On the application of CFD in the oil and gas sector, and how we can improve confidence in the CFD

Steve Howell

18 September 2018

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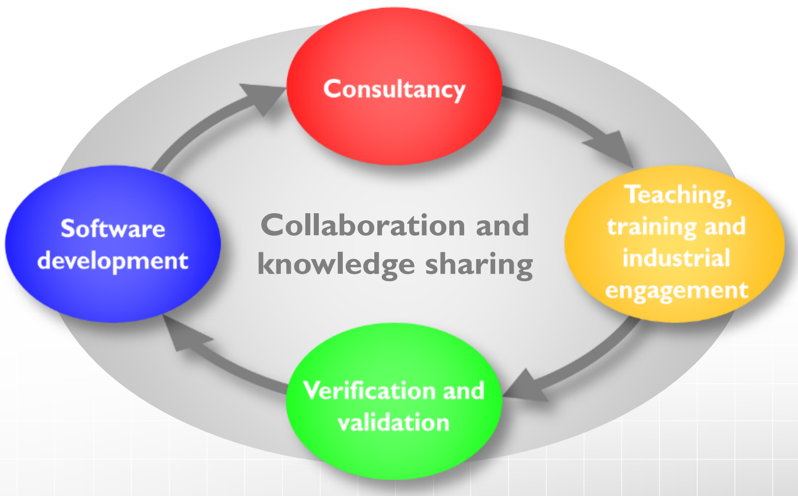
Abercus

Abercus is an independent 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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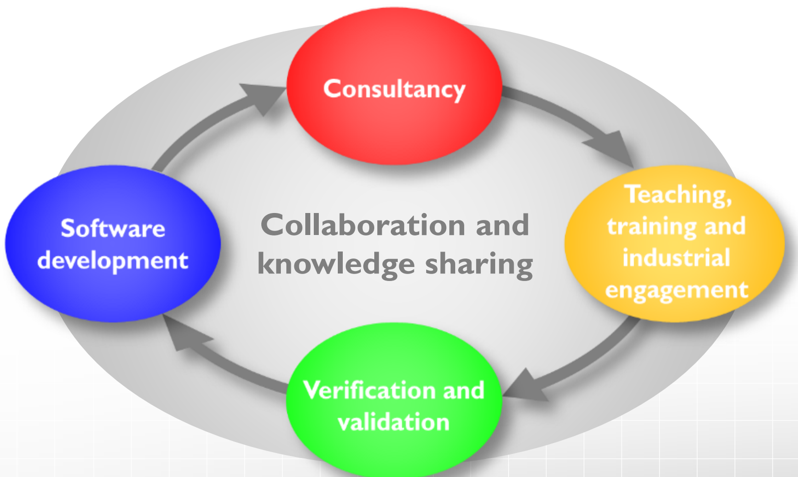
Abercus' goal is the **democratisation** of advanced engineering simulation. **Abercus enables its clients to build expertise and develop their own engineering simulation capabilities**.



Agenda

- Introduction
- Why use CFD in the oil and gas sector?
  - Technical safety
  - Flow assurance
  - Subsea hydrodynamics
- Application specific CFD codes
- Verification and validation
- Consistency across the industry
- Summary.

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Introduction

- CFD and other simulation technologies are being increasingly used in the oil and gas sector
- The industry has benefitted from developments in the general-purpose simulation tools pushed by other industries
- Some industry specific tools have emerged – KFX/Exsim and FLACS, for example, for simulating fires and explosions
- How confident can we be in any of the CFD predictions?
- Fit for purpose approach?
- NAFEMS oil and gas focus group.

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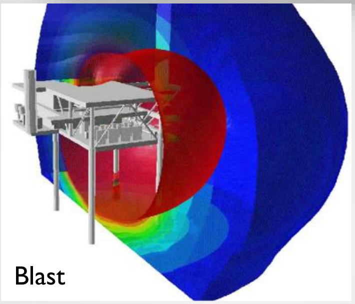
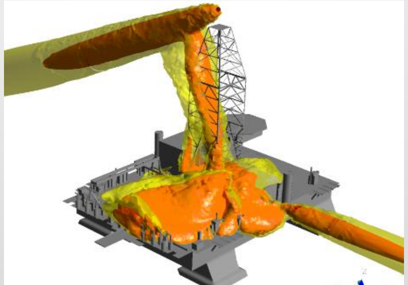
Why use CFD in the oil and gas sector?

Technical safety



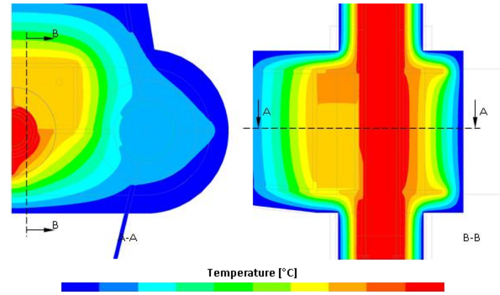
Blast

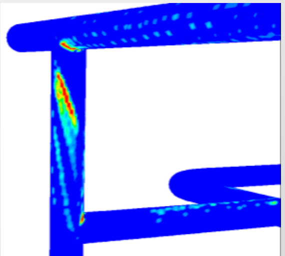


Deepwater Horizon : http://abercus.com/News_20110622.aspx

Flow assurance

Hydrate avoidance

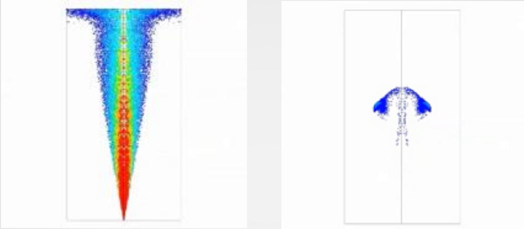


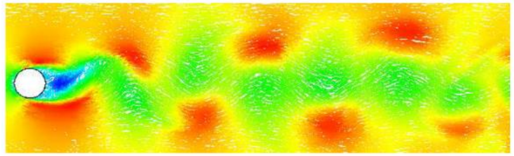


Erosion

Subsea engineering

Subsea loss of containment / bubble plumes





Flow induced vibration

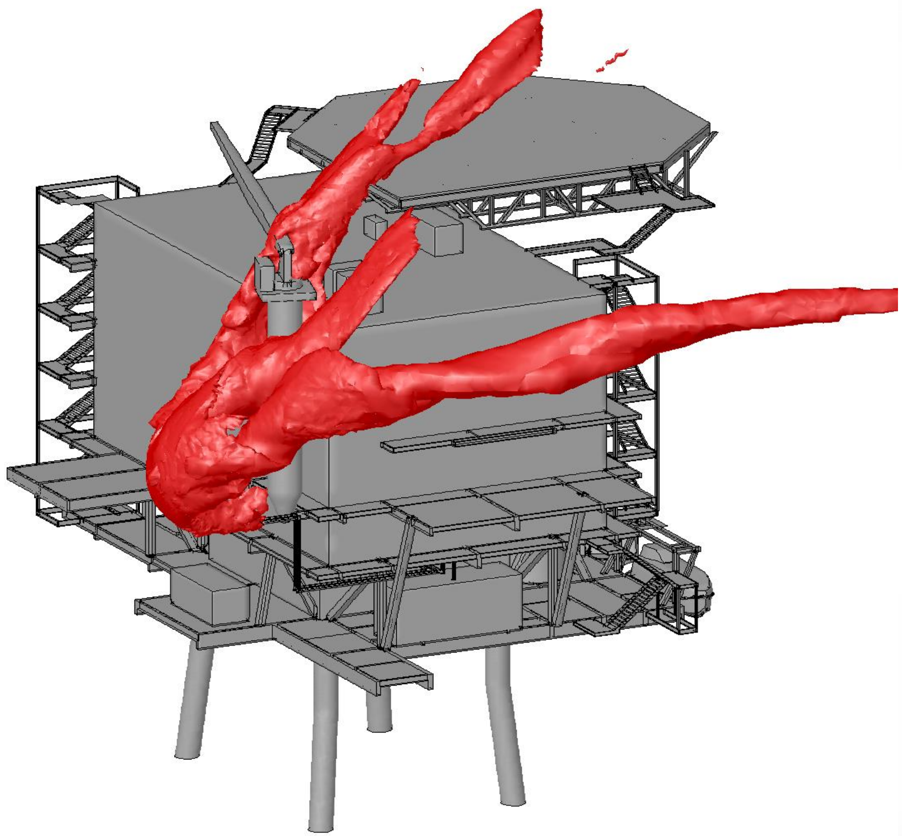
Why use CFD in the oil and gas sector?

Atmospheric dispersion


Offshore helideck design guidelines, HSE.

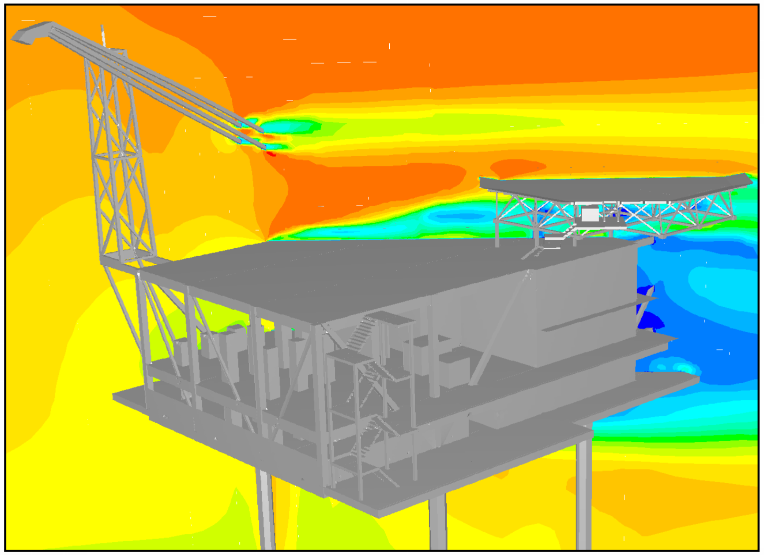
Why use CFD in the oil and gas sector?

Atmospheric dispersion

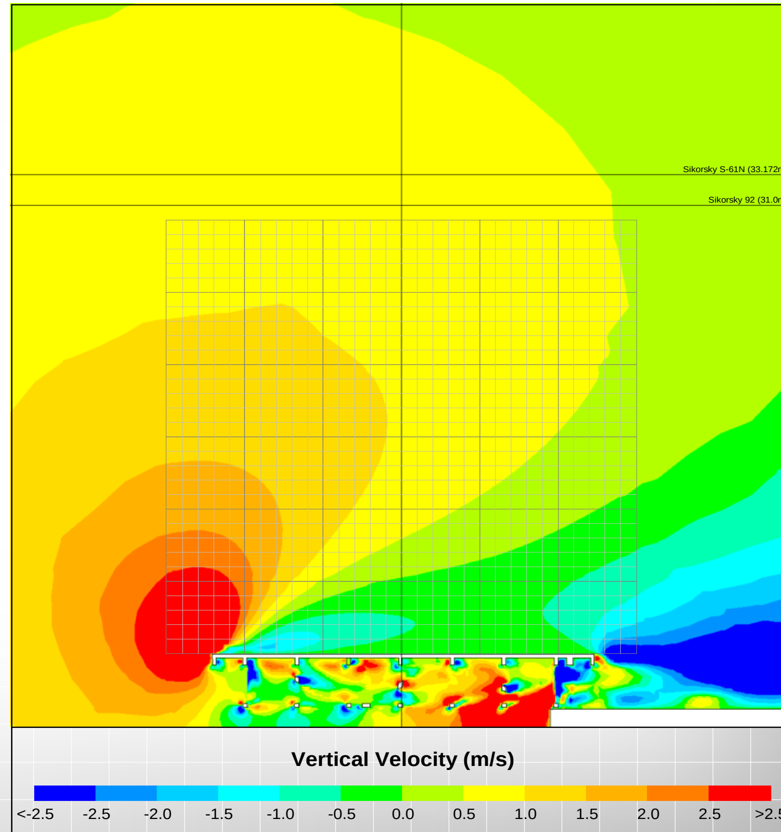


Why use CFD in the oil and gas sector?

Helideck turbulence environment



Prediction of velocity field and turbulence fluctuations over the helideck



Why use CFD in the oil and gas sector?

Fire and explosion

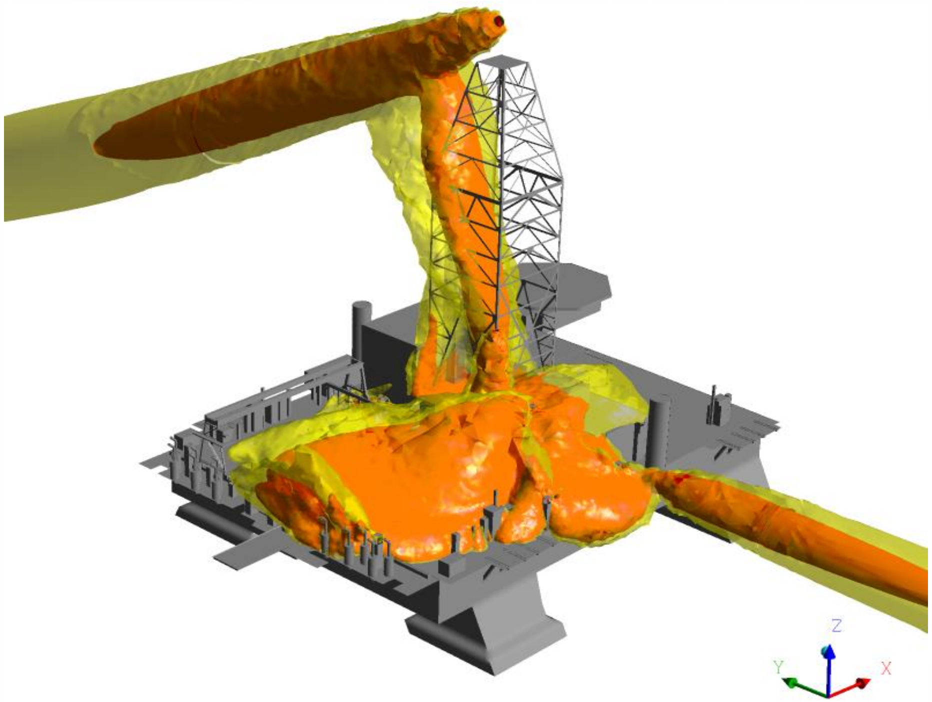

Deepwater Horizon

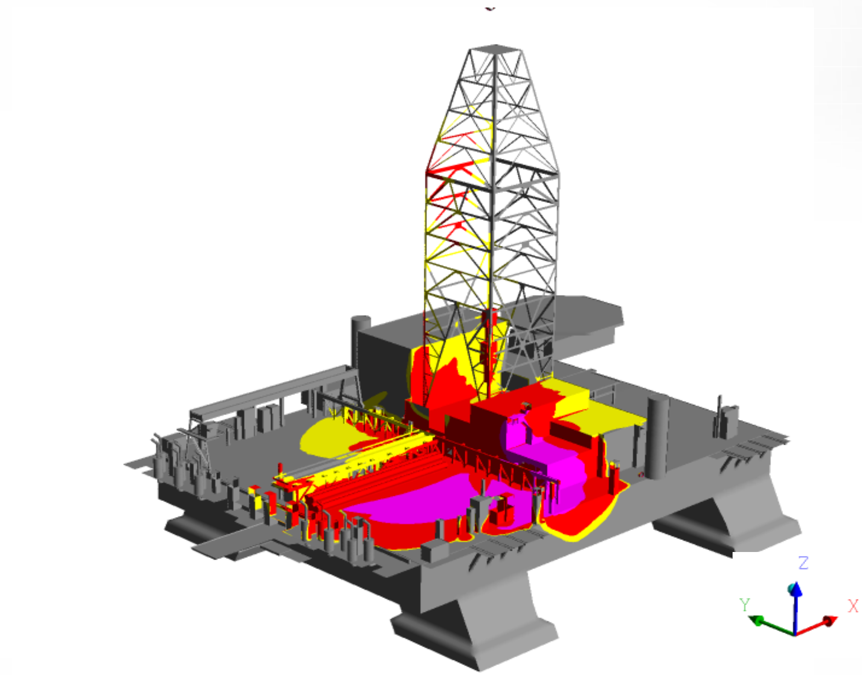

Piper Alpha


Buncefield

Why use CFD in the oil and gas sector?

Gas leak dispersion

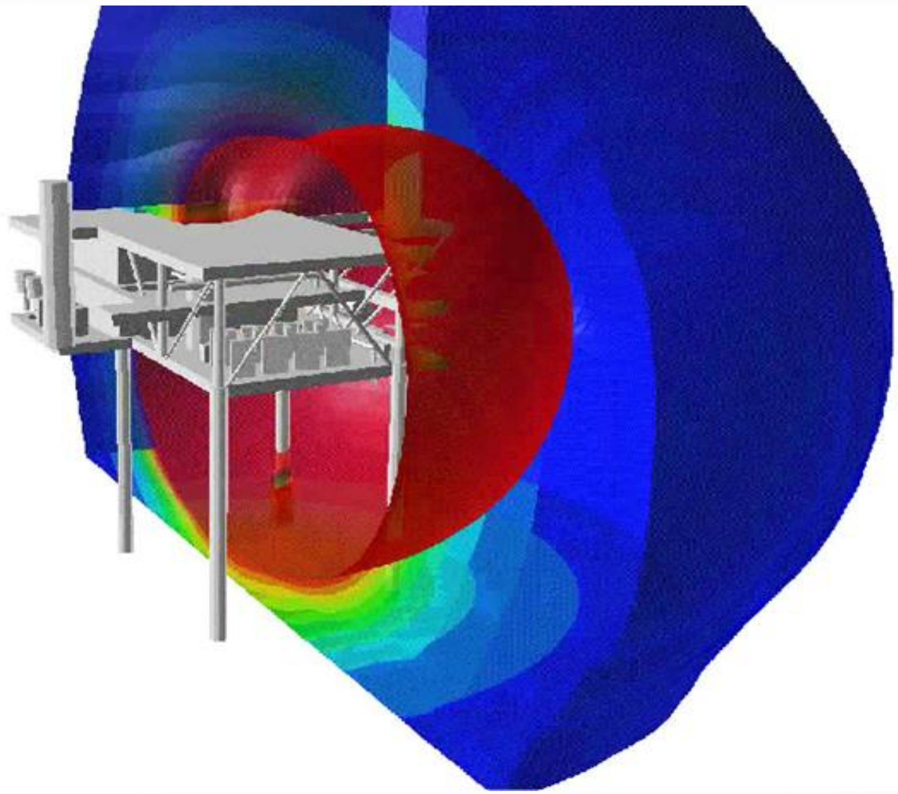




Deepwater Horizon investigation: http://abercus.com/News_20110622.aspx

Why use CFD in the oil and gas sector?

Explosions



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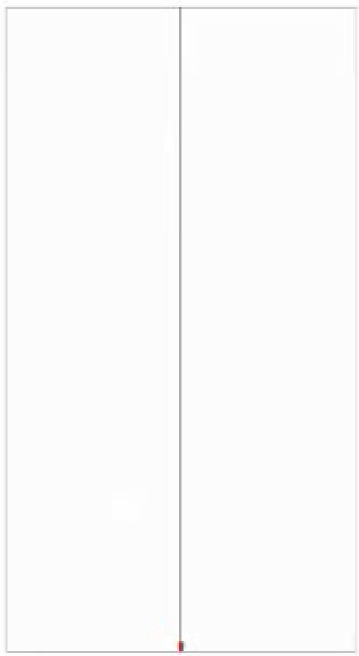
Why use CFD in the oil and gas sector?

Subsea releases

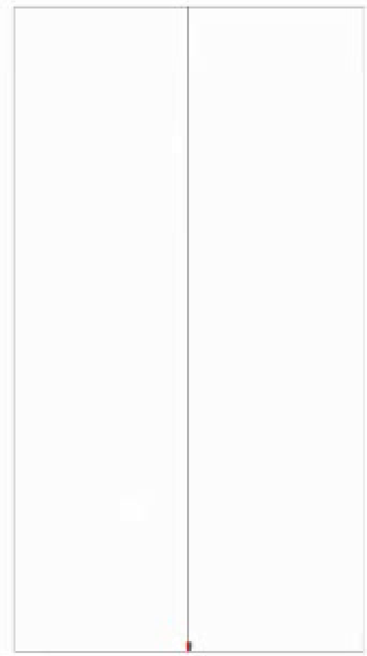
https://www.youtube.com/watch?v=yRD5QYAkOoA

Why use CFD in the oil and gas sector?

Subsea releases



Sustained release

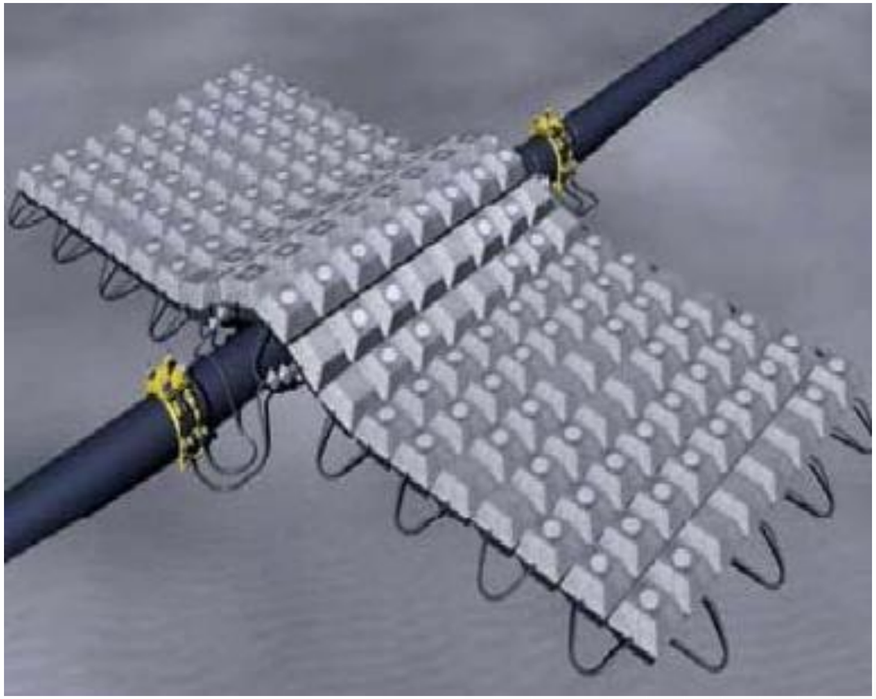


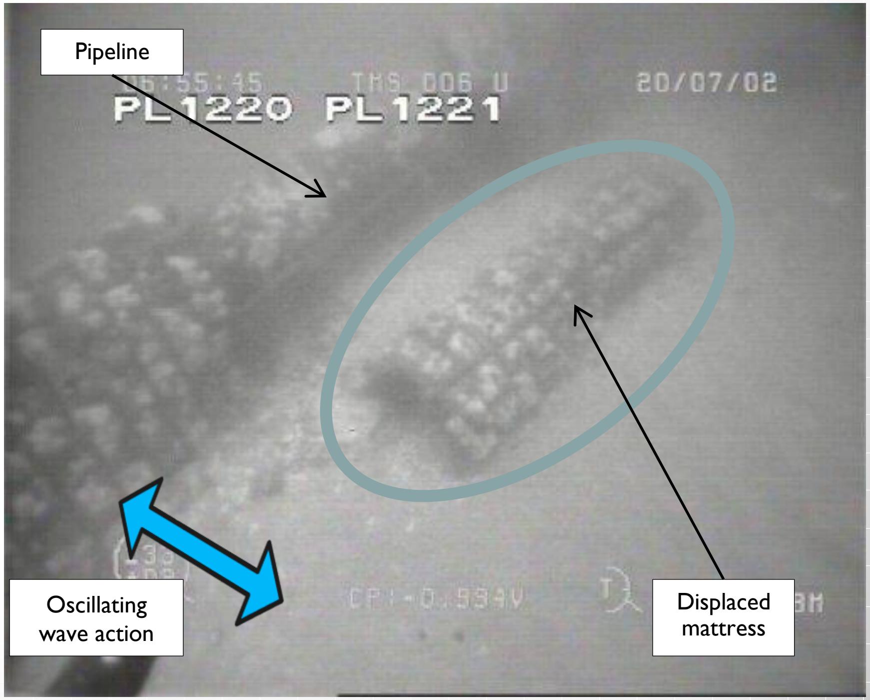
Pulsed release

Gas concentration [% volume at atmospheric pressure]

Why use CFD in the oil and gas sector?

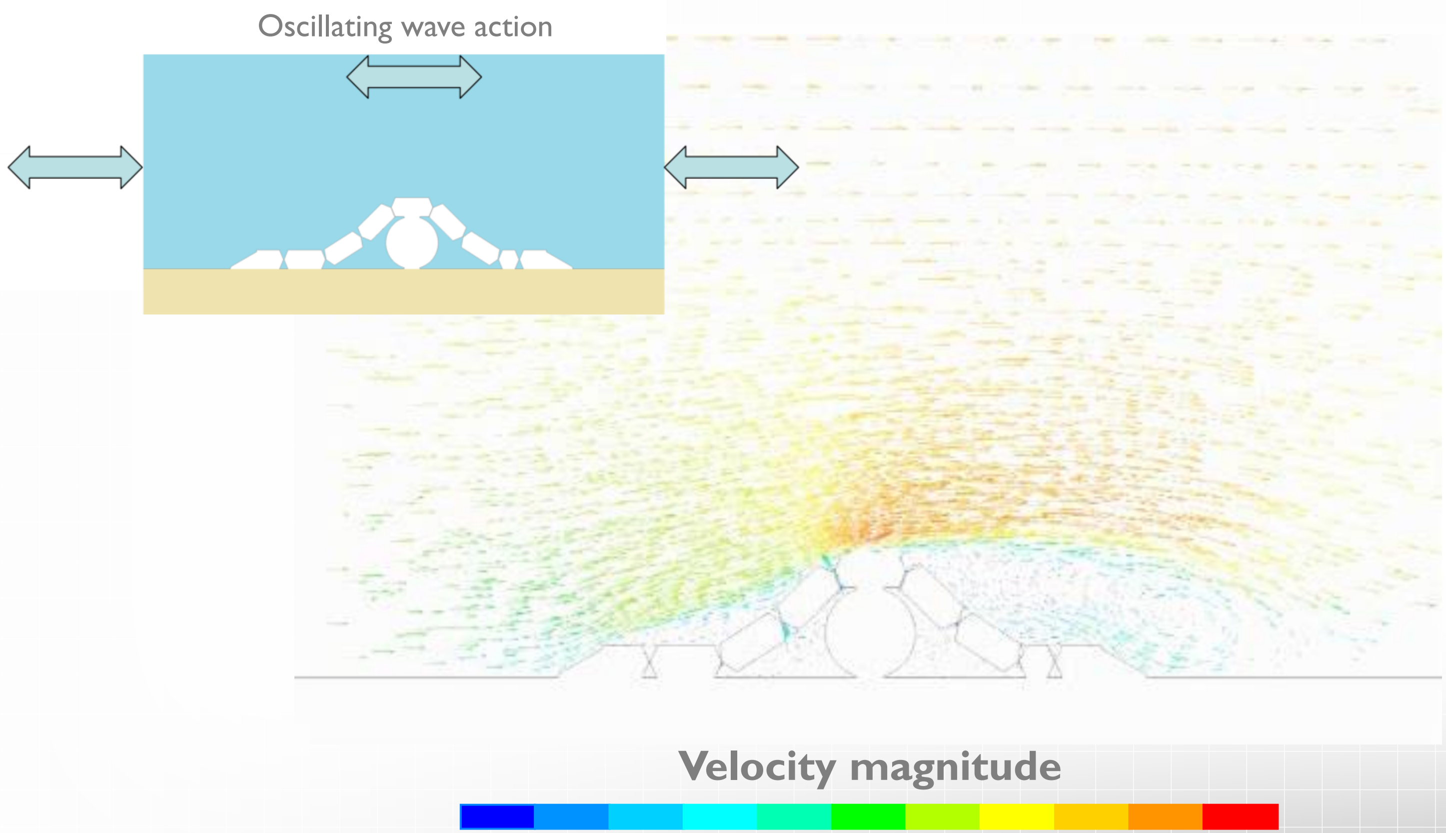
Subsea stability





Why use CFD in the oil and gas sector?

Subsea stability



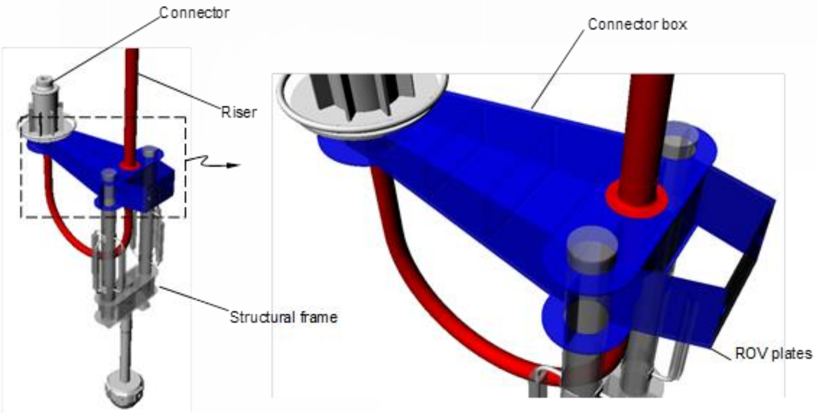
Why use CFD in the oil and gas sector?

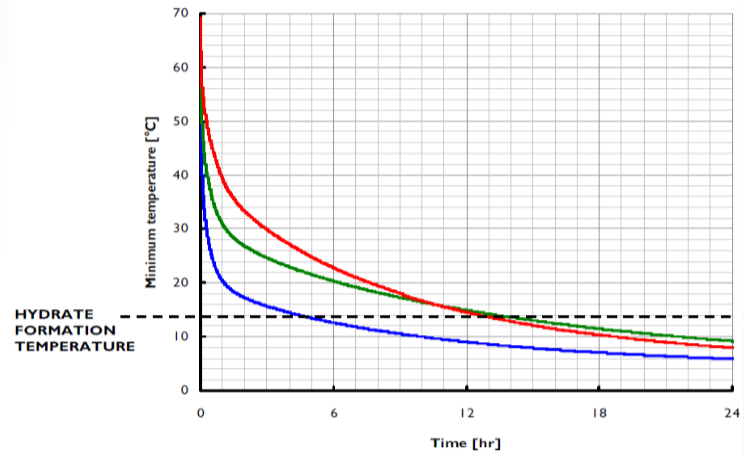
Hydrate avoidance

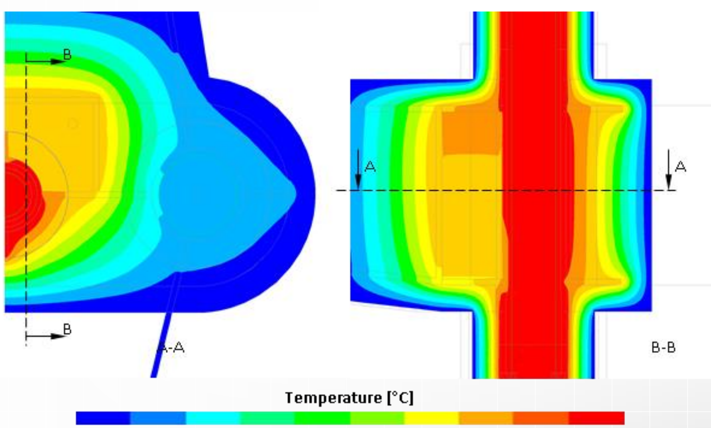
A hydrate plug (Offshore Brazil)

Why use CFD in the oil and gas sector?

Hydrate avoidance

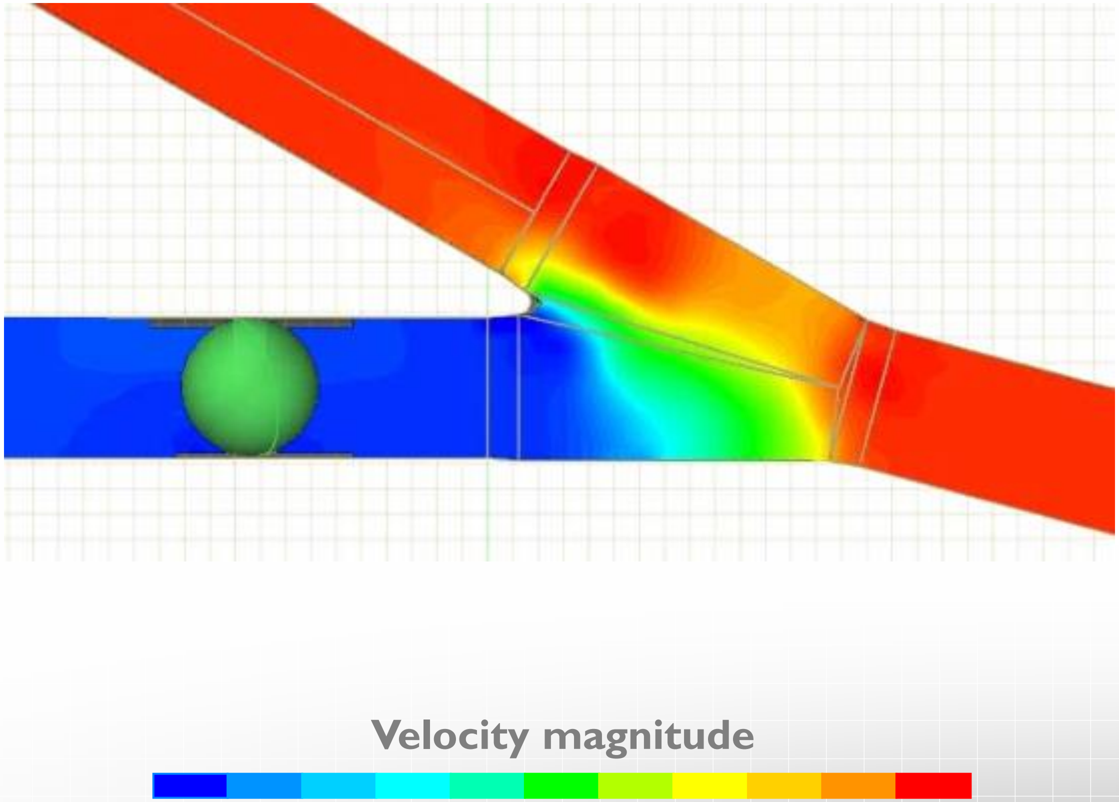






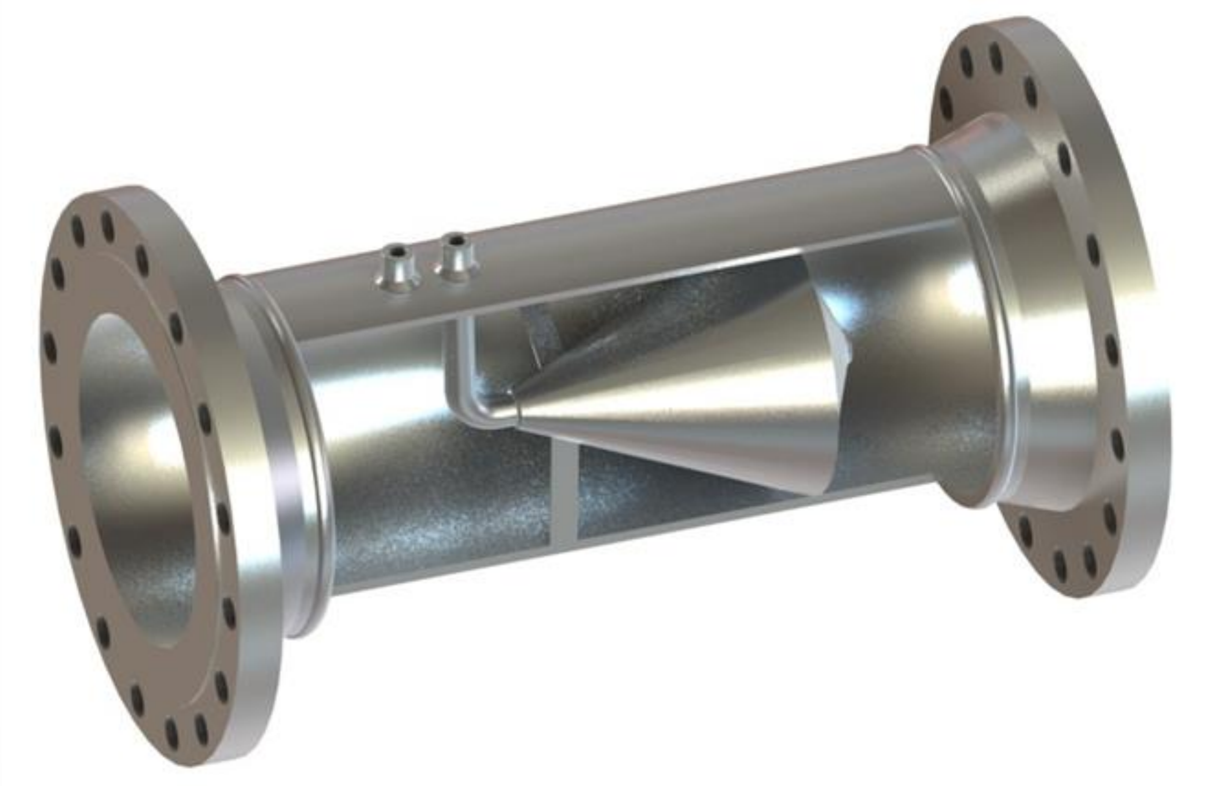
Why use CFD in the oil and gas sector?

Pigging



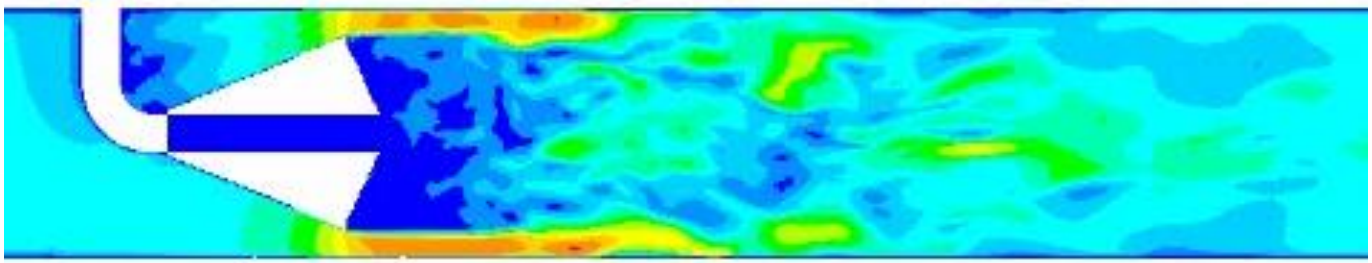
Why use CFD in the oil and gas sector?

Flow-induced vibration and fatigue life

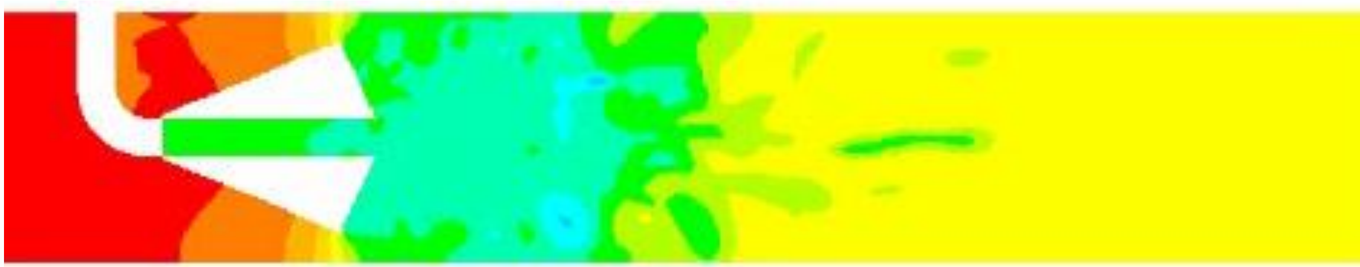


Why use CFD in the oil and gas sector?

Flow-induced vibration and fatigue life



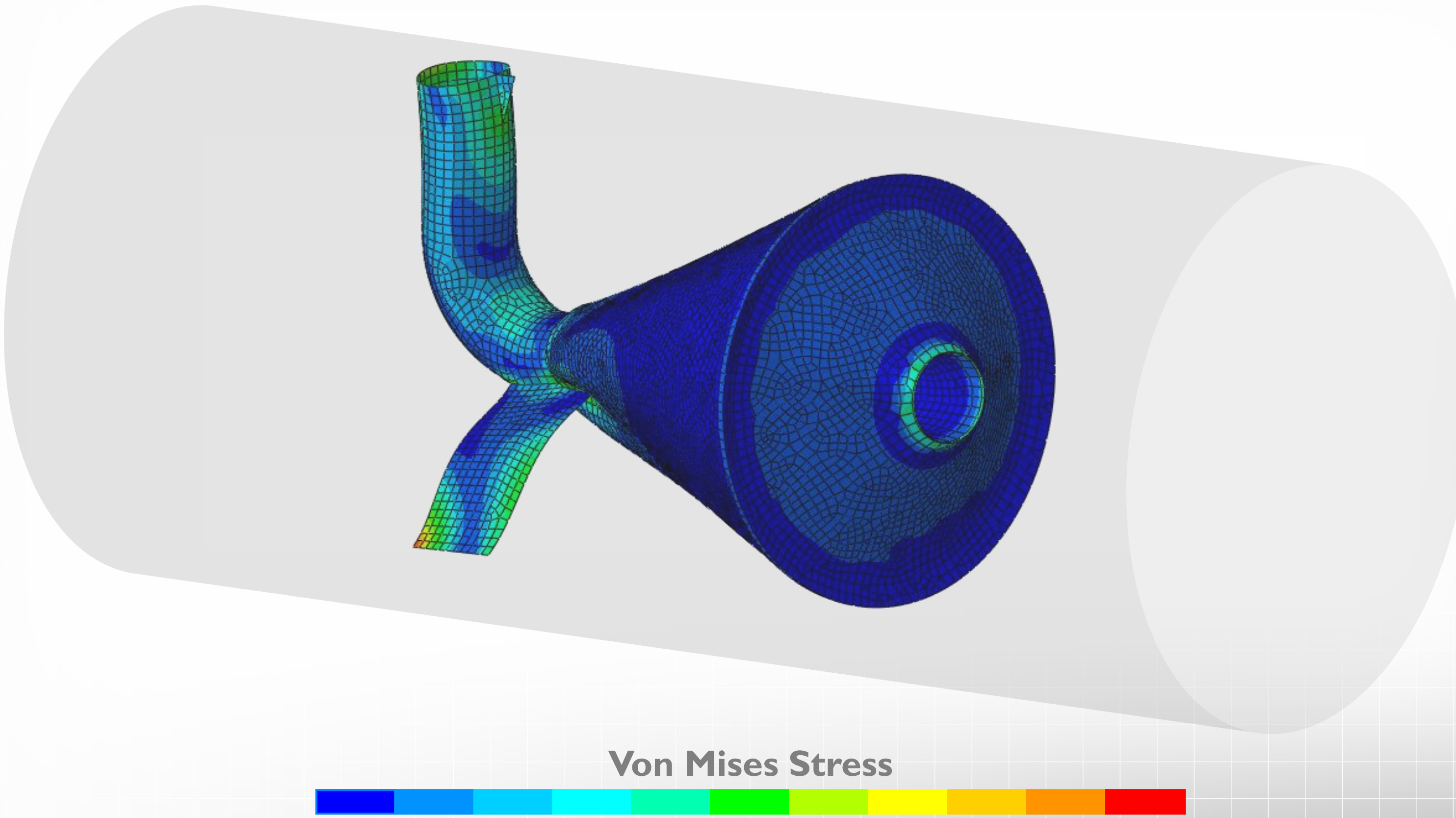
Velocity magnitude



Pressure

Why use CFD in the oil and gas sector?

Flow-induced vibration and fatigue life



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Application specific CFD codes

Explosions (deflagations – subsonic)

(Courtesy of Gexcon)

Both configurations contain the same volume of gas and volumetric fill of pipe work

The configuration on the left comprises a few large diameter pipes

The configuration on the right comprises many small diameter pipes

The intensity of the explosion for the right-hand configuration is increased significantly.

Application specific CFD codes

Explosions (deflagations – subsonic)

(Courtesy of DNVGL)

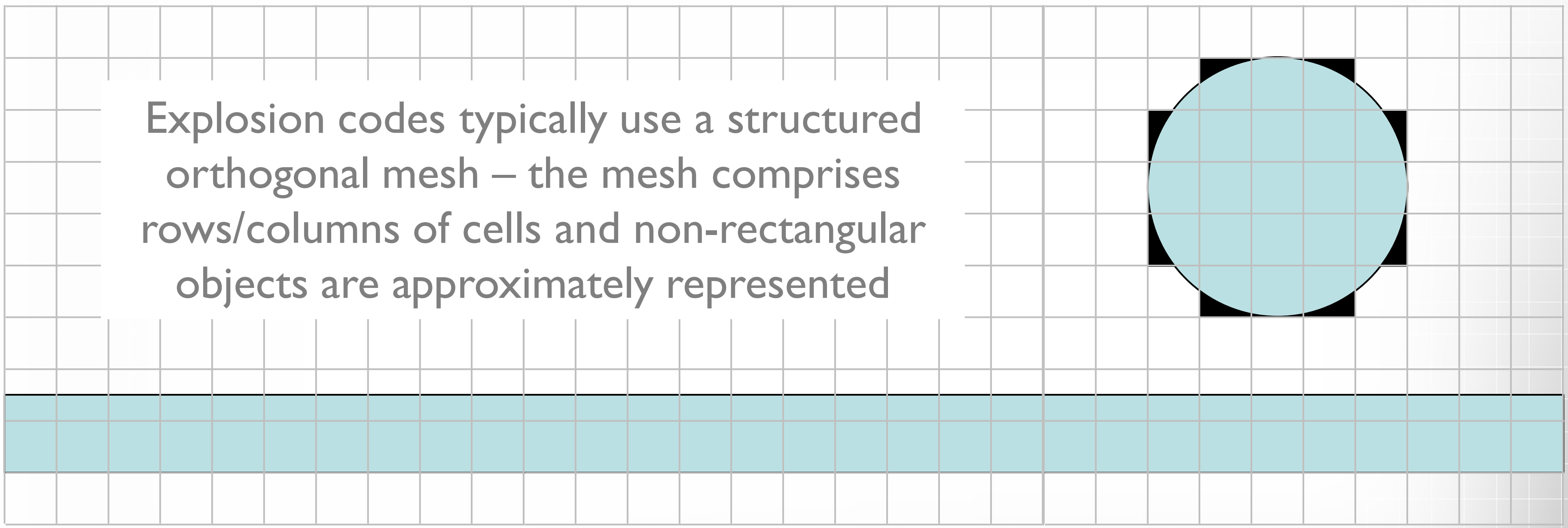
Both configurations contain the same volume of gas

The configuration on the left is entirely filled with small-scale congestion

The configuration on the right is half-filled with small-scale congestion.

Application specific CFD codes

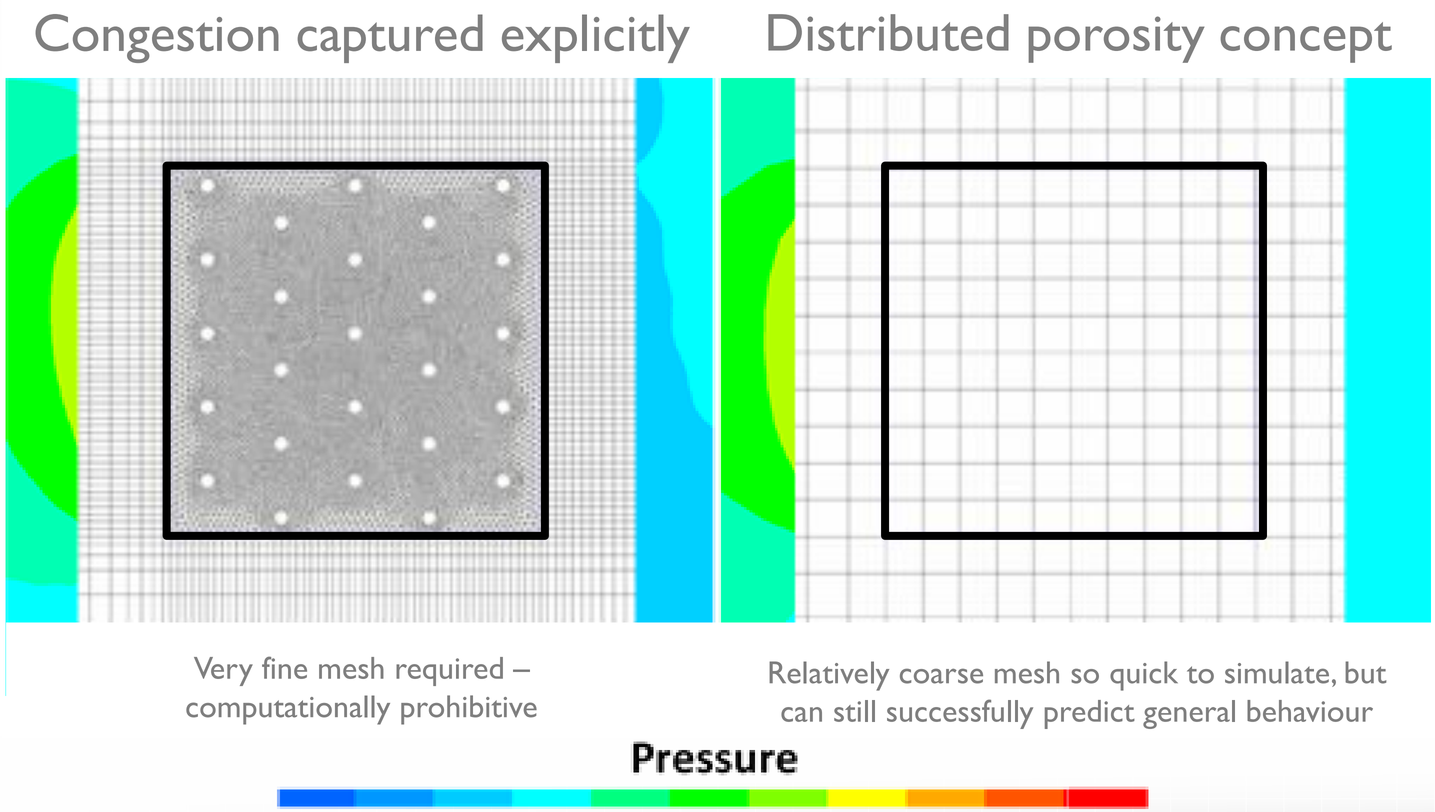
Modelling deflagrations – KFX/Exsim and FLACS



Explosion codes typically use a structured orthogonal mesh – the mesh comprises rows/columns of cells and non-rectangular objects are approximately represented

Application specific CFD codes

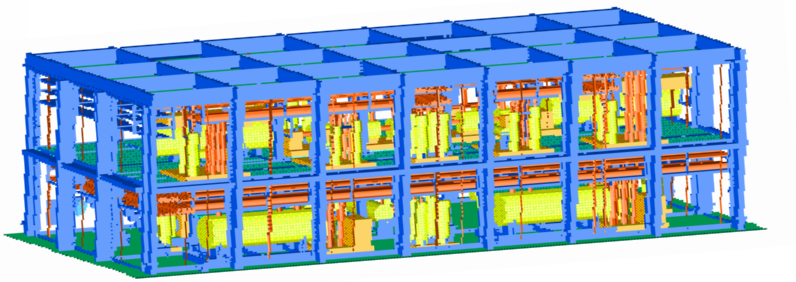
Modelling deflagrations – capturing congestion



For the implementation of the distributed porosity concept on an unstructured mesh, refer to the ACE method: http://abercus.com/SoftwareSolutions_ACEMethod.aspx

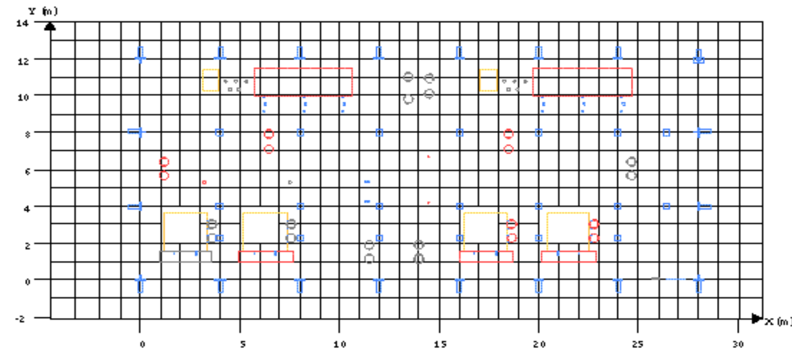
Application specific CFD codes

Modelling deflagrations – capturing congestion

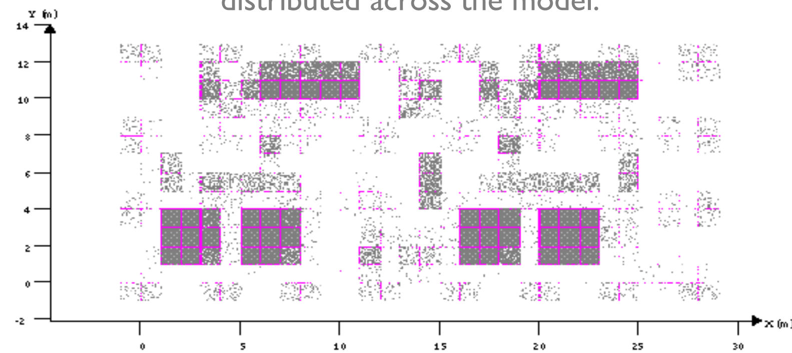


FLACS model for the 2600m^3 full-scale rig at Spadeadam
(Courtesy of Gexcon)

Underlying FLACS mesh (structured orthogonal mesh)



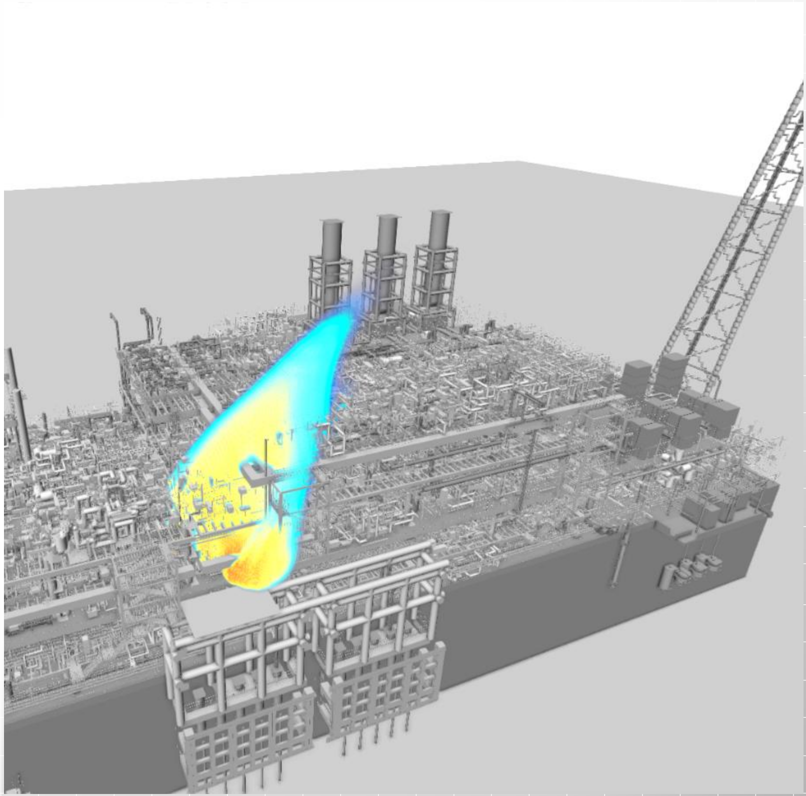
Congestion represented by varying degree of porosity distributed across the model.



Application specific CFD codes

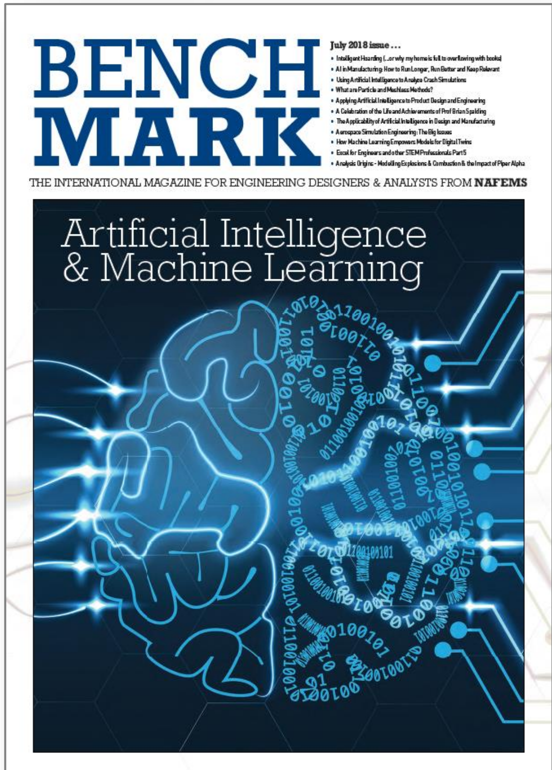
Modelling deflagrations – capturing congestion

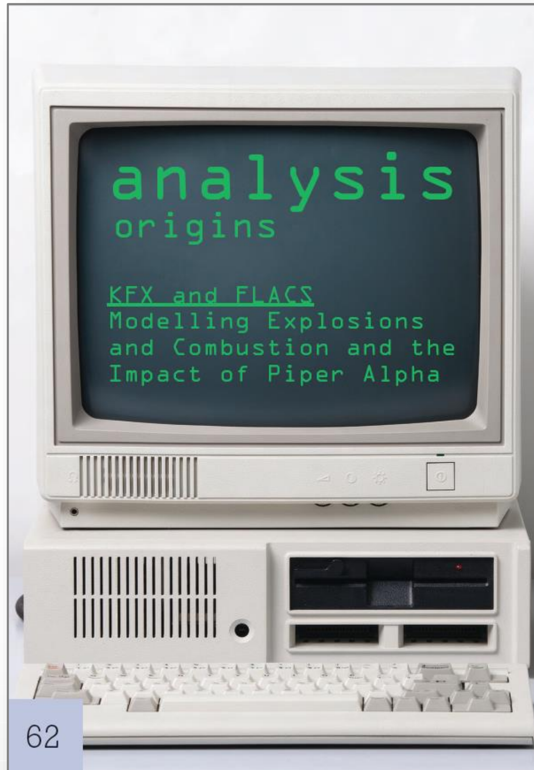
- Congestion down to one-inch must be included to properly capture Shchelkin mechanism
- This is handled by sub-grid models – congestion is not explicitly captured within the CFD mesh
- Explosion CFD models can look extremely impressive – but don't forget that under the hood, they're essentially simplified *Lego* geometry.

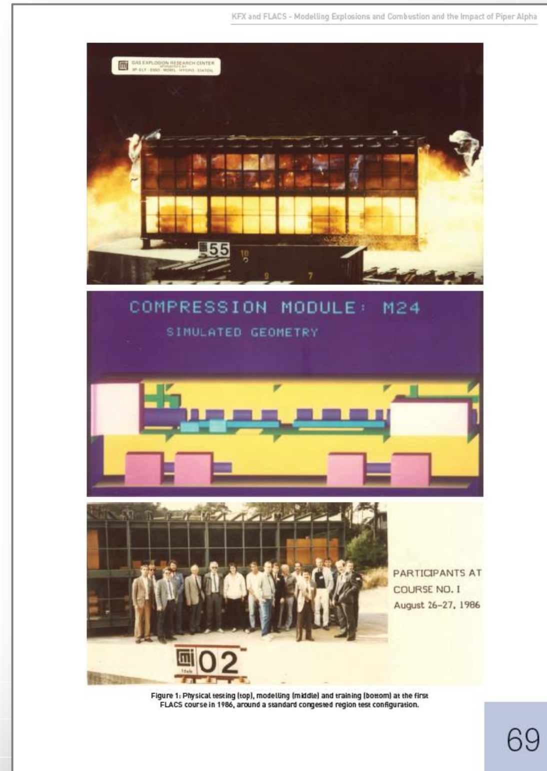


Application specific CFD codes

Modelling deflagrations – KFX/Exsim and FLACS





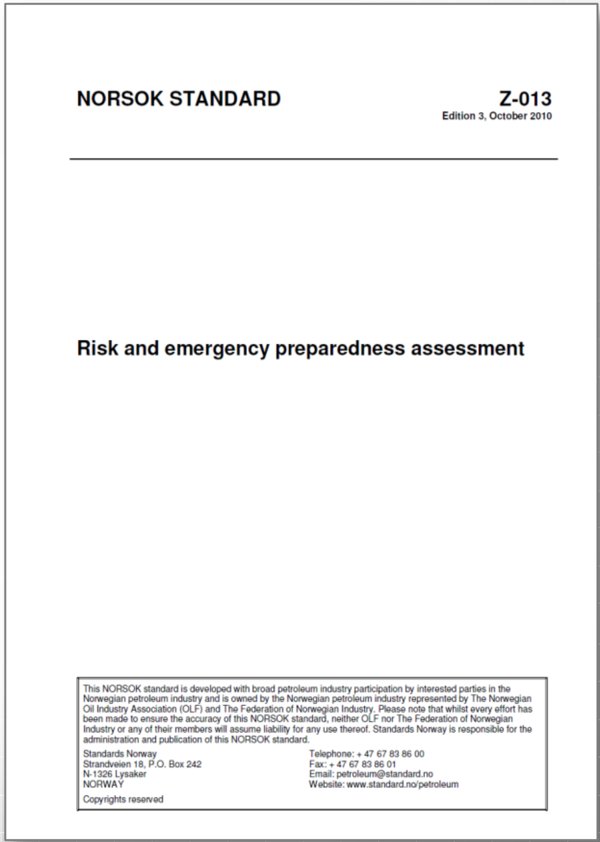


NAFEMS Benchmark magazine, July 2018.

Application specific CFD codes

Probabilistic explosion assessment – exceedance curves

- 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 is outlined in Annex F).
- A deterministic worst case analysis generally yields loads that are too severe for practical design.



NORSOK STANDARD

Z-013
Edition 3, October 2010

Risk and emergency preparedness assessment

This NORSOK standard is developed with broad petroleum industry participation by interested parties in the Norwegian petroleum industry and is owned by the Norwegian petroleum industry represented by The Norwegian Oil Industry Association (OLF) and The Federation of Norwegian Industry. Please note that whilst every effort has been made to ensure the accuracy of this NORSOK standard, neither OLF nor The Federation of Norwegian Industry or any of their members will assume liability for any use thereof. Standards Norway is responsible for the administration and publication of this NORSOK standard.

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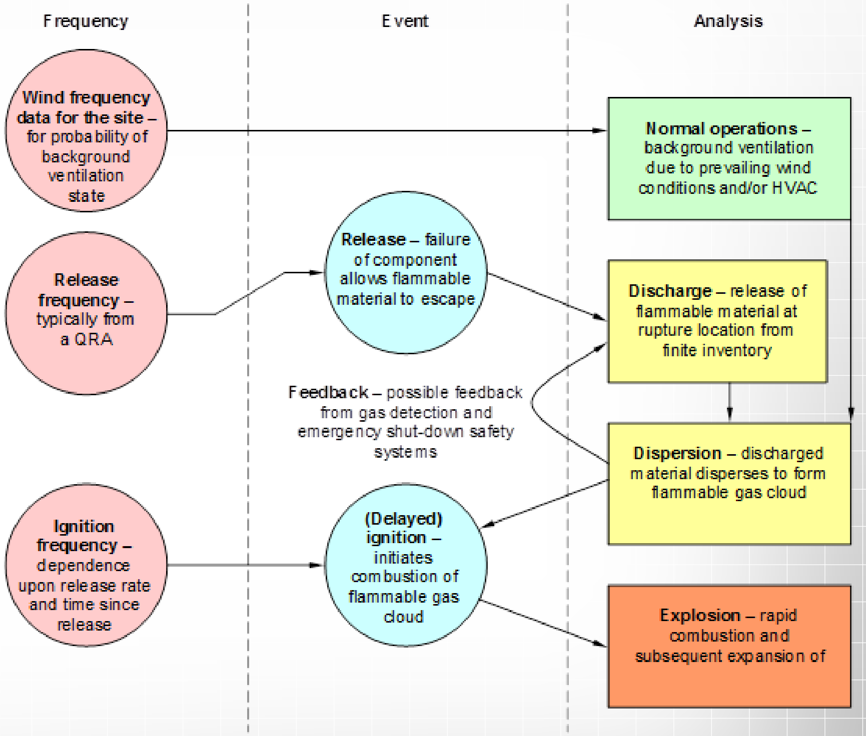
Application specific CFD codes

Probabilistic explosion assessment – exceedance curves

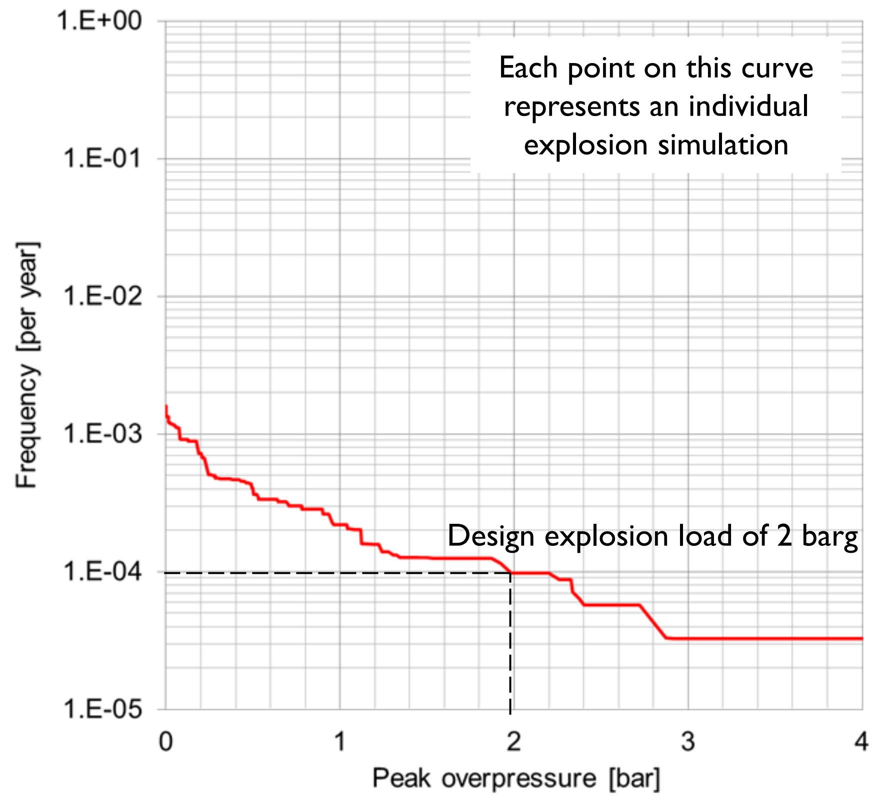
- The probabilistic approach requires a large dataset of scenarios to be simulated at each stage in the sequence leading to the explosion event
- With an understanding of the frequencies of occurrence at each stage, **exceedance curves** for the explosion load can be constructed.



Application specific CFD codes

Probabilistic explosion assessment – exceedance curves

- Exceedance curves show the predicted frequency for explosion loading at a target of interest
  (in this example, for a blast wall)
- For a specified allowable frequency, the design load is read from the curve and can be used as the basis of the structural design
  (in this example, the DAL corresponding to a 1 in 10000 year event is 2 barg).



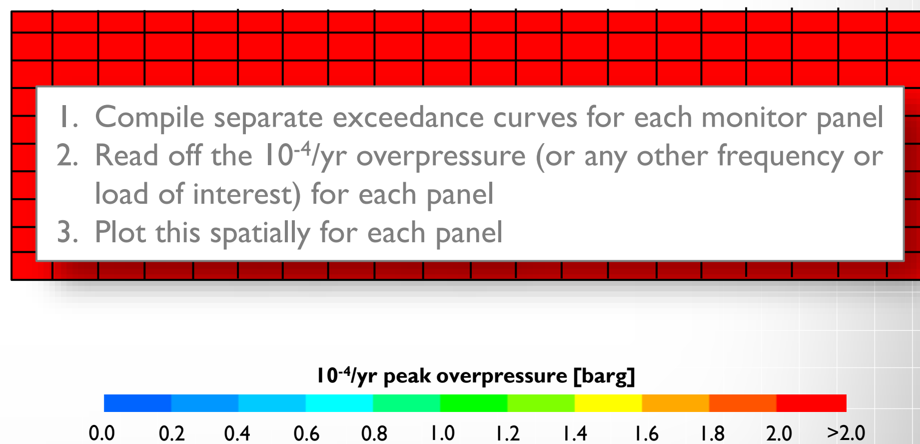
Application specific CFD codes

Probabilistic explosion assessment – 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



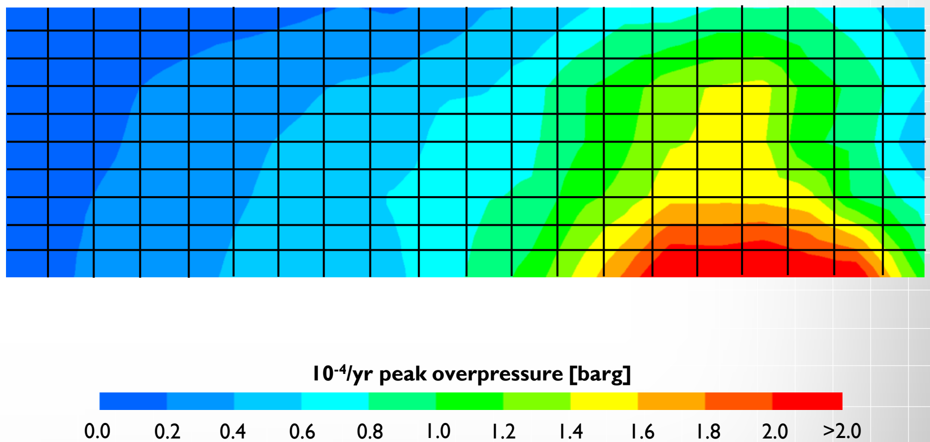
Application specific CFD codes

Probabilistic explosion assessment – 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
- This can have a significant impact upon the structural response of the blast wall under DAL loading.

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

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



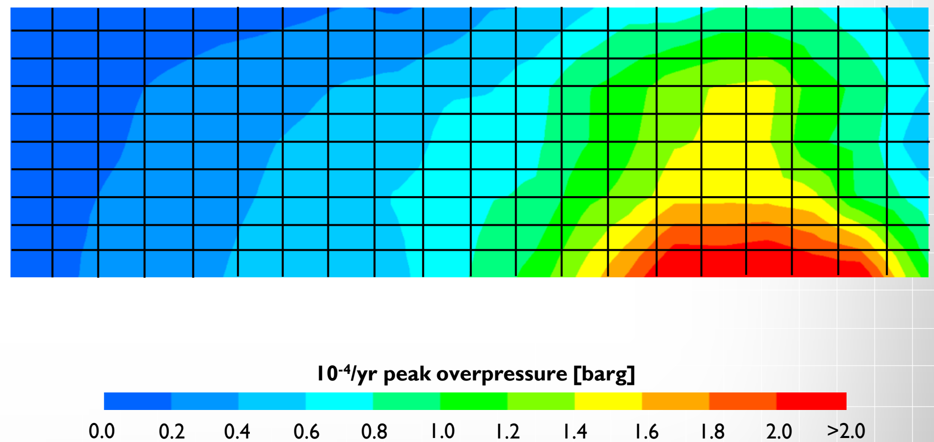
Application specific CFD codes

Probabilistic explosion assessment – 3D risk assessment

- In this example, the 2 barg DAL is localised at the bottom-right corner of the blast wall – this was adjacent to a compression module operating at high pressure.
- The 10^{-4}/yr peak overpressure is significantly less than 2 barg for the majority of the wall.

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

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



For more information on 3D risk and other novel topics relating to using CFD for determining design loads, please refer to our recent FABIG paper: http://www.fabig.com/video-publications/TechnicalPresentations-Videos# - TM89)

Application specific CFD codes

Modelling detonations – deflagration vs detonation

(Courtesy of DNVGL)

Both configurations contain the same volume of gas and are half filled with small-scale congestion

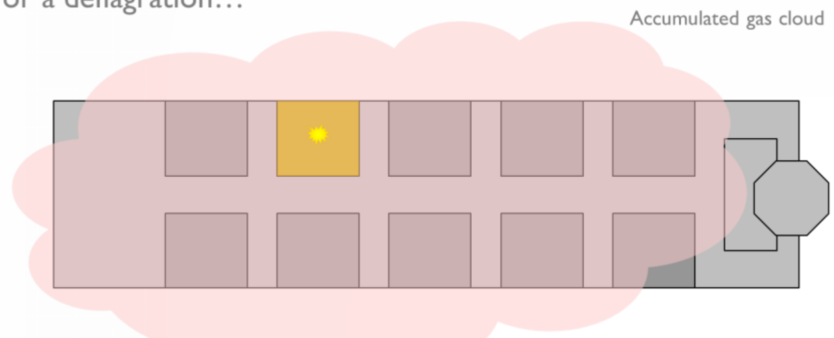
The configuration on the left is the deflagration we saw earlier in the presentation

The configuration on the right has a confined region around the ignition location at the left to get 'faster' start-up.

Application specific CFD codes

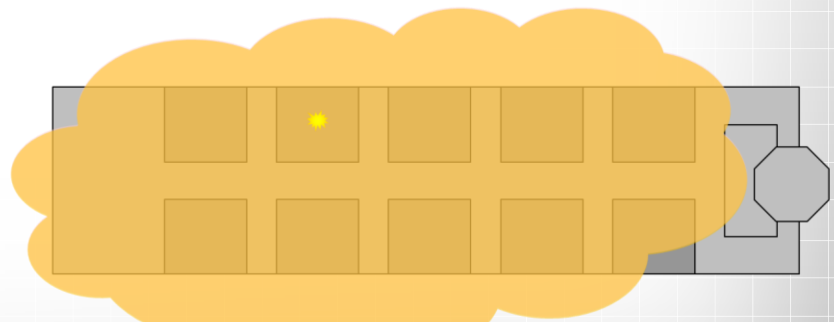
Modelling detonations – deflagration vs detonation

For a deflagration…



… the explosion may be confined to a single module if there is a sufficient safety gap around the module.

For a detonation…



… the explosion will propagate beyond the module and continue until all flammable material is consumed.

Application specific CFD codes

Modelling detonations

- The explosion CFD codes cannot yet reliably model detonations
- There is, however, a criterion to consider the onset of deflagration-detonation transition (DDT)
  - Abercus consultant Prankul Middha: Prediction of deflagration to detonation transition (DDT) in hydrogen explosions, Process Safety Progress 27(3):192 - 204 · September 2008, https://www.researchgate.net/publication/227537550_Prediction_of_deflagration_to_detonation_transition_Ddt_in_hydrogen_explosions
- The criterion is now implemented within the FLACS CFD code, so it is relatively easy to check as part of a FLACS simulation
- When undertaking deflagration simulations using CFD, always check for DDT using Prankul's pressure gradient criterion.

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Verification and validation

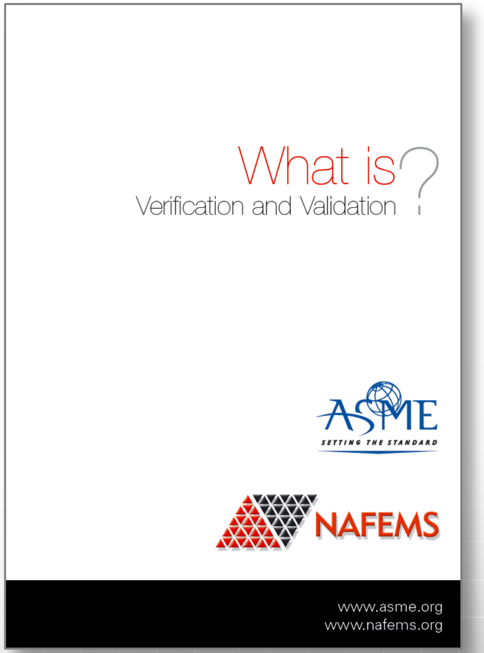
"All models are wrong but some are useful"

Robustness in the strategy of scientific model building, Box GEP,
in *Robustness in Statistics*, Launer RL and Wilkinson GN, Academic Press, pp 201–236, 1979.

In order to gain confidence in our models and ensure that they are useful and fit for purpose, verification and validation is essential.

Verification and validation

- ASME and NAFEMS have published a *What is?* guide that is freely available for download: http://www.nafems.org/publications/browse_buy/browse_by_topic/qa/verification_and_validation/

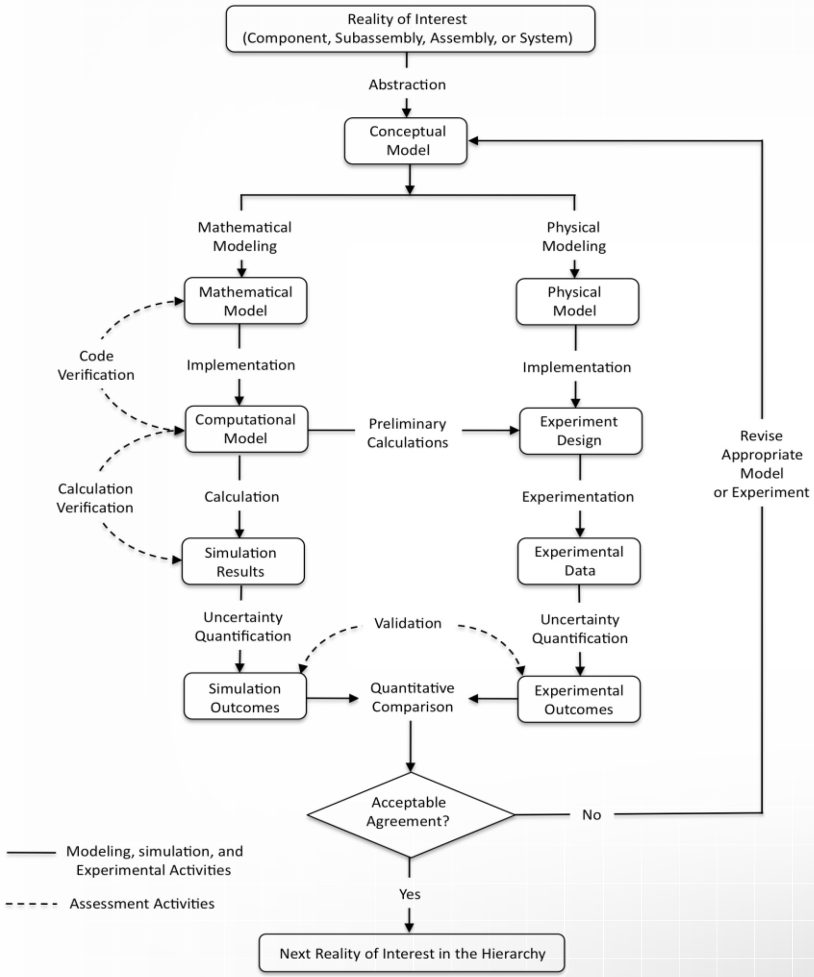


Verification and validation

- **Verification**: the process of determining that a computational model accurately represents the underlying mathematical model and its solution
- **Validation**: the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model

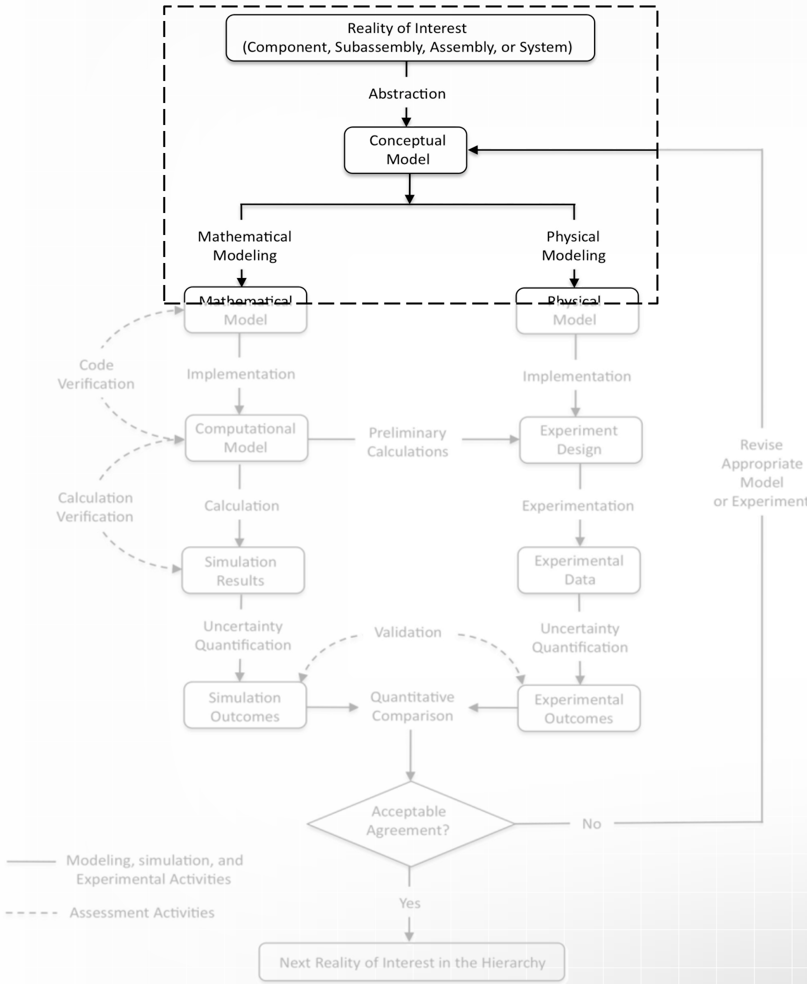
- Verification is the domain of mathematics and validation is the domain of physics.

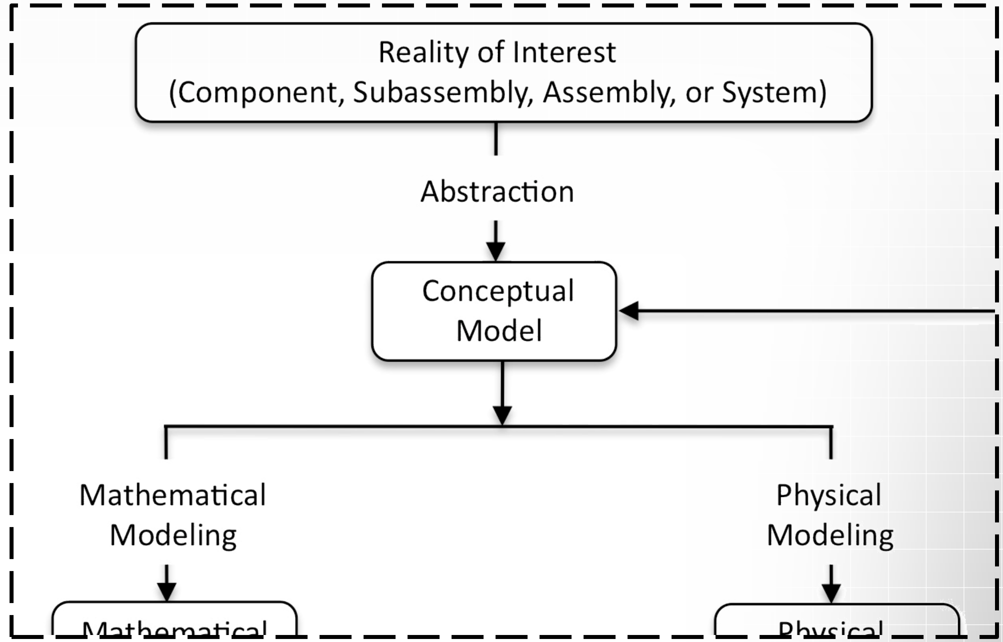
Verification and validation



From ASME/NAFEMS *What is?* Guide.

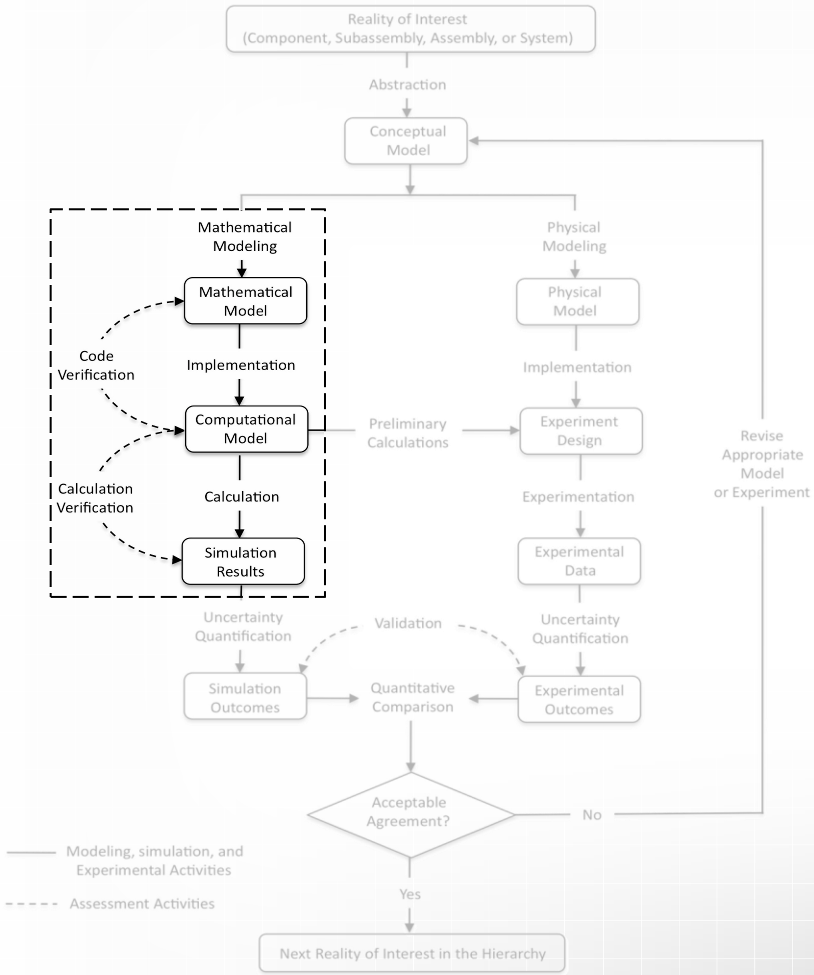
Verification and validation

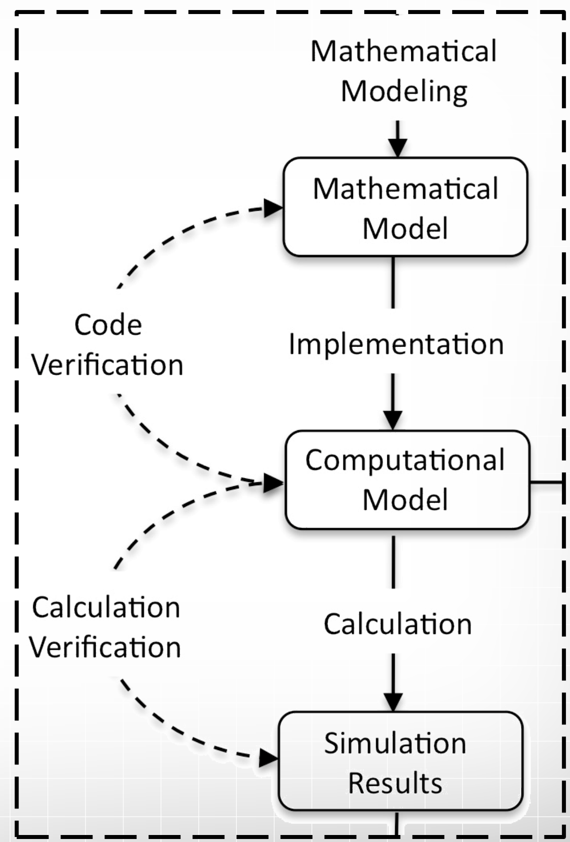




From ASME/NAFEMS *What is?* Guide.

Verification and validation





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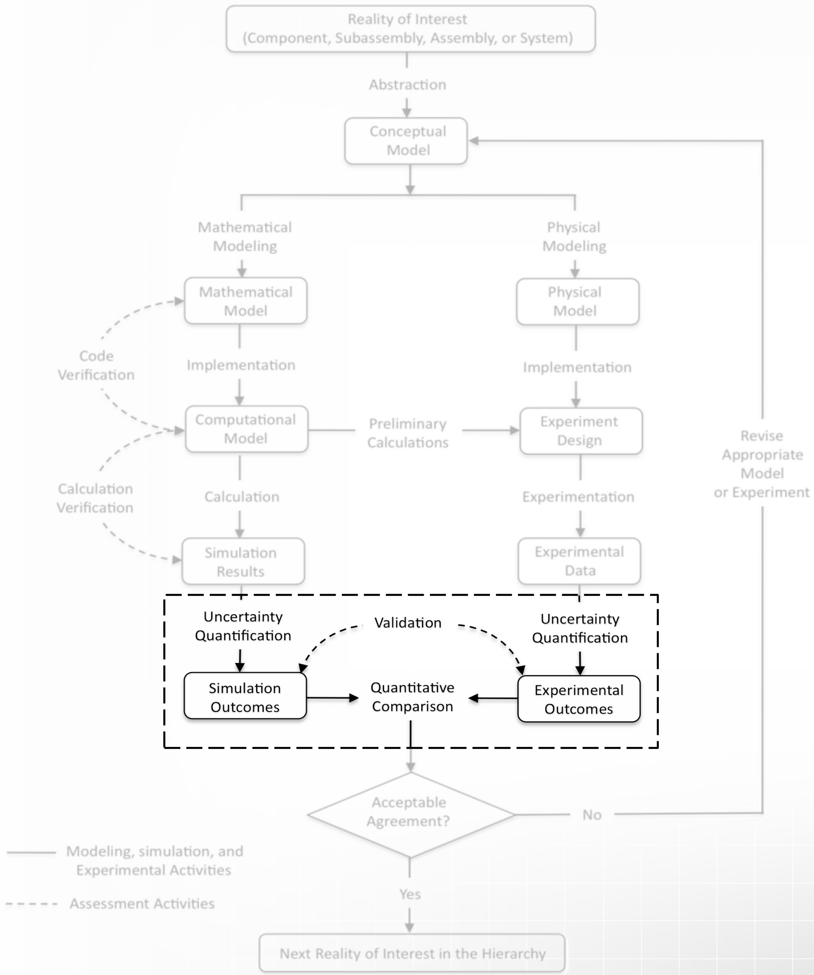
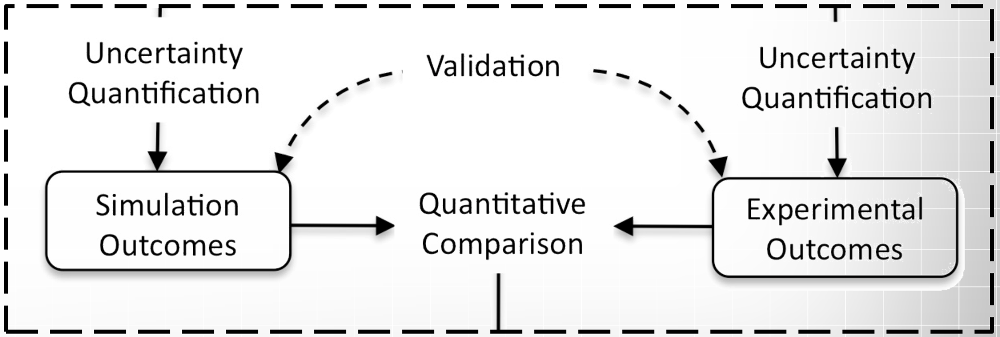
Verification and validation





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Verification and validation

- One of the major benefits of CFD and FEA is that they are *first principles* approaches, which enables a large degree of flexibility on the applications to which it can be applied
- However… with this flexibility come great responsibility
- Generally, code verification is the responsibility of the software vendor, but also, ultimately with the analyst/engineer
- The abstraction and derivation of the mathematical model, calculation verification and validation is entirely the responsibility of the analyst/engineer
- For the explosion specific codes, the vendors also take on the responsibility of calculation verification and validation.

Verification and validation

- Often, the issue is not whether CFD or FEA can model something – it's the validation of the approach for the application of interest which is crucial
- It's important to recognise the envelope of applicability for the tools used and choose an appropriate **fit for purpose** tool for the application of interest
- Do not blame CFD and FEA software tools if they don't yield a useful prediction
  - They are verified for solving equations, so if they yield dubious predictions it's probable that the conceptual model has not been correctly defined, or the simulation workflow has not been verified by the analyst.

Agenda

- Introduction
- Why use CFD in the oil and gas sector?
  - Technical safety
  - Flow assurance
  - Subsea hydrodynamics
- Application specific CFD codes
- Verification and validation
- Consistency across the industry
- Summary.

Consistency across the industry

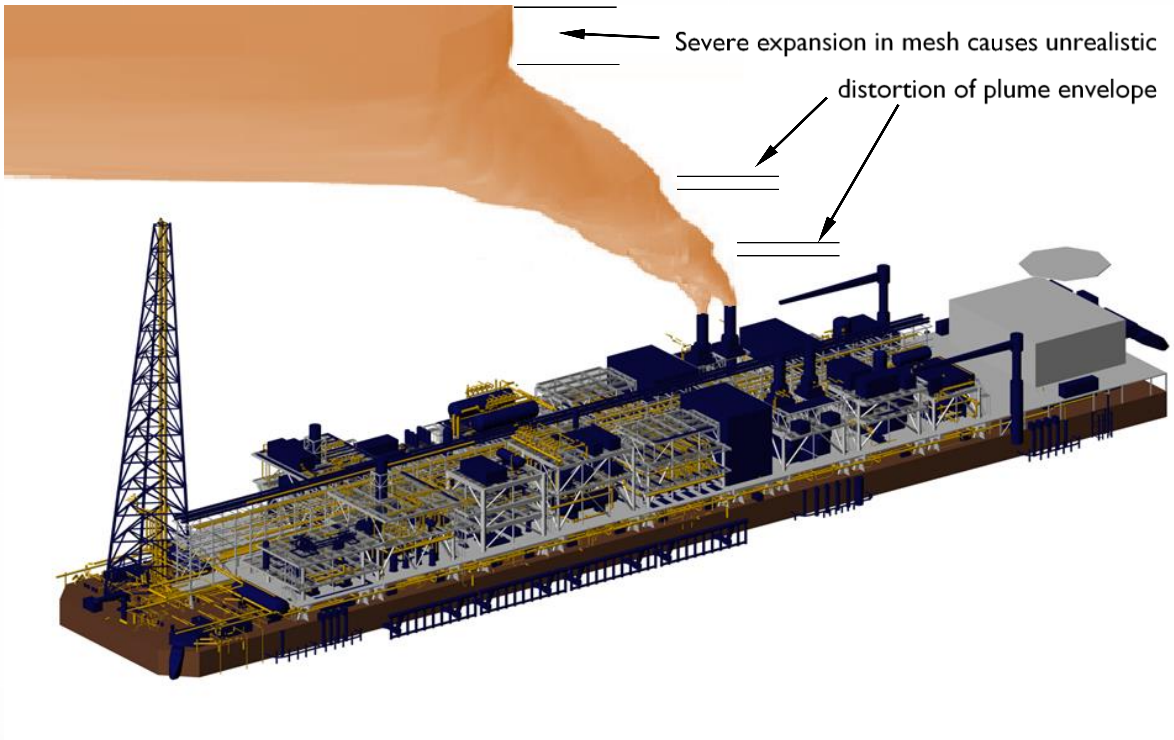
- CFD is becoming increasingly used in the oil and gas sector as the benefits of the approach in terms of improved insight and better understanding of flow phenomena are realized
- However, there is currently little detailed practical guidance for how to use CFD within the sector, so each practitioner has had to develop their own analysis methodologies over the years
- Whilst there might be high-level agreement within industry regarding the general approach for many routine applications, the **devil is in the detail** – inevitably there must be **inconsistency**
- An approach that is considered to be routine for one industry may not be appropriate for another industry.

Consistency across the industry

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

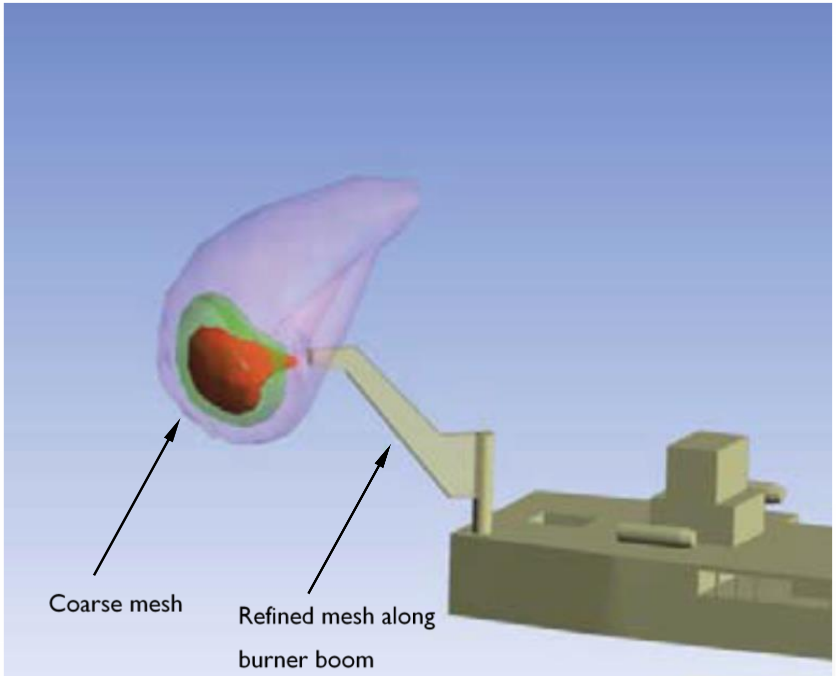
Consistency across the industry

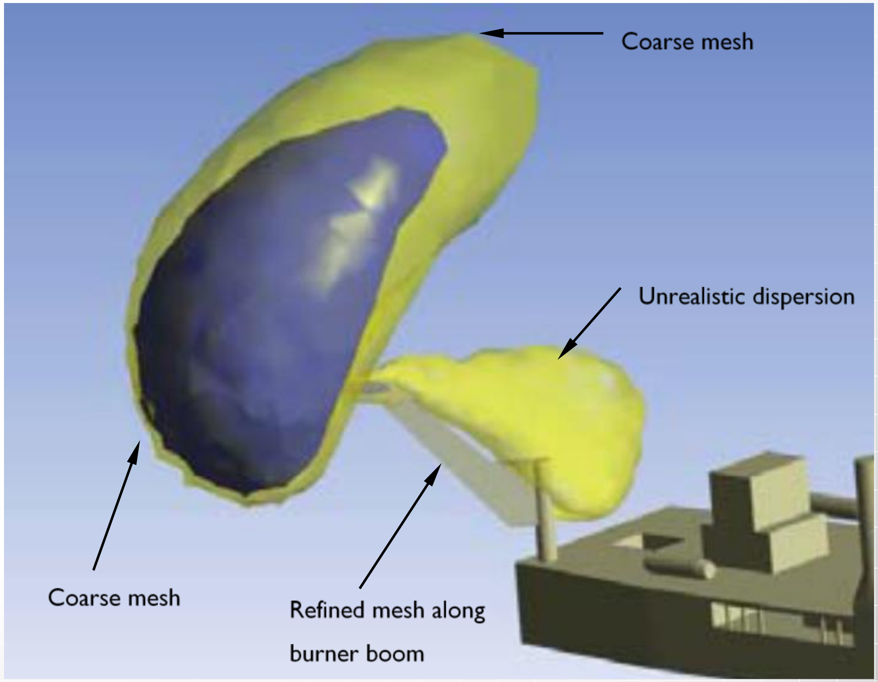
Atmospheric dispersion – examples of poor practice



Consistency across the industry

Atmospheric dispersion – examples of poor practice





Consistency across the industry

Atmospheric dispersion – blind benchmark exercise


INERIS

Guide de Bonnes Pratiques pour la réalisation de modélisations 3D pour des scénarios de dispersion atmosphérique en situation accidentelle

Rapport de synthèse des travaux du Groupe de Travail National

GT3D DISPERSION

N° de version	Date	Commentaire
1.0	Juillet 2015	Première version publiée Ref : DRA-15-148997-06852A

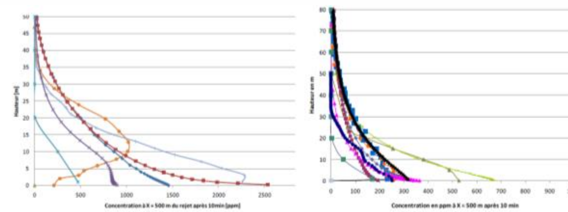


Figure 12 : Exemples de résultats obtenus sur le cas n°1. A gauche, concentration en ammoniac à 500 m en aval du point de rejet après 10 minutes pour une classe de vent F3 – A droite, concentration en propane à 500 m en aval du point de rejet après 10 minutes pour une classe de vent D5.

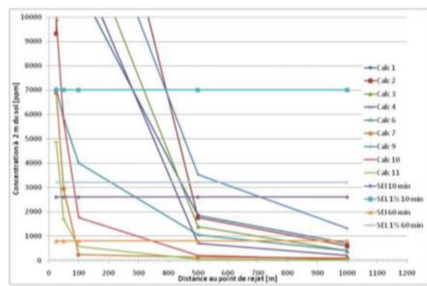


Figure 13 : Distances d'effet obtenues par les différentes modélisations.

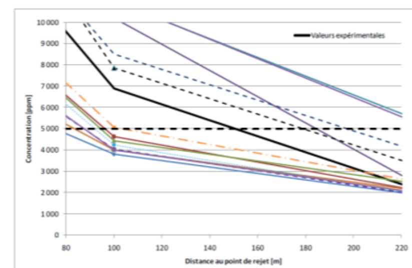
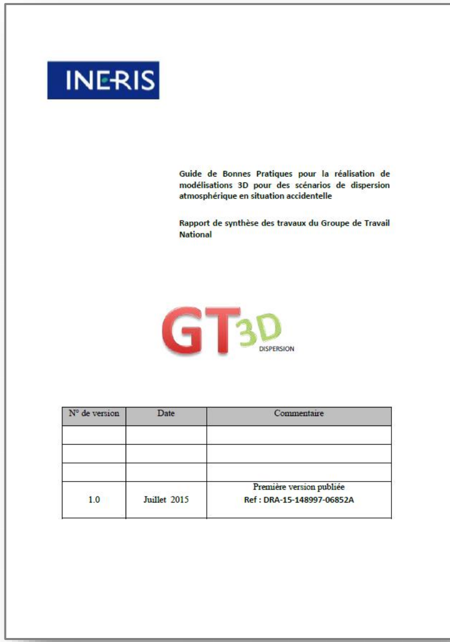


Figure 18 : Relation concentration, distance d'effets, zoom sur la courbe de la Figure 17 pour des valeurs de concentration de 5 000 ppm.

https://aida.ineris.fr/sites/default/files/gesdoc/86009/Guide_Bonnes_Pratiques.pdf

Consistency across the industry

Atmospheric dispersion – blind benchmark exercise


INERIS

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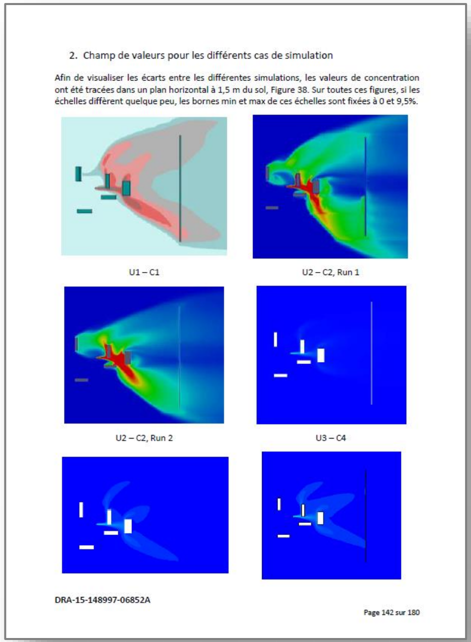
2. Champ de valeurs pour les différents cas de simulation

Afin de visualiser les écarts entre les différentes simulations, les valeurs de concentration ont été tracées dans un plan horizontal à 1,5 m du sol, Figure 38. Sur toutes ces figures, si les échelles diffèrent quelque peu, les bornes min et max de ces échelles sont fixées à 0 et 9,5%.

U1 – C1
U2 – C2, Run 1
U2 – C2, Run 2
U3 – C4

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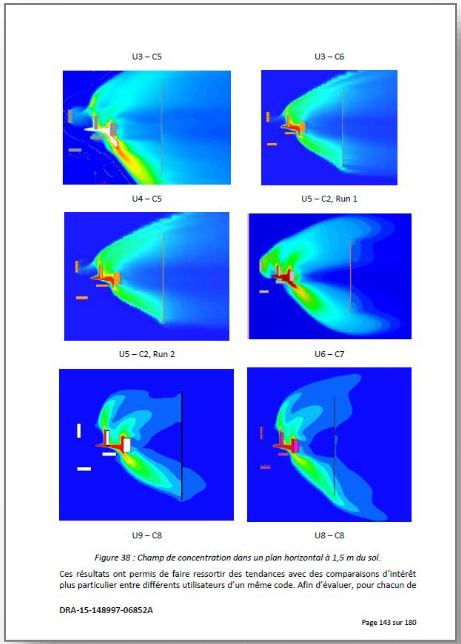
U3 – C5
U3 – C6
U4 – C5
U5 – C2, Run 1
U5 – C2, Run 2
U6 – C7
U9 – C8
U8 – C8

Figure 38 : Champ de concentration dans un plan horizontal à 1,5 m du sol.

Ces résultats ont permis de faire ressortir des tendances avec des comparaisons d'intérêt plus particulier entre différents utilisateurs d'un même code. Afin d'évaluer, pour chacun de

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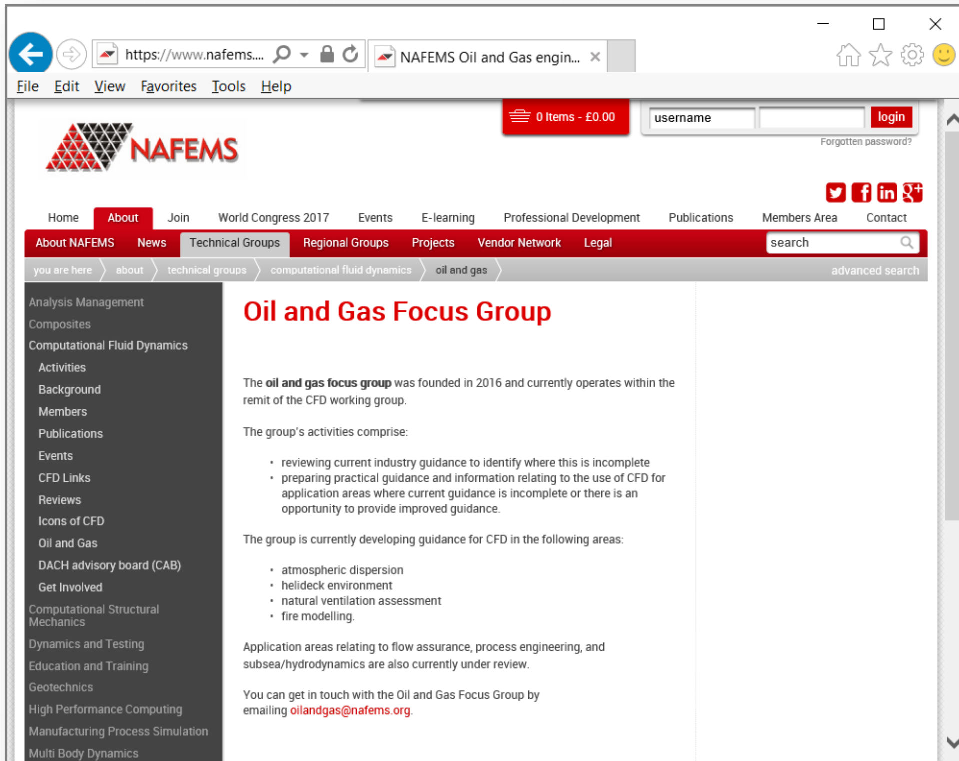
Consistency across the industry



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
  - Blind benchmarking (anonymous) activities within the group
- Open questions are being freely discussed within the group and hopefully new practical guidance will begin to emerge through the coming months.

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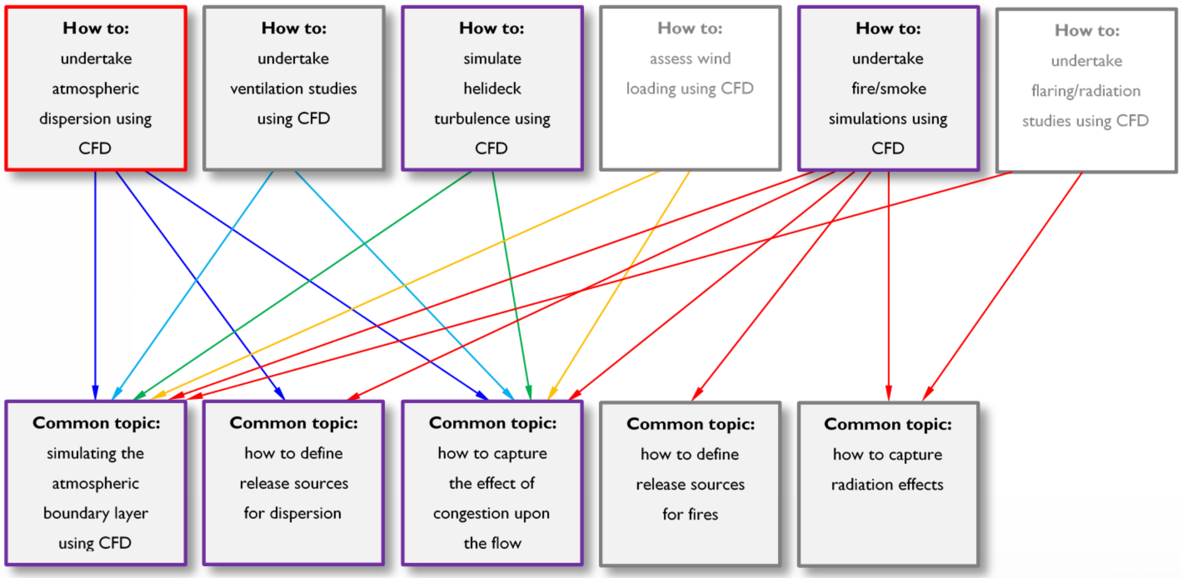
Consistency across the industry

Guidance documentation for technical safety

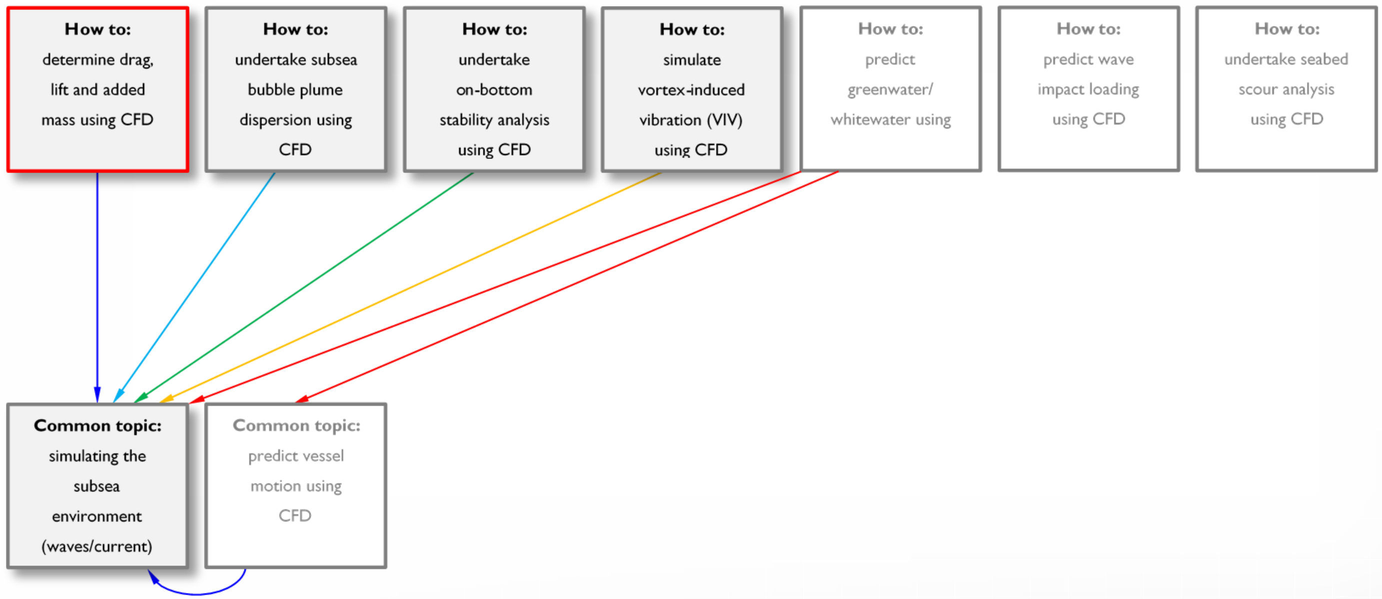


Consistency across the industry

Guidance documentation for flow assurance

Consistency across the industry

Guidance documentation for subsea/hydrodynamics



Consistency across the industry

- Common structure to each guide:
  - Introduction to application area and existing calculation approaches
  - How to use CFD
  - Verification and validation
  - Fit for purpose approach
  - Appendices.
- Each guide provides an opportunity to move towards consensus within the group on the practical details of an analysis
- If we're not able to arrive at a consensus then we're able to identify the open questions, which itself is progress – at least they are documented and something can be done in future.

Agenda

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Summary

- CFD is becoming increasingly used in the oil and gas sector to provide improved insight and understanding
- However, how can we, as an industry, be confident in any of the CFD predictions?
  - Confidence is achieved through verification and validation. Without robust validation, CFD will always remain, for some, simply *colourful fluid dynamics*
- The NAFEMS oil and gas focus group has been established to improve confidence in CFD in the oil and gas sector through blind benchmarking exercises and the preparation of practical, fit for purpose guidance developed through consensus.

Contact us

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