curves in the figure below are the representative 10^{-4}/yr events, each of which has a **peak overpressure of 1 barg.**

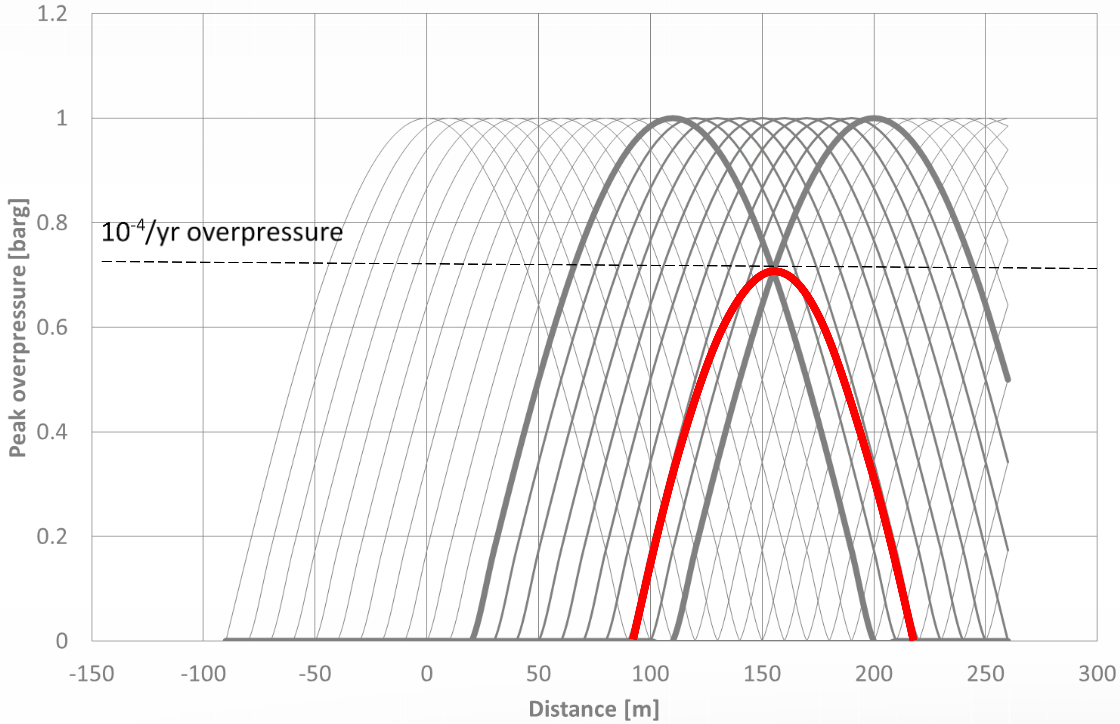
3D risk assessment (representative 10^{-4}/yr events)



3D risk assessment (representative 10^{-4}/yr events)

- When selecting representative events it is important not to simply select an event which has a peak overpressure comparable to the local 10^{-4}/yr overpressure – doing so would be equivalent to selecting the red curve, which is a lesser event than either of the 10^{-4}/yr events we identified previously, represented by the grey bold curves.

3D risk assessment (representative 10^{-4}/yr events)



3D risk assessment (representative 10^{-4}/yr events)

- Whether it is possible to identify representative 10^{-4}/yr explosion events from those simulated remains an **open question**
- The 10^{-4}/yr overpressure is constructed from contributions received from many explosion events
- How can we proceed?
  - One-to-one coupling between explosion CFD and NLFEA
  - Is it possible to construct a 10^{-4}/yr pseudo-event?

Agenda

Introduction

Simulation data management

Sensitivity to assumptions

3D risk assessment

Probabilistic structural response

Consistency across the industry

Summary

Probabilistic structural response

- Rather than try to identify representative 10^{-4}/yr events from those simulated, or construct a 10^{-4}/yr pseudo-event by combining simulated events, why not simulate the structural response of a large object for each simulated explosion using NLFEA?

One-to-one coupling between explosion CFD and NLFEA

This does not introduce any new assumptions

Probabilistic structural response

NORSOK Standard Z-013 Edition 3, October 2010

Risk acceptance criteria are in general related to the implications for the explosion. An explosion response analysis is required to establish a relation between explosion loads and their consequences on structures and equipment.

F.7.2 Limit state

Structural response shall be classified according to ALS, as defined in F.6.1.

The following scenarios shall be amongst those considered related to strength and functionality requirements:

- global structural collapse;
- rupture or unacceptable deflection of an explosion barrier including unacceptable damage of the passive fire protection of the barrier;
- damage to equipment and piping resulting in unacceptable escalation of events (applies also for pipe and cable penetrations through barriers). This includes damage due to deflection/damage of supporting structure;
- unacceptable damage to safety critical equipment which need to function after the explosion.

F.7.3 Structural response interface

Calculation of structural response to explosion load is described in NORSOK N-004, A.6.

The response of structural components can conveniently be classified into three categories according to the duration of the explosion pressure pulse, td, relative to the fundamental period of vibration of the component, T:

- impulsive domain (where t_d is small compared to T);
- dynamic domain (where td and T are of similar duration);
- quasi-static domain (where t_d is long compared to T).

There are two different uses of a probabilistic explosion analysis with respect to the structural response (A and B) as follows:

A. To provide a dimensioning explosion load as input to a structural design process based on an acceptance criteria either for the load or for the corresponding response. In the general case load will have to be described as an exceedance curve both for pressure and impulse or duration. In cooperation with the structural dicipline this can be simplified to pressure exceedance curves or impulse/time exceedance curves alone for those cases where the structural response is within the quasi-static domain or the impulsive domain.

B. Assessment of the response of a known structure to ensure that the response is within the given acc

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B2. then The

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Typ the wall or deck. Therefore, the explosion analysis should describe the size and shape of the areas for which the given loads are applicable. These areas correspond to monitoring panels in the simulator, and it is highly recommended that these are defined in close cooperation with structural engineers. The relation between the size of the exposed area and the explosion load should be described.

F.8 Uncertainty

Uncertainty in the explosion modelling shall be addressed.

NORSOK standard Page 100 of 107

NORSOK Standard Z-013

A. To provide a dimensioning explosion load as input to a structural design process based on an acceptance criteria either for the load or for the corresponding response. In the general case load will have to be described as an exceedance curve both for pressure and impulse or duration. In cooperation with the structural dicipline this can be simplified to pressure exceedance curves or impulse/time exceedance curves alone for those cases where the structural response is within the quasi-static domain or the impulsive domain.

B. Assessment of the response of a known structure to ensure that the response is within the given acceptance criteria. In such cases there are two different approaches:

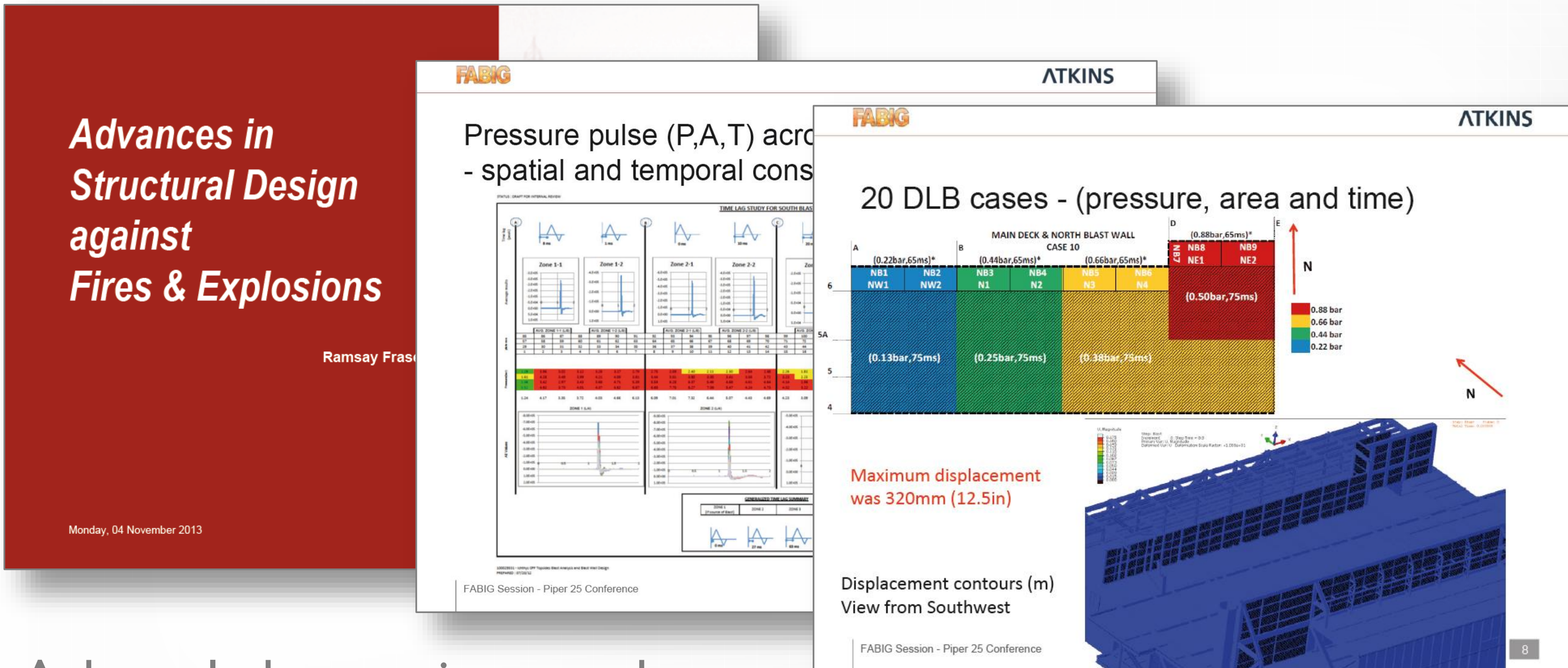
B1. Assessment of the structural response based on the load - frequency relation. As the structure response characteristics are known, the iso-damage curves in terms if pressure and impulse/time for the dimensioning response can be calculated. Then the frequency of exceeding that response, i.e. for pressures and impulses/times above the iso-damage curves, can be calculated and checked against the acceptance criteria.

B2. Direct response calculation on the pressure-time history from each explosion simulation. The response is then evaluated as acceptable or unacceptable according to the damage criterion in the acceptance criteria. The frequency of unacceptable response is then checked against the acceptance criteria.

B2. Direct response calculation on the pressure-time history from each explosion simulation. The response is then evaluated as acceptable or unacceptable according to the damage criterion in the acceptance criteria. The frequency of unacceptable response is then checked against the acceptance criteria.

Page 100 of 107

Probabilistic structural response



Acknowledge previous work:

Frazer, Sari and Nordstrom, FABIG TM 75, 2013.

Probabilistic structural response

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Risk-based Structural Response against Explosion Blast Loads: Systematic One-to-one CFD (FLACS) / NLFEA (Impetus Afea solver) Coupling to Derive Quantified Response Exceedance

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This paper proposes an advanced and innovative methodology for risk-based structural response assessment against accidental explosions. Focus is shifted from dimensioning load to barrier integrity. A full spatial mapping of blast overpressure transients obtained with Computational Fluid Dynamics (CFD) modelling is used in combination with a Non-Linear Finite Element model (NLFEA). The GexCon-Impetus methodology is so-called advanced due to the innovative extensive one-to-one CFD-NLFEA job solution scheme used over several explosion runs. Using a detailed explosion loads mapping for the response evaluations provides a comprehensive probabilistic description of the response characteristics, easy to combine with risk acceptance criteria and performance requirements. The 3D codes involved are FLACS (CFD) and IMPETUS Afea solver (NLFEA). The response of an offshore fire partition wall is specifically studied against dynamic explosion loads. Detailed modeling of the wall is made in IMPETUS Afea solver. Systematic direct coupling between 90 FLACS risk-based explosion simulations and 90 IMPETUS Afea dynamic response calculations is used. The safety barrier performance is quantified using adequate wall response parameters reported for every explosions. The innovative outcome is a probabilistic picture of the response parameters exceedance. The barrier ability to perform the related safety function(s) is efficiently documented. Of utmost importance, mechanisms that cause possible lack of integrity are highlighted. The results are compared with existing offshore approaches based on the Dimensioning Accidental Load (DAL) concept. A uniform triangular loading and a realistic dimensioning explosion are used. Promoting more consideration of adequate response assessment as part of the safety studies, the paper shows how the advanced method pinpoints limitations of conventional approaches. For the risk owner, it improves the comprehension and implications upon the relation between explosion loads and their consequences on structures carrying critical safety functions. Several benefits result from the GexCon-Impetus approach among which: a more accurate streamlined workflow, an improved understanding of the safety barrier behavior, perception of safety margins, justifications for design optimization, cost & weight savings.

1. Introduction

1.1 Background and objectives

In the hazardous industries, safety studies are mandatory to document a safe design. These are either performed during design phase and/or during an assessment phase for existing installations. In the offshore industry, (Bakke & Hansen, 2003) introduced the consequence assessment workflow quite a long time ago. It implies extensive gas dispersion and explosion modelling to calculate Dimensioning Accidental Loads specifications (DAL spec.) for identified safety critical elements. Such an approach is formalized in several standards for offshore design e.g. (NORSOK Z-013, 2010) and is often taken on as a company standard in the oil & gas industry. Onshore, examples are illustrated in (Hoorelbeke, et al., 2006) and (Paris, et al., 2010). In the nuclear industry, similar consideration are used to document the protective effect of confinement (Daudey

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Salaun, Hanssen and Nilsen, 2016.

Probabilistic structural response

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Explosion induced dynamic responses of blast wall on FPSO topside: Blast loading application methods☆

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Abstract

Topside areas on an offshore oil and gas platform are highly susceptible to explosion. A blast wall on these areas plays an important role in preventing explosion damage and must withstand the expected explosion loads. The uniformly distributed loading condition, predicted by Explosion Risk Analyses (ERAs), has been applied in most of the previous analysis methods. However, analysis methods related to load conditions are inaccurate because the blast overpressure around the wall tends to be of low-level in the open area and high-level in the enclosed area. The main objectives of this paper are to study the effects of applying different load applications and compare the dynamic responses of the blast wall. To do so, various kinds of blast pressures were measured by Computational Fluid Dynamics (CFD) simulations on the target area. Nonlinear finite element analyses of the blast wall under two types of identified dynamic loadings were also conducted.

Keywords: Topside platform; Blast wall; Geometrical effect; Identified explosion loading condition; Explosion wave profiles

1. Introduction

The probability of a gas explosion on Floating, Production, Storage, and Offloading (FPSO) topside platforms is higher than other offshore structures because they are exposed to many explosion risk elements, including combustible substances and flammable materials, during operations. In addition, topsides are packed area with equipment, so dramatic damage can occur if an explosion occurs there (Dan et al., 2014). Consequently, many core facilities are designed for explosion resistance in preliminary conceptual design. A blast wall is one of the structures that must be required to apply the explosion resistance design. Its purpose is to protect the topside apparatus and related installation from the explosion wave by separating each topside module (Schleyer and Langdon, 2005). Hence, many studies on wall-type structures were carried out in order to understand the effects of explosion waves on them and to investigate the structural response of a blast wall subjected to gas explosion loads (Kang et al., 2016; Moghimi and Driver, 2015; Nguyen and Tran, 2011; Langdon and Schleyer, 2006). Moghimi and Driver (2015) developed the constitutive model to understand the blast response for steel materials. To do this, they considered mixed-hardening, strain-rate effects, and damage initiation. In addition, Nguyen and Tran (2011) performed the analysis for structural dynamic response of wall type structures. In terms of analysis methods, a variety of analysis methods were carried out including the various boundary conditions, TNT volumes, and standoff distance from ignition position.

☆ This research greatly contributes to the oil and gas field especially the offshore industries where probabilistic approaches are required to define design loads and investigate the characteristics of structural dynamic response for such an explosive event.

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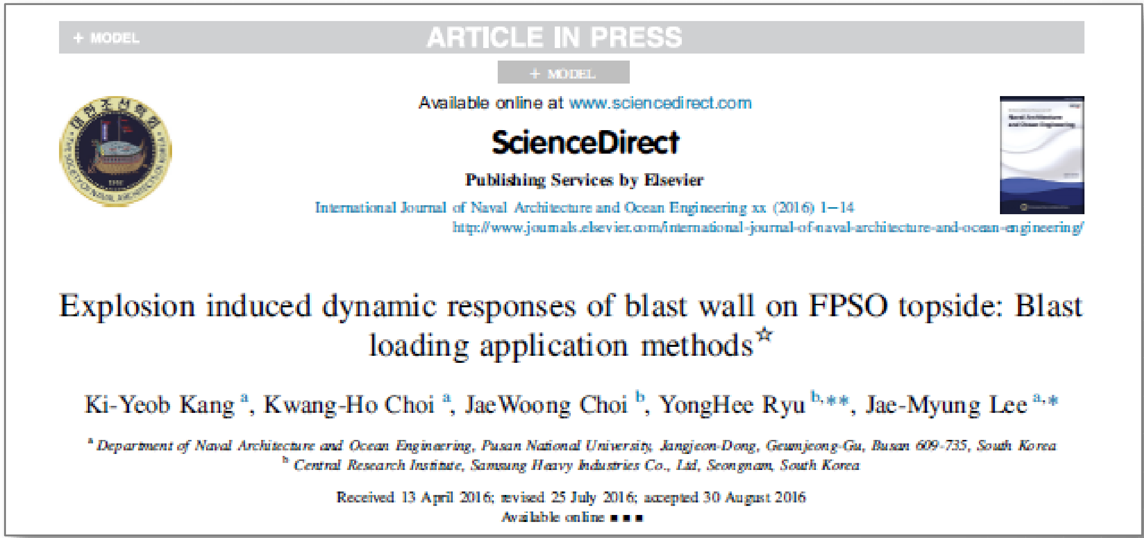

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Explosion induced dynamic responses of blast wall on FPSO topside: Blast loading application methods☆
Ki-Yeob Kang[a], Kwang-Ho Choi[a], JaeWoong Choi[b], YongHee Ryu[b,**], Jae-Myung Lee[a,*]
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Acknowledge current work (about to be published):

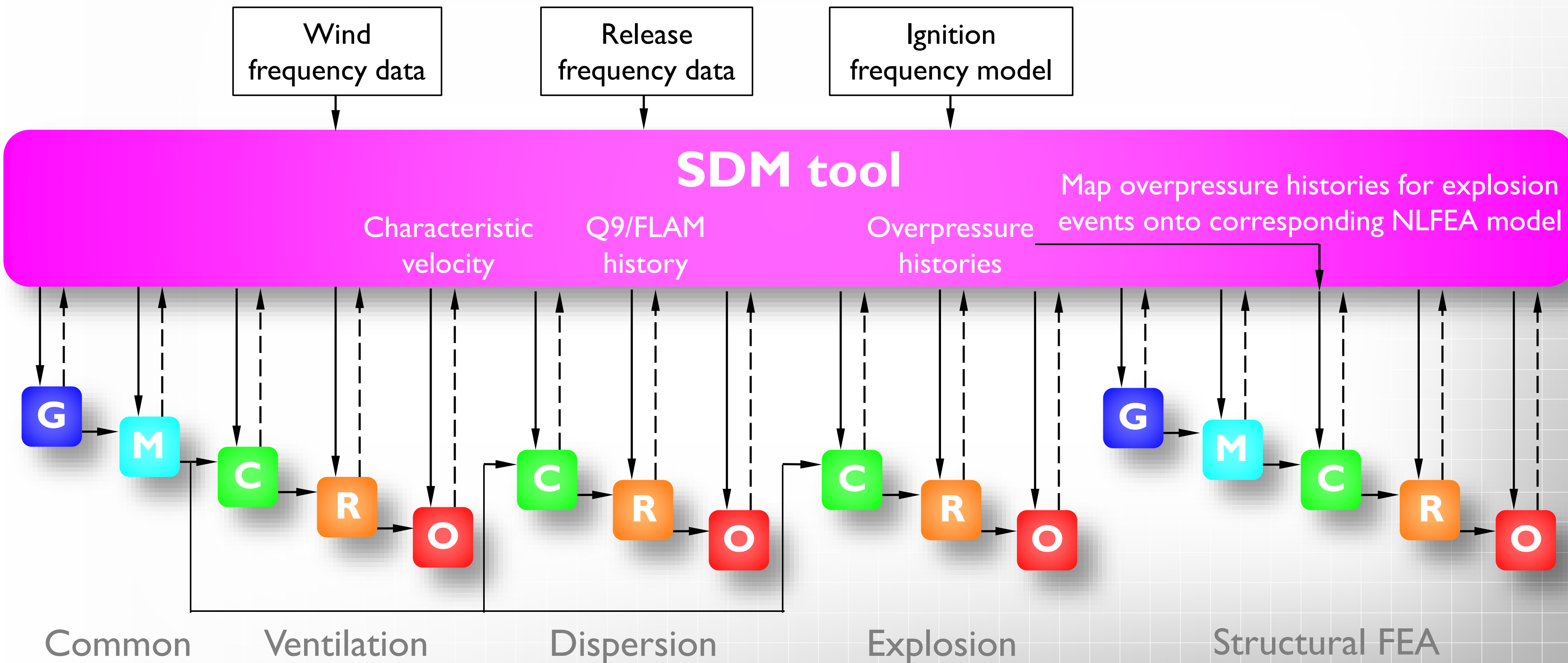
Kang et. al., 2016.

Probabilistic structural response

- Rather than try to identify representative 10^{-4}/yr events from those simulated, or construct a 10^{-4}/yr pseudo-event by combining simulated events, why not simulate the structural response of a large object for each simulated explosion using NLFEA?
- Traditionally this may have been prohibitive in terms of computational effort, but with SDM tools like EXCGEN this can become feasible.

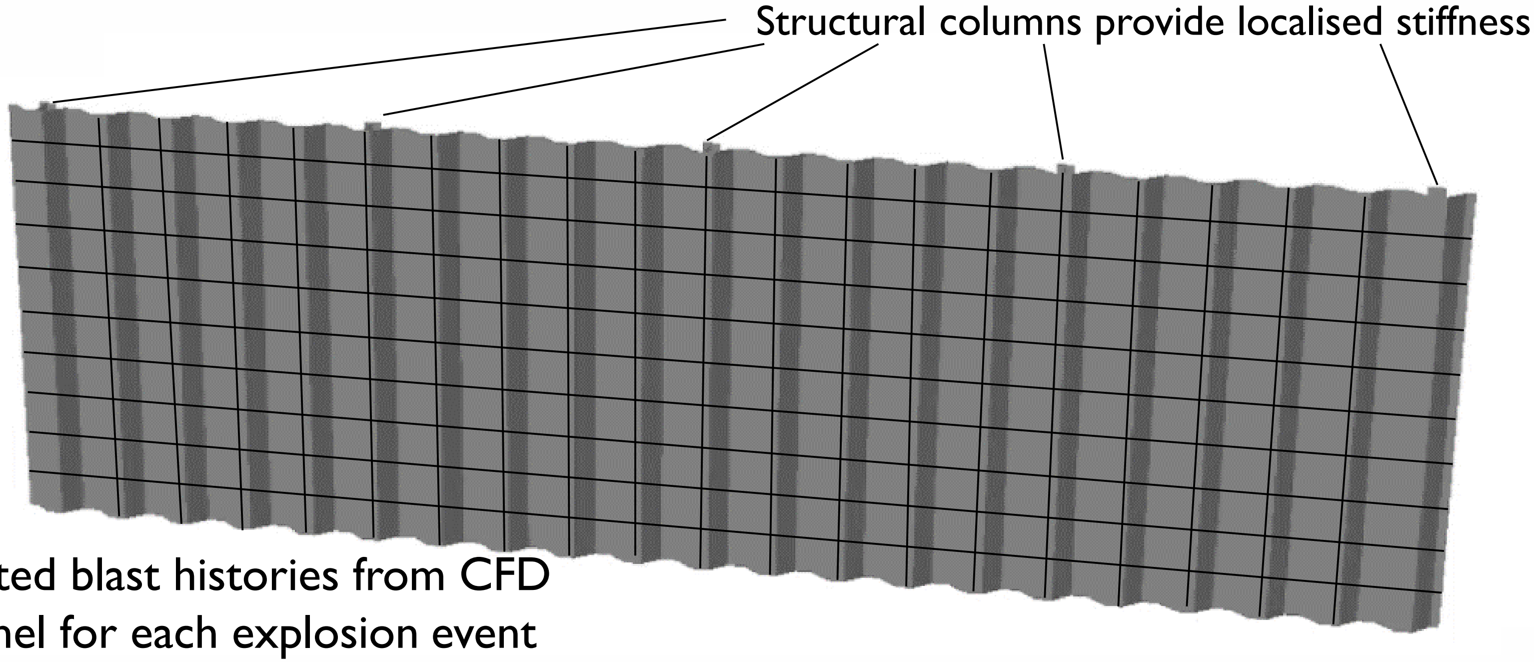
Probabilistic structural response

Probabilistic explosion assessment + structural response



Probabilistic structural response

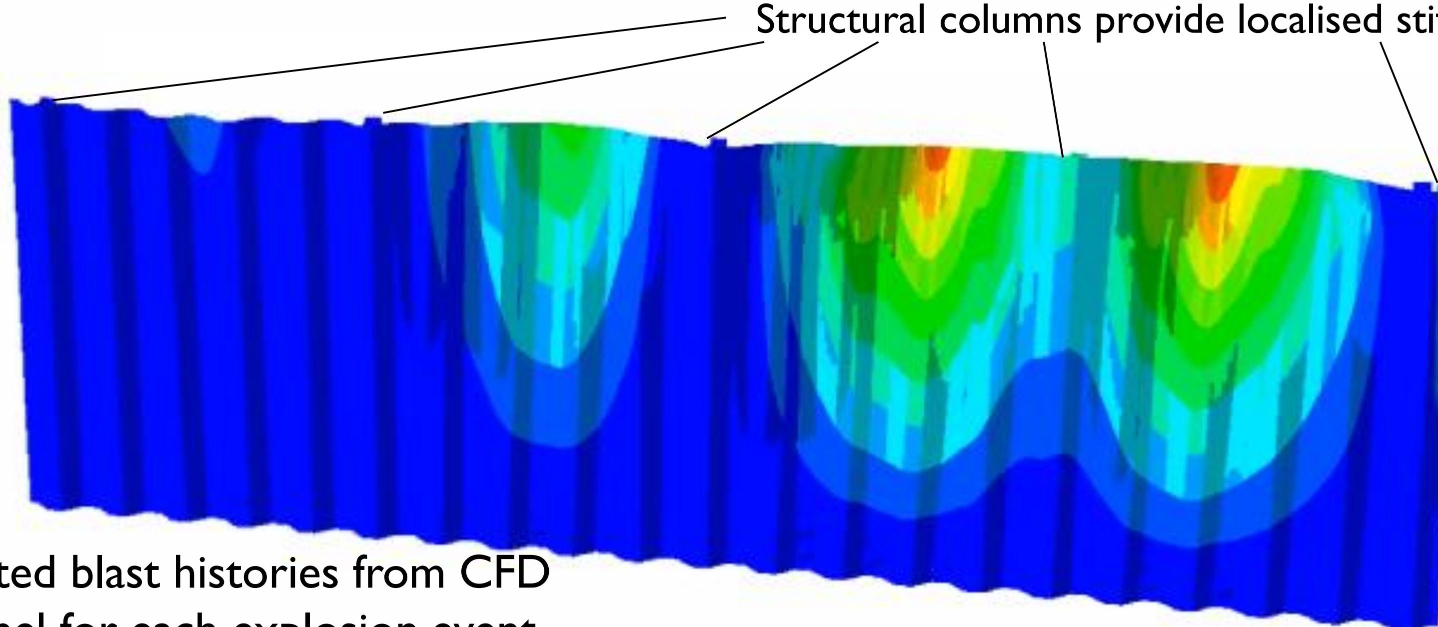
Case study – one-to-one CFD/NLFEA coupling



Structure of the blast wall

Probabilistic structural response

Case study – one-to-one CFD/NLFEA coupling

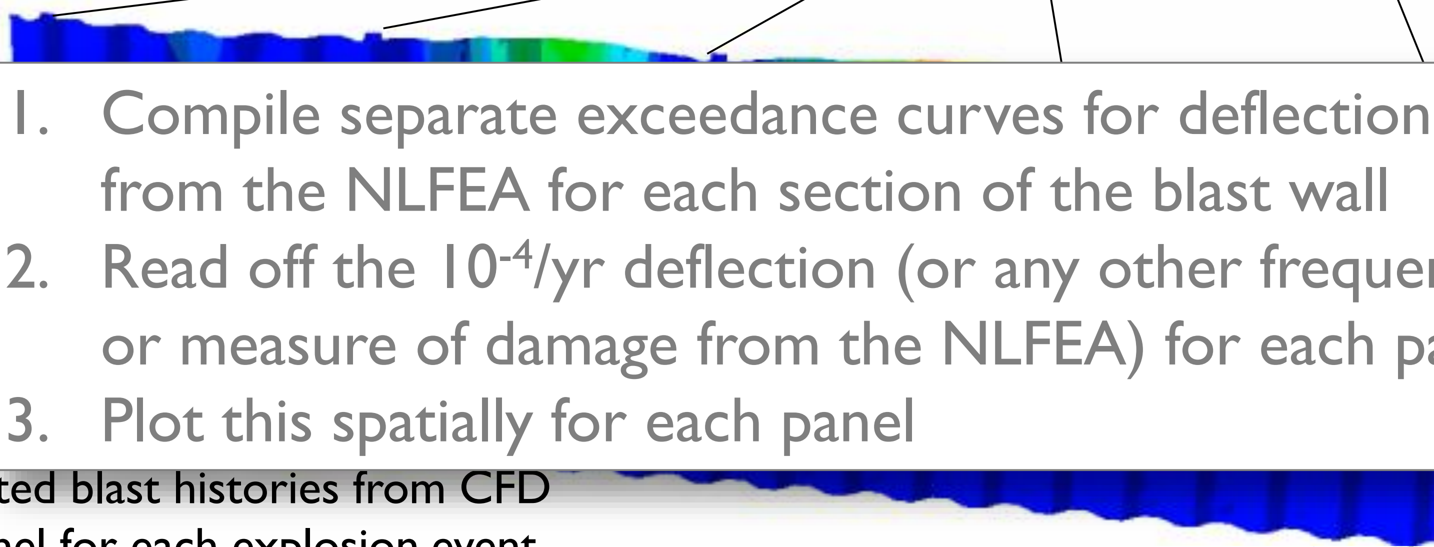


Map predicted blast histories from CFD at each panel for each explosion event

Structure of the blast wall

Probabilistic structural response

Case study – one-to-one CFD/NLFEA coupling



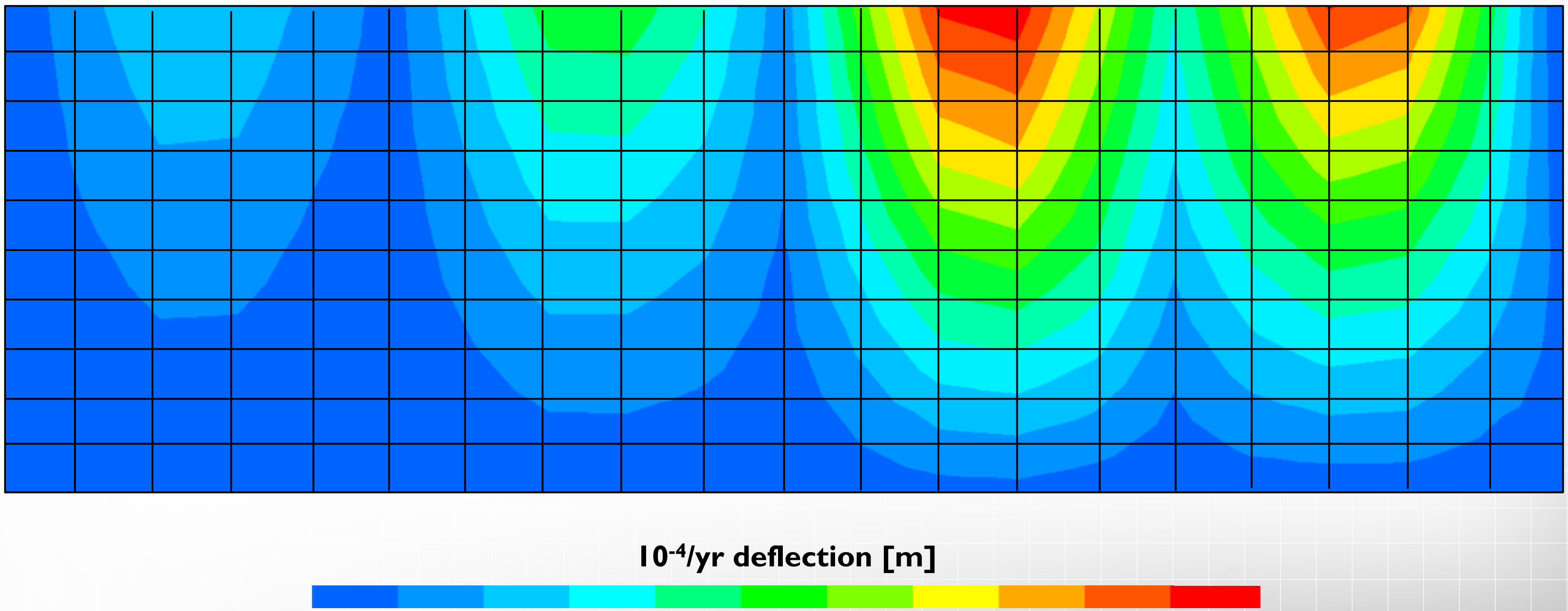
1. Compile separate exceedance curves for deflection from the NLFEA for each section of the blast wall
2. Read off the 10^{-4}/yr deflection (or any other frequency or measure of damage from the NLFEA) for each panel
3. Plot this spatially for each panel

Structure of the blast wall

Probabilistic structural response

Case study – one-to-one CFD/NLFEA coupling

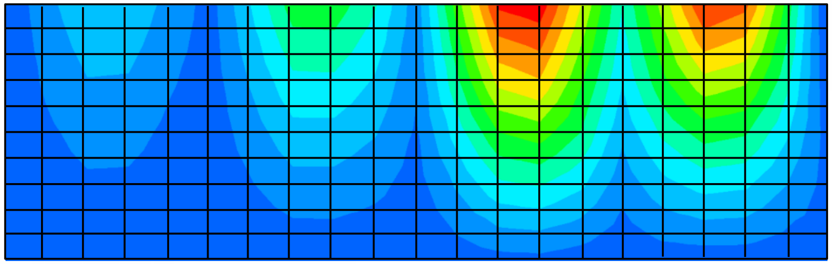
Contours of 10^{-4}/yr deflection



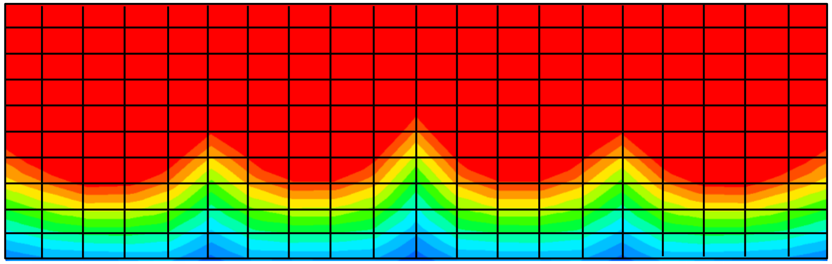
Abercus Riverside House Riverside Drive Aberdeen AB11 7LH www.abercus.com

Probabilistic structural response

Contours of 10^{-4}/yr deflection



Using a probabilistic structural response approach



Traditional approach – uniformly applying the 10^{-4}/yr overpressure (2 barg) from the exceedance curve

10^{-4}/yr deflection [m]

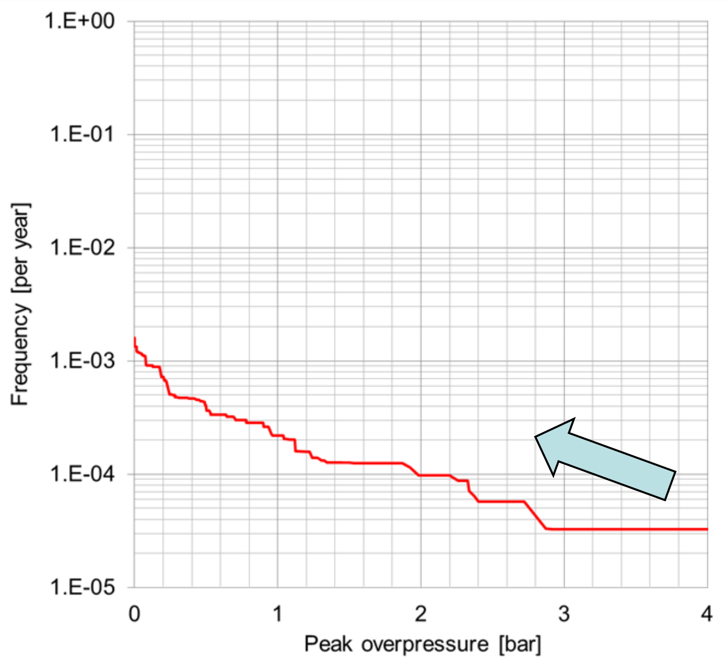
Probabilistic structural response

Abercus learnings:

- The computational effort required for the NLFEA of selected structures can be comfortably undertaken alongside the rest of the probabilistic assessment – it is often the dispersion phase of the assessment which is the bottleneck
- Not all explosion events need to be simulated using NLFEA – start with the large events and work towards smaller events and you'll reach a point where your 10^{-4}/yr measure of damage/deflection stops changing.

Probabilistic structural response

Start with the largest explosion events, and work towards the smaller events – may not need to simulate the structural response for all explosion events.



Probabilistic structural response

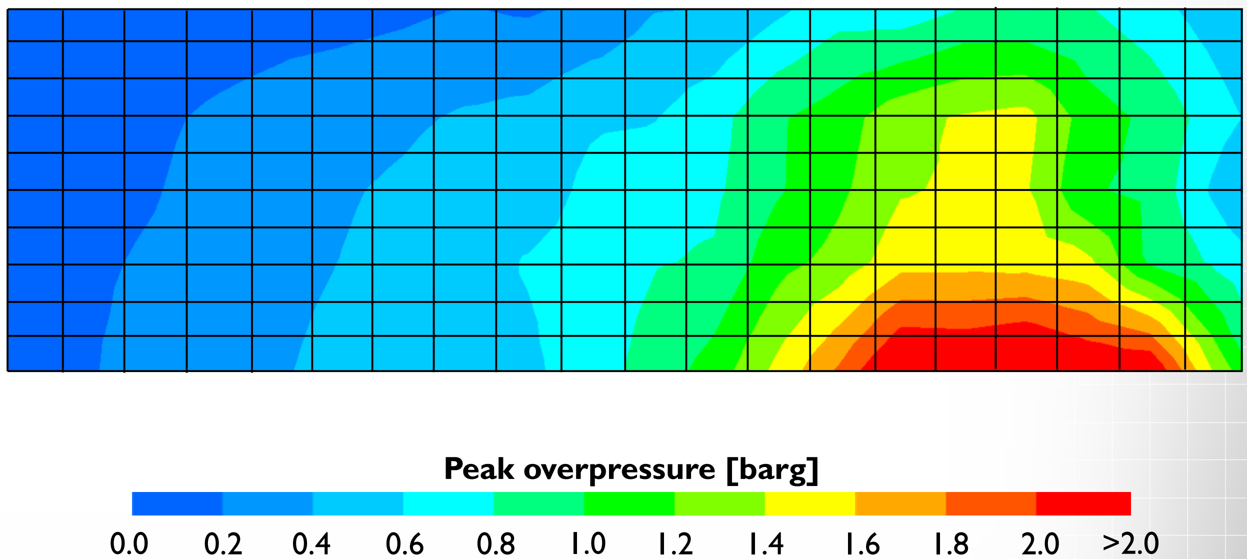
Abercus learnings:

- The computational effort required for the NLFEA of selected structures can be comfortably undertaken alongside the rest of the probabilistic assessment – it is often the dispersion phase of the assessment which is the bottleneck
- Not all explosion events need to be simulated using NLFEA – start with the large events and work towards smaller events and you'll reach a point where your 10^{-4}/yr measure of damage/deflection stops changing
- Is it possible to construct a 10^{-4}/yr pseudo-event?

Probabilistic structural response (10^{-4}/yr pseudo-event)

The 10^{-4}/yr overpressure is just part of the DAL definition – need to consider the dynamic behaviour with respect to the duration of the blast and how the blast might travel across the blast wall.

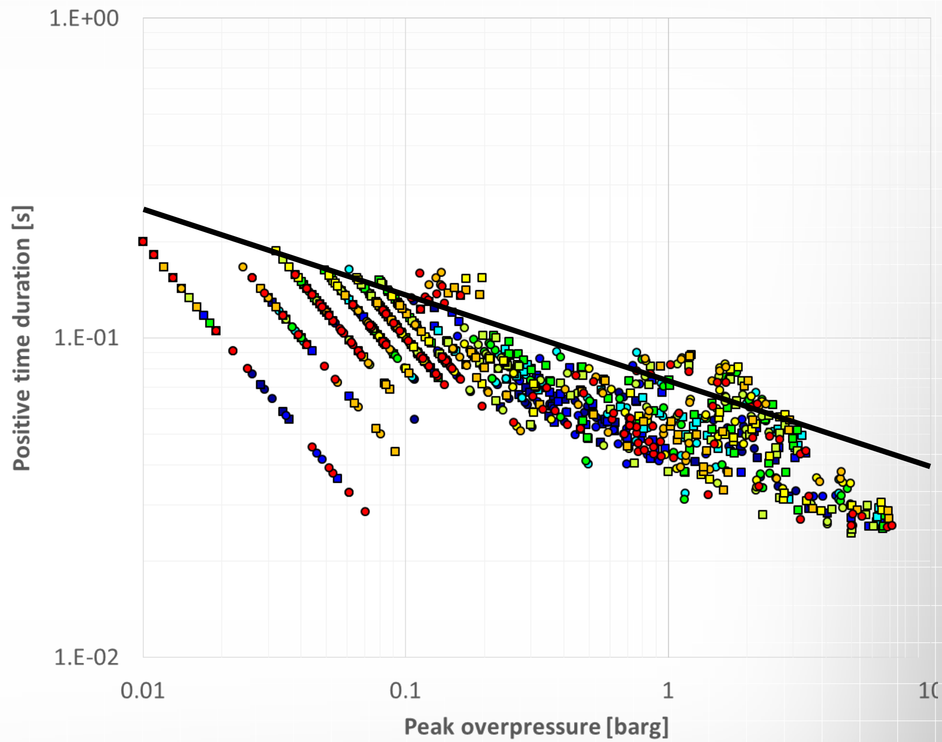
Contour plot of 10^{-4}/yr peak overpressure



Probabilistic structural response (10^{-4}/yr pseudo-event)

Trends from the underlying explosion data set can define the associated time duration of the positive blast phase

Similarly for the negative blast phase, so that the shape of a (triangulated) 10^{-4}/yr pseudo-blast can be fully described.



Scatter plot showing time duration of the positive blast phase with peak overpressure

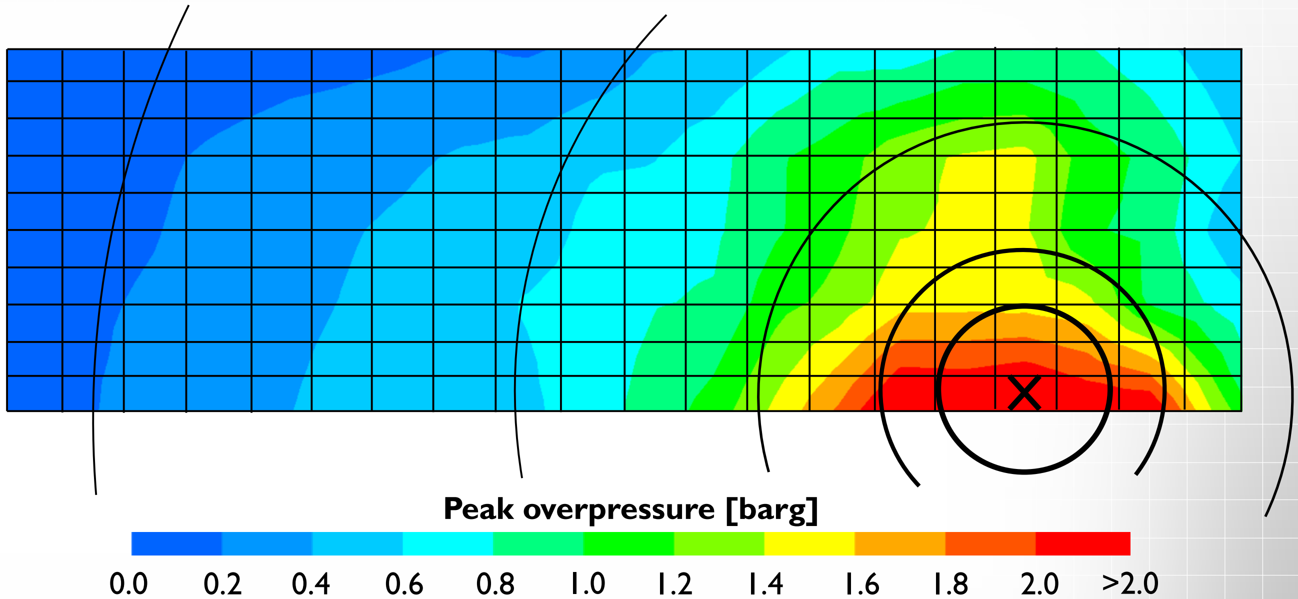
Probabilistic structural response (10^{-4}/yr pseudo-event)

- Blast events do not impinge everywhere instantaneously
- If it can be assumed that the initial impingement is at the location of the peak, the time delay across the blast wall can be included into the pseudo-event blast behaviour, based upon the local speed of sound

Probabilistic structural response (10^{-4}/yr pseudo-event)

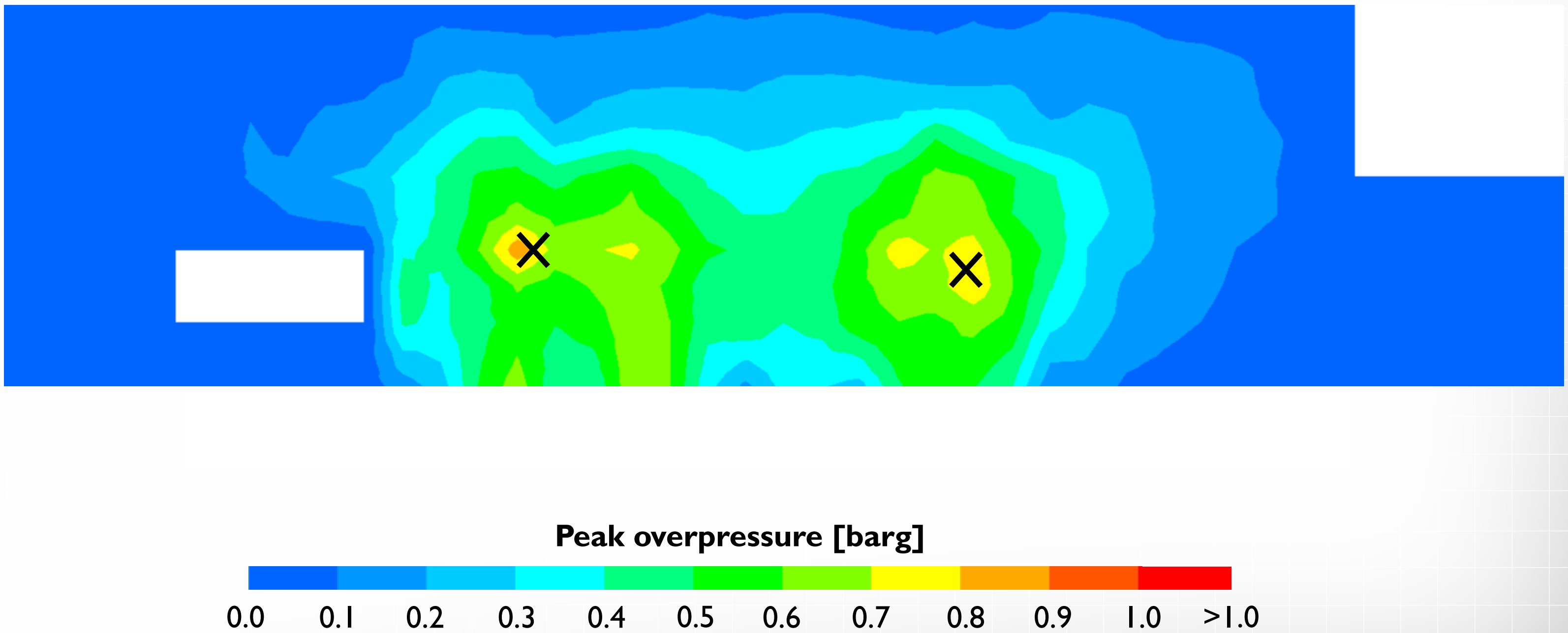
If it can be assumed that the initial impingement is at the location of the peak, the time delay across the blast wall can be included into the pseudo-event blast behaviour.

Contour plot of 10^{-4}/yr peak overpressure



Probabilistic structural response (10^{-4}/yr pseudo-event)

Contour plot of 10^{-4}/yr peak overpressure

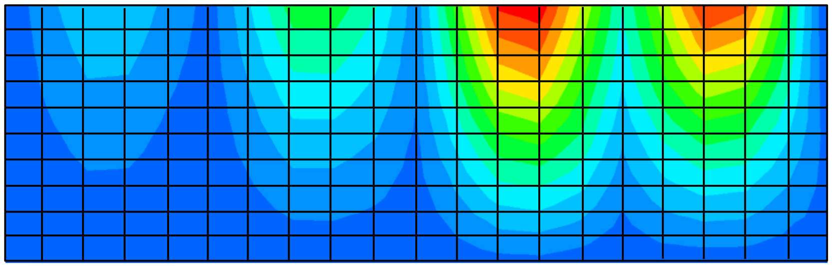


Probabilistic structural response (10^{-4}/yr pseudo-event)

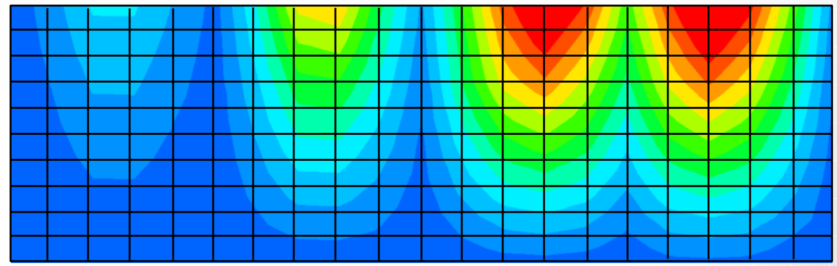
- Blast events do not impinge everywhere instantaneously
- If it can be assumed that the initial impingement is at the location of the peak, the time delay across the blast wall can be included into the pseudo-event blast behaviour, based upon the local speed of sound
- What happens if there are two local peaks in the 10^{-4}/yr peak overpressure?
- There remain open questions about this approach!

Probabilistic structural response (10^{-4}/yr pseudo-event)

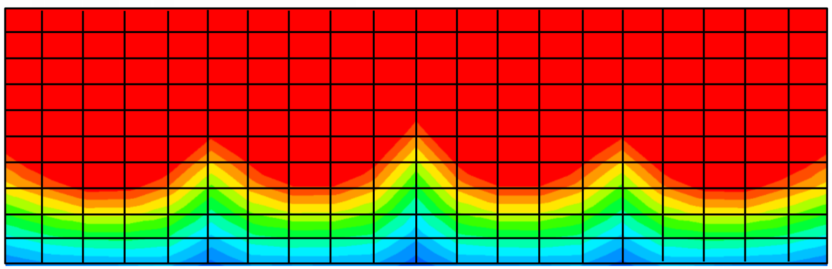
Contours of 10^{-4}/yr deflection



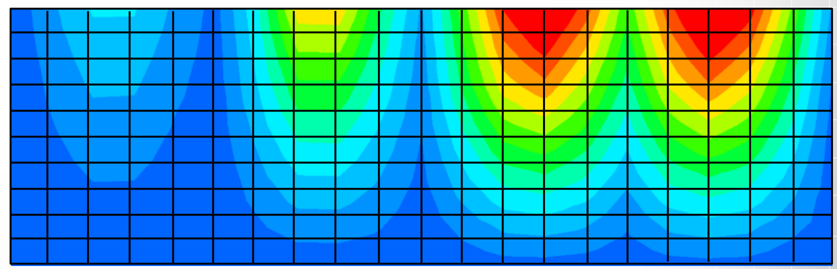
Using a probabilistic structural response approach



Using the 10^{-4}/yr pseudo-event without time delay

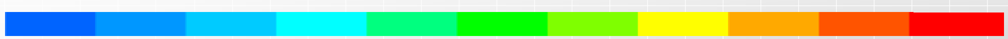


Traditional approach – uniformly applying the 10^{-4}/yr overpressure (2 barg) from the exceedance curve



Using the 10^{-4}/yr pseudo-event with time delay

10^{-4}/yr deflection [m]



Probabilistic structural response (10^{-4}/yr pseudo-event)

- For the case study presented here, it turns out that there is **reasonable agreement** between the pseudo-event and probabilistic structural response approaches
- However, we **need to consider a much wider range** of examples to determine whether this is generally the case, so this **remains an open question**
- **One-to-one coupling** does not require the definition of a 10^{-4}/yr pseudo-event and is, therefore, **free from further assumptions** that may need to be justified.

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Probabilistic structural response (10^{-4}/yr pseudo-event)

- What is clear is that the **traditional approach** with a uniformly applied 10^{-4}/yr load is **overly conservative** when compared to the probabilistic structural response and pseudo-event approaches.

Agenda

Introduction

Simulation data management

Sensitivity to assumptions

3D risk assessment

Probabilistic structural response

Consistency across the industry

Summary

Consistency across the industry

- One major benefit of an automated SDM approach is that it can provide a robust, consistent method for the implementation of the probabilistic methodology
- Abercus uses EXCGEN
- Many other consultants have developed in-house tools that we expect have similar functionality
- Gexcon is developing RISK
- Other parties will likely develop similar tools.

Consistency across the industry

- Whilst there might be **high-level agreement** within the industry regarding the general approach, **the devil is in the detail**
- Even if all of the underlying simulations are undertaken identically by different parties, the exceedence data constructed from them is likely to be different
- **User variation and inconsistencies in approach/ detailed assumptions are bad for our industry**.

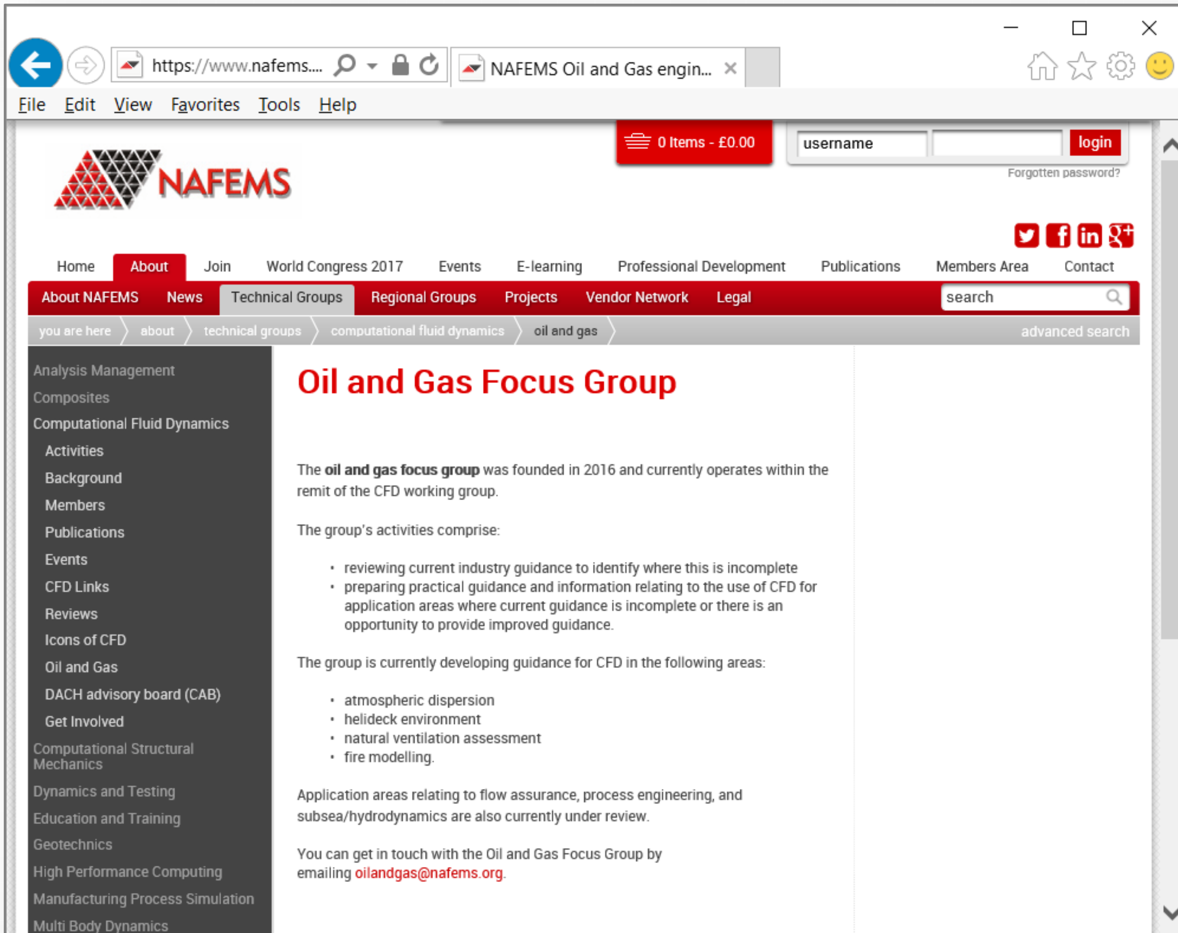
Consistency across the industry

- Maybe there is a need to think about better guidance for the industry, documenting the probabilistic methodology in detail, with practical worked examples so that there are actual numbers to compare against?
- Maybe a **blind benchmarking exercise** could be undertaken to investigate whether there is a degree of variation across the industry?
- What are the **open questions**?
- Is there a need for some **FABIG technical guidance**?

Consistency across the industry

- User variation and inconsistencies is a potential issue wherever engineering simulation methods are used
- Abercus is a member of NAFEMS, the international association for the engineering simulation community
- NAFEMS has established an oil and gas focus group

Consistency across the industry



Consistency across the industry

- NAFEMS has established an oil and gas focus group
- The groups activities include:
  - Reviewing existing industry guidance
  - Preparing practical guidance and information relating specifically to the use of CFD for application areas where current guidance is incomplete or there is an opportunity to provide improved practical guidance
- Open questions are being openly discussed within the group and hopefully new practical guidance will begin to emerge later in 2017.

Agenda

Introduction

Simulation data management

Sensitivity to assumptions

3D risk assessment

Probabilistic structural response

Consistency across the industry

Summary

Summary

- Effective use of SDM tools can allow data to be shared with the design team, thus democratising the approach
  - This can enable the sensitivity of the exceedence data to many of the probabilistic assumptions to be explored on-the-fly, in the company of the wider design team
  - 3D risk assessment information where the spatial variation of an explosion load can be presented across large structures
  - One-to-one coupling between explosion CFD and NLFEA, extending the probabilistic methodology to cover structural response.

Summary

- As new methods are enabled though software tools, there may be a need for updated guidance to minimise inconsistency across our industry – perhaps some FABIG technical guidance?