Reducing CAPEX and OPEX in the subsea sector through the use of advanced engineering simulation

Dr Steve Howell – 22nd June 2016

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.

Agenda

- Introduction
- Case studies
  - Hydrodynamic stability of a concrete mattress on a subsea pipeline
  - Thermal cool-down for hydrate avoidance
  - Pigging/sphering through a wye-piece at a new tie-in
  - Subsea bubble plumes following a loss of containment at the sea bed
- Lower cost and open source simulation tools
- Verification and validation
- Simulation data management
- Summary.

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Introduction

- In the current lower oil price environment it is increasingly necessary for companies to collaborate and innovate to reduce capital and operating expenditures
- Now is the time to invest in research and development to deliver improved performance and reduced costs
- This is particularly relevant to the subsea sector where a shift from topsides facilities to the subsea domain may deliver real benefits, particularly within the UKCS.

Introduction

- Advanced engineering simulation approaches including computational fluid dynamics (CFD) and finite element analysis (FEA) are being used increasingly within the subsea sector
- CFD and FEA are used:
  - To deliver valuable insight at the design stage
  - To provide improved understanding of installation and operational issues
  - To demonstrate technology readiness for novel products and approaches
- This presentation will introduce some case studies showing the application of CFD within the subsea sector
- Just be mindful that CFD and FEA may not always be appropriate – if there are simpler methods that are fit for purpose, use them!

Introduction

- Traditionally CFD and FEA tools have perhaps been considered as high-cost niche simulation tools
- There is now a growing range of lower cost and open source fit for purpose simulation tools emerging that can be successfully employed within the subsea sector
- It is Abercus' expectation that open source simulation tools will become increasingly used in future and this will accelerate the democratisation of advanced simulation methods
- Whilst this is a massive opportunity for our industry, we need to be rigorous with respect to **verification and validation**.

Introduction

- Our case studies will show the kind of information and value you can get through the use of advanced simulation, and we hope that this presentation will act as an incentive for you to investigate these methods further for yourselves

- **As an industry, now is the time to be developing and improving our advanced simulation capabilities**
- **Low cost and open source tools will accelerate the democratisation of advanced simulation methods.**

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Case studies – hydrodynamics

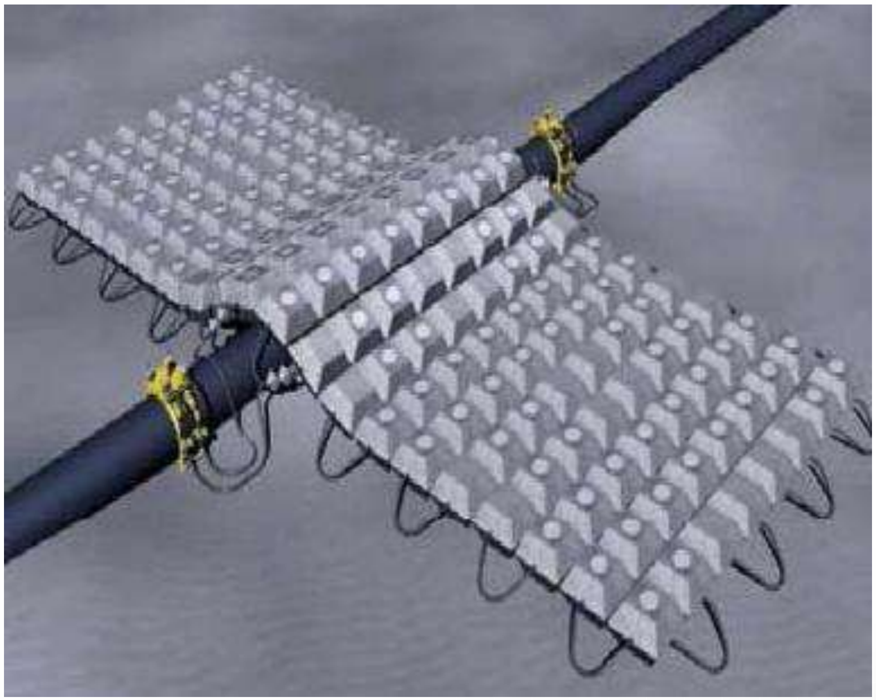
- CFD can be used to predict the drag, lift and added mass for complex geometries (and for simple geometries too, but there may be correlations that are more appropriate for simple cases)
- This can be used to predict overturning moments in order to assess on-bottom stability for subsea structures and underwater vehicles.

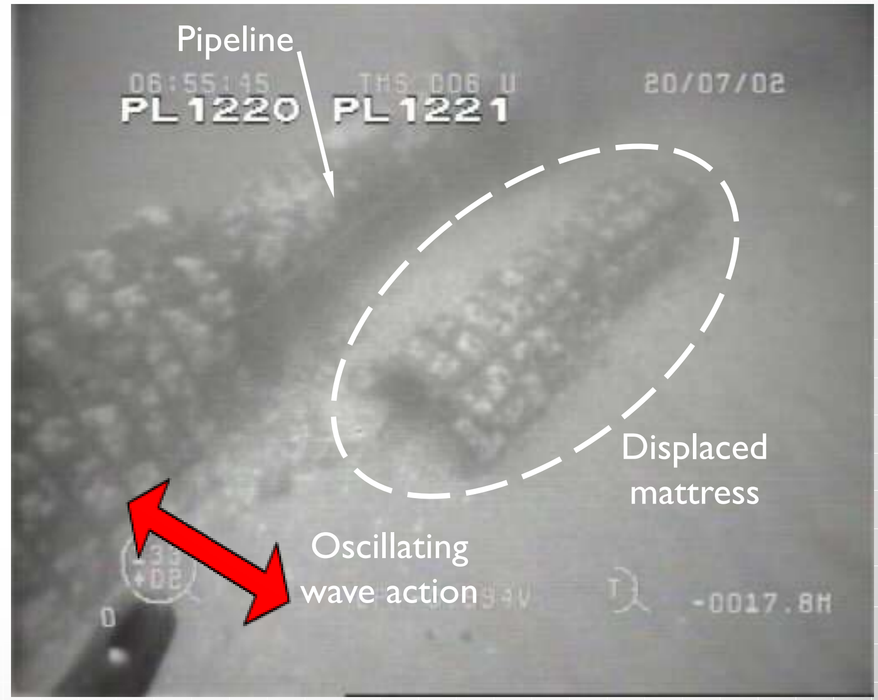
Case studies – hydrodynamics

- The current case study relates to a new pipeline which was to be installed on the sea bed and be protected by a series of concrete mattresses along its length
- Whilst this is a recognised engineering solution for providing protection and additional stability, there have been several instances where mattresses have been found to be displaced from the pipeline due to environmental loading (see overleaf)
- For the current case study, the CFD approach was used to assess the on-bottom stability of the concrete mattresses under wave/tide loading for several alternative mattress configurations.

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

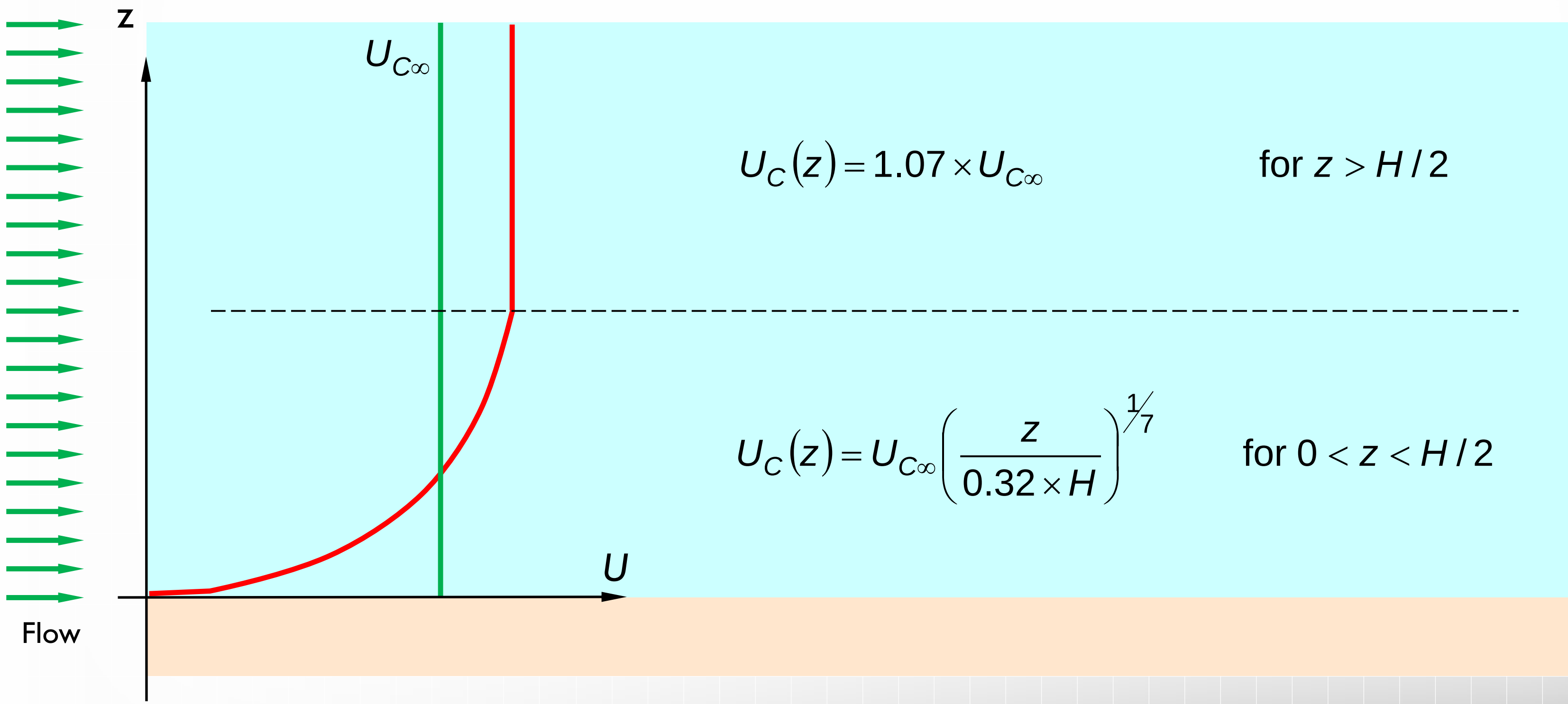




Case studies – hydrodynamics

On-bottom stability of a concrete mattress

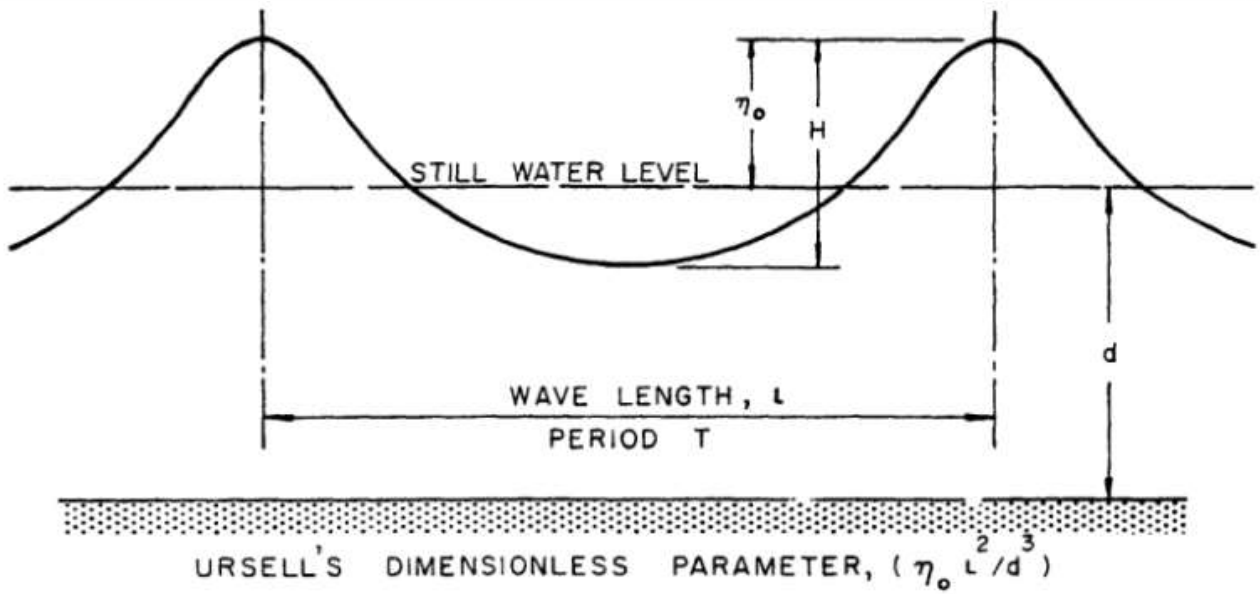
Loading/boundary conditions – tide loading



Case studies – hydrodynamics

On-bottom stability of a concrete mattress

Loading/boundary conditions – wave loading

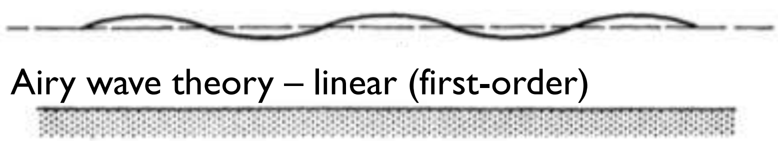


Hydrodynamics of offshore structures, Chakrabarti SK, WIT Press

Case studies – hydrodynamics

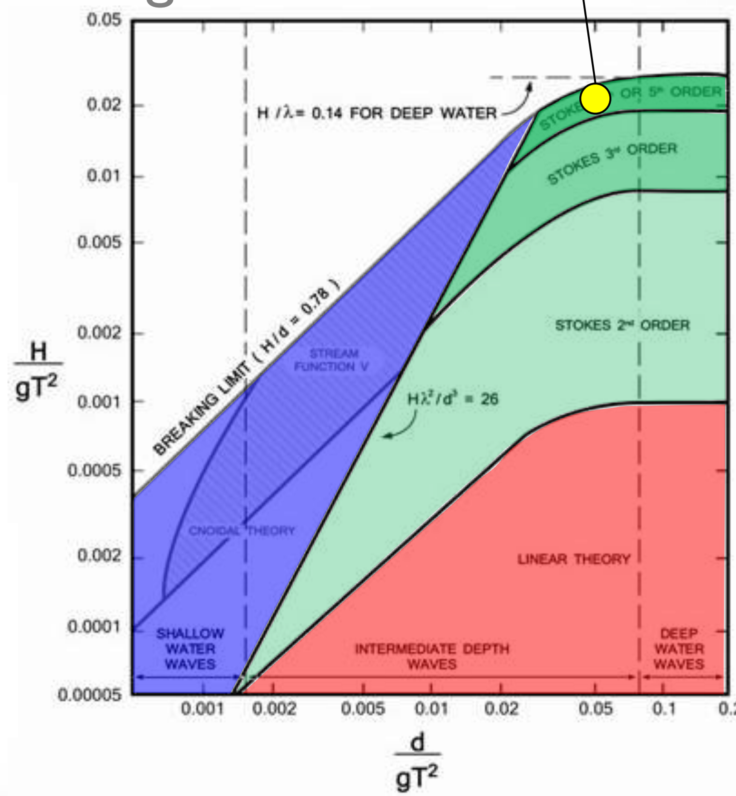
On-bottom stability of a concrete mattress

Loading/boundary conditions – wave loading



Airy wave theory – linear (first-order)

Typical wave condition from the MetOcean data for the site



Le Mehaute (1976) and USACE (2008)

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

Loading/boundary conditions – wave loading

A Fifth-Order Stokes Theory

A Fifth-Order Stokes Theory for Steady Waves

By John D. Fenton[1]

Abstract: An alternative Stokes theory for steady waves in water of constant depth is presented where the expansion parameter is the wave steepness itself. The first step in application requires the solution of one nonlinear equation, rather than two or three simultaneously as has been previously necessary. In addition to the usually specified design parameters of wave height, period and water depth, it is also necessary to specify the current or mass flux to apply any steady wave theory. The reason being that the waves almost always travel on some finite current and the apparent wave period is actually a Doppler-shifted period. Most previous theories have ignored this, and their application has been indefinite, if not wrong, at first order. A numerical method for testing theoretical results is proposed, which shows that two existing theories are wrong at fifth order, while the present theory and that of Chappelear are correct. Comparisons with experiments and accurate numerical results show that the present theory is accurate for wavelengths shorter than ten times the water depth.

The solution to the steady wave problem is as follows:

in which the mean horizontal fluid speed, $\bar{u}$, is given by

The Landau order symbol $0(\epsilon^n)$ means that neglected terms are of the order of ϵ^n. It should be pointed out that $\bar{u}$ is the quantity usually referred to as the "wave speed" in presentations of wave theory, which is Stokes' first definition of wave speed. It is numerically equal to the wave speed only relative to a frame in which the mean current is zero. This will be further examined in the following.

The expression for the free surface profile is

while the expansion for the volume flux under the wave is

and that for the Bernoulli constant is

221

TABLE 1.—Formulas for Coefficients in Fifth-Order Solution, Eqs. 12–16

In terms of hyperbolic functions of kd, including S = sech $2kd$.

http://johndfenton.com/Papers/Fenton85d-A-fifth-order-Stokes-theory-for-steady-waves.pdf

http://johndfenton.com/Papers/Fenton90b-Nonlinear-wave-theories.pdf

http://johndfenton.com/Steady-waves/Fourier.html

Case studies – hydrodynamics

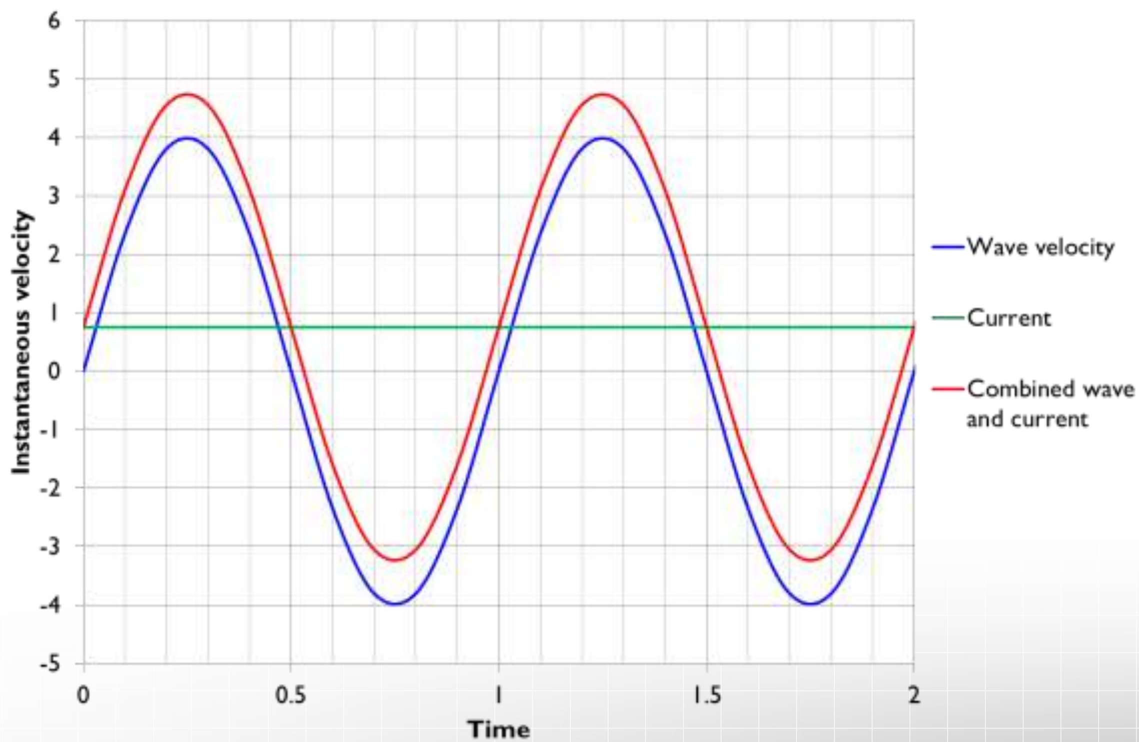
On-bottom stability of a concrete mattress

Loading/boundary conditions – wave loading

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

Loading/boundary conditions – combined tide and wave loading

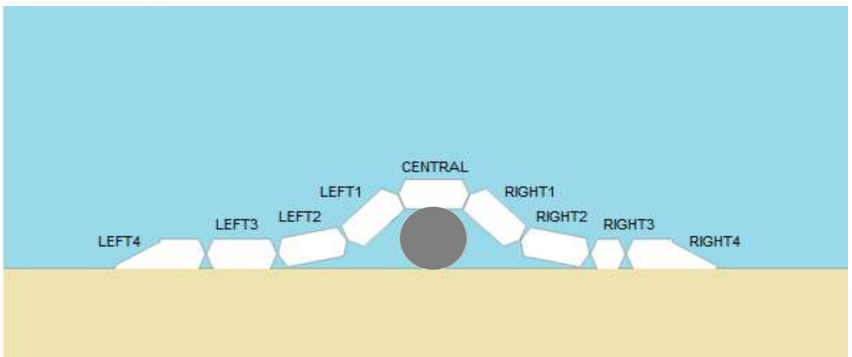


Case studies – hydrodynamics

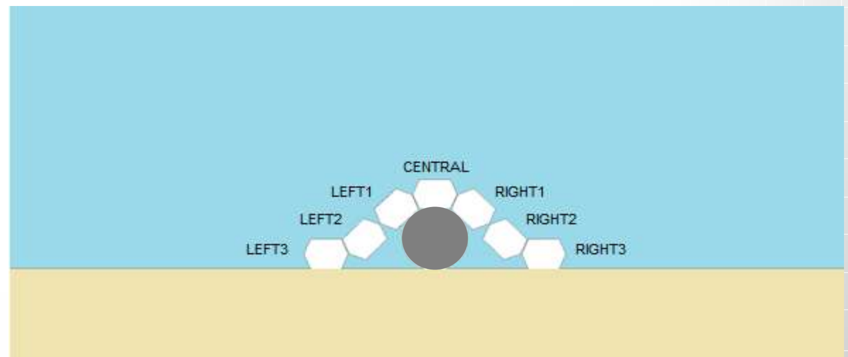
On-bottom stability of a concrete mattress

Alternative mattress configurations to consider

Installed laterally



Installed longitudinally



Case studies – hydrodynamics

On-bottom stability of a concrete mattress

CFD approach

- A 2D slice through the pipeline/mattress geometry was simulated
- Incompressible flow was assumed – solved for pressure, two components of velocity and turbulence (k and ε)
- A transient approach was required to capture the oscillating wave motion
  - Ten wave cycles were allowed
  - Predictions reported for the tenth cycle
- The instantaneous pressure and skin friction force was monitored on each mattress element to predict associated forces and overturning moments.

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

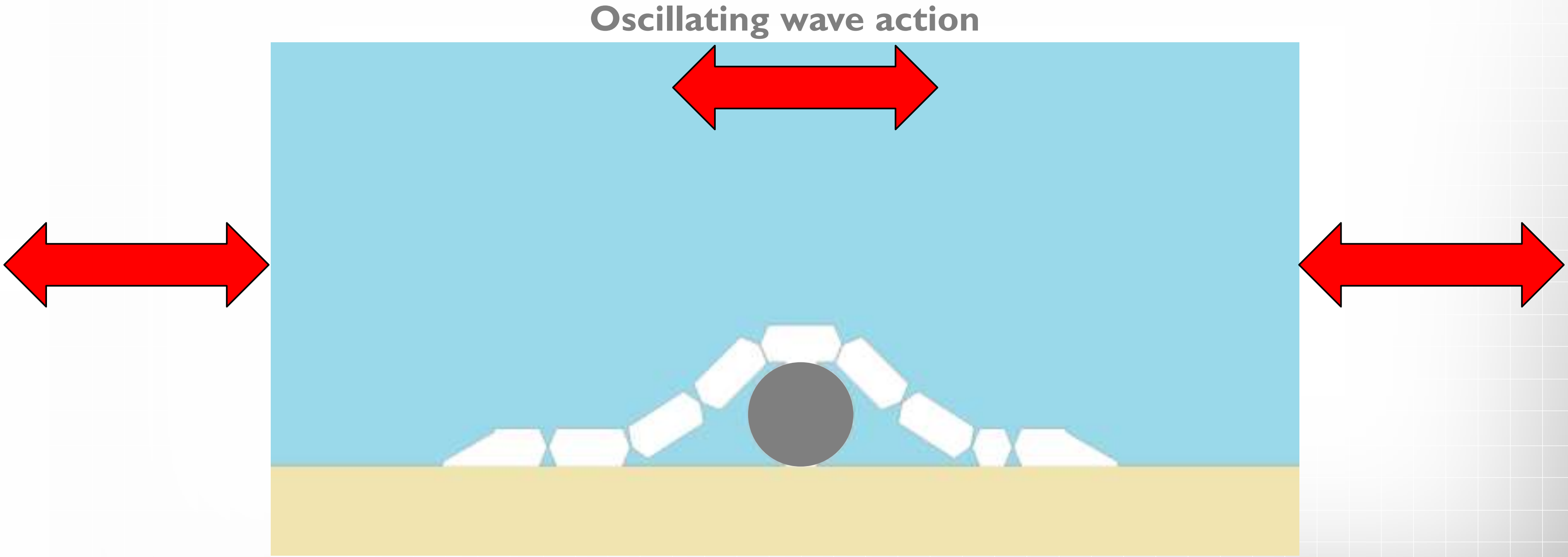
CFD approach

- Oscillating velocity profiles were imposed around far boundaries
  - The velocity profiles combined tide and wave loading and their variation with height above the sea bed
  - The wave motion was calculated according to Fenton (5^{th} order)
  - Boundary profiles were programmed in C
- The far boundaries were sufficiently far away so that their proximity did not influence the flow of interest
- Free-surface effects were ignored.

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

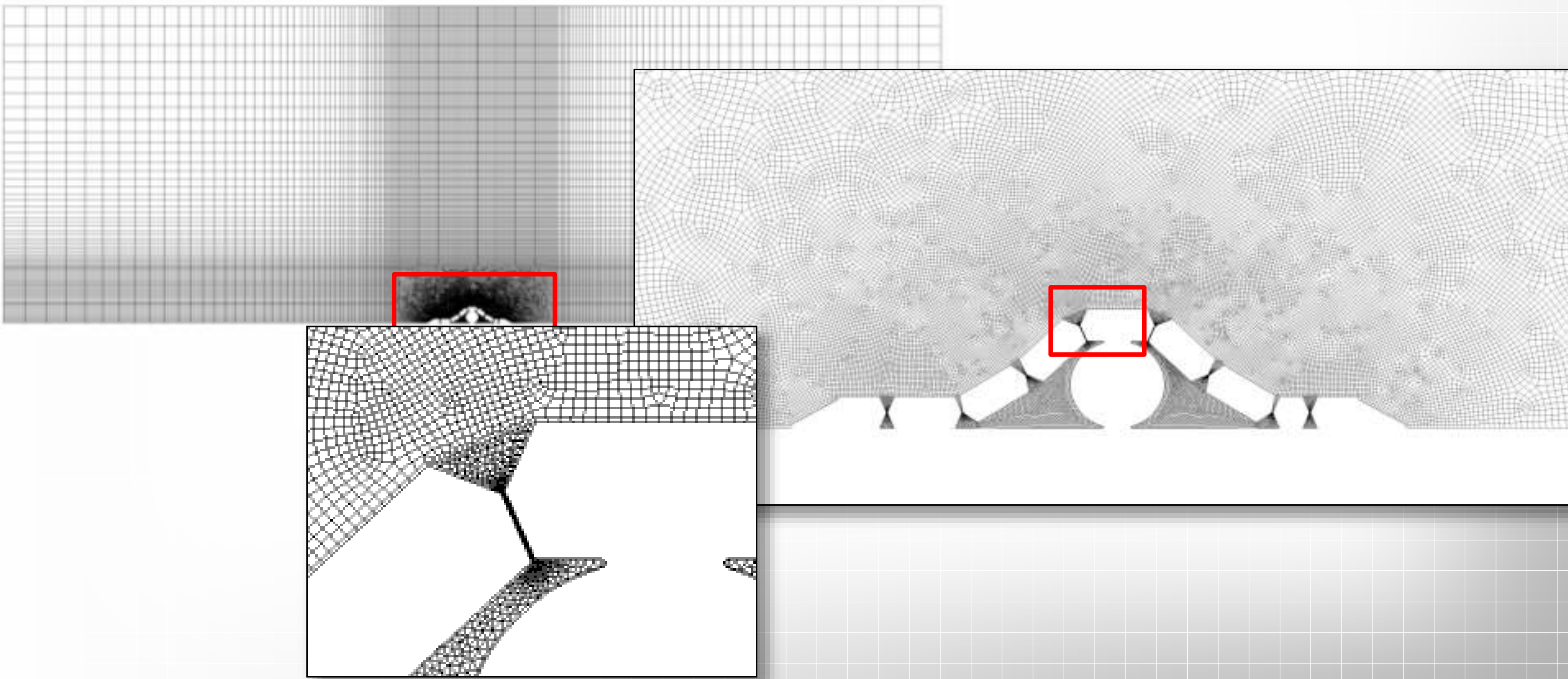
CFD approach



Case studies – hydrodynamics

On-bottom stability of a concrete mattress

CFD mesh



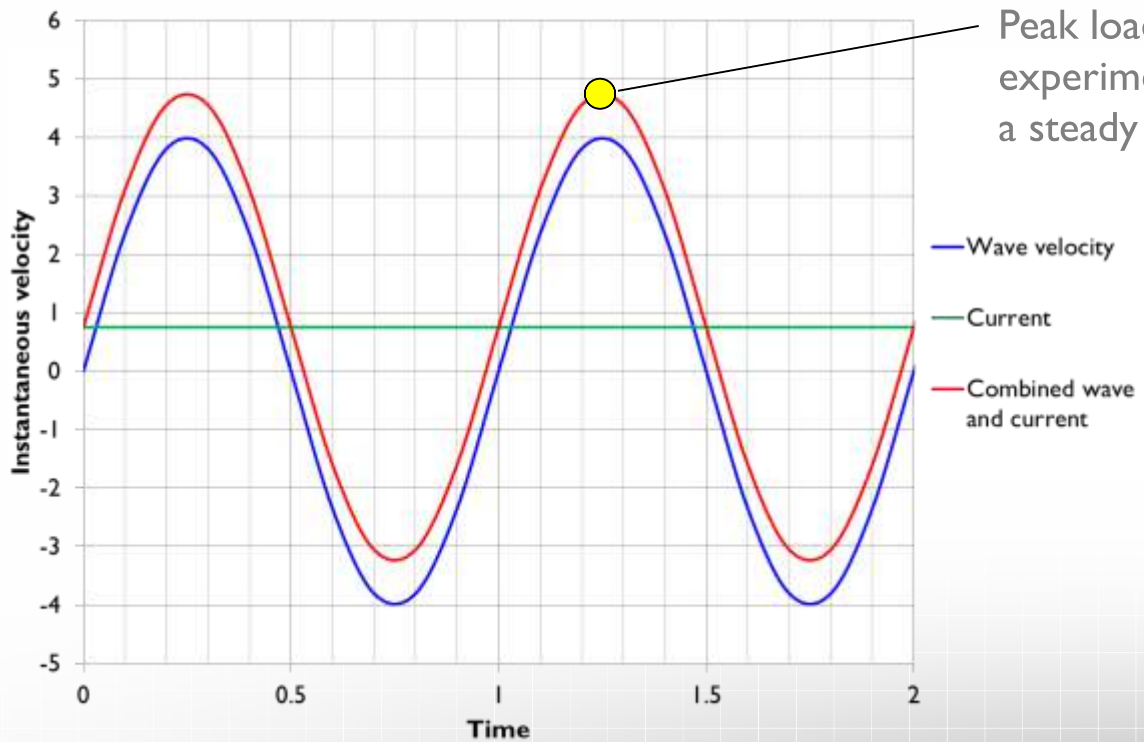
Case studies – hydrodynamics

On-bottom stability of a concrete mattress

- Previous experimental work considering a scaled model submerged in a flume tank
- However, the experimental set-up did not consider transient wave loading – only the maximum loading (corresponding to the sum of the maximum wave speed plus the maximum current) was considered, applied as a steady flow within the flume tank

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

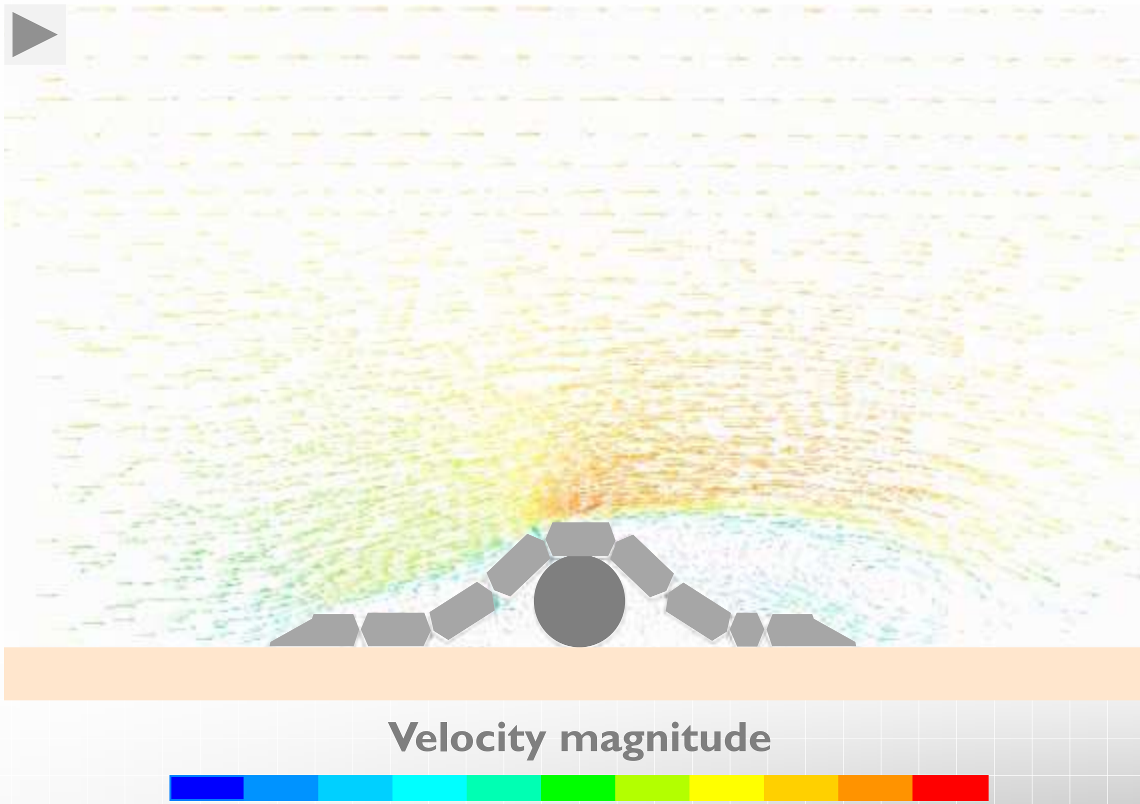


Peak loading used for previous experimental studies – applied as a steady load in the flume tank

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

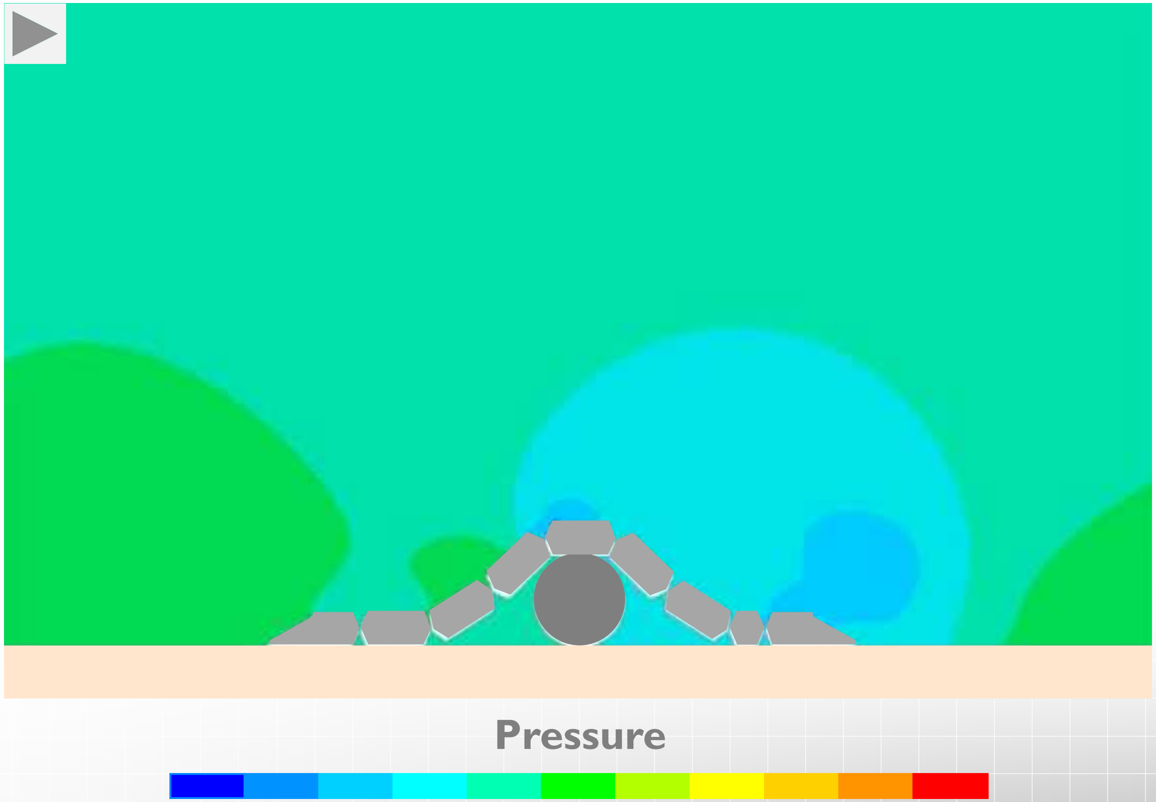
CFD predictions



Case studies – hydrodynamics

On-bottom stability of a concrete mattress

CFD predictions



Case studies – hydrodynamics

On-bottom stability of a concrete mattress

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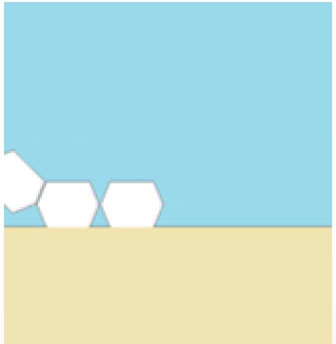
- However, the experimental set-up did not consider transient wave loading – only the maximum loading (corresponding to the sum of the maximum wave speed plus the maximum current) was considered, applied as a steady flow within the flume tank
- **The CFD predictions showed that transient effects were the significant factor.**

Case studies – hydrodynamics

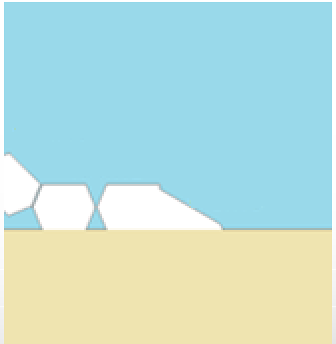
On-bottom stability of a concrete mattress

- The CFD predicted that forces and overturning moments could be reduced if:
  - The mattresses were installed laterally
  - Tapered elements were used at the leading edge.

Without taper



With taper



Case studies – hydrodynamics

On-bottom stability of a concrete mattress

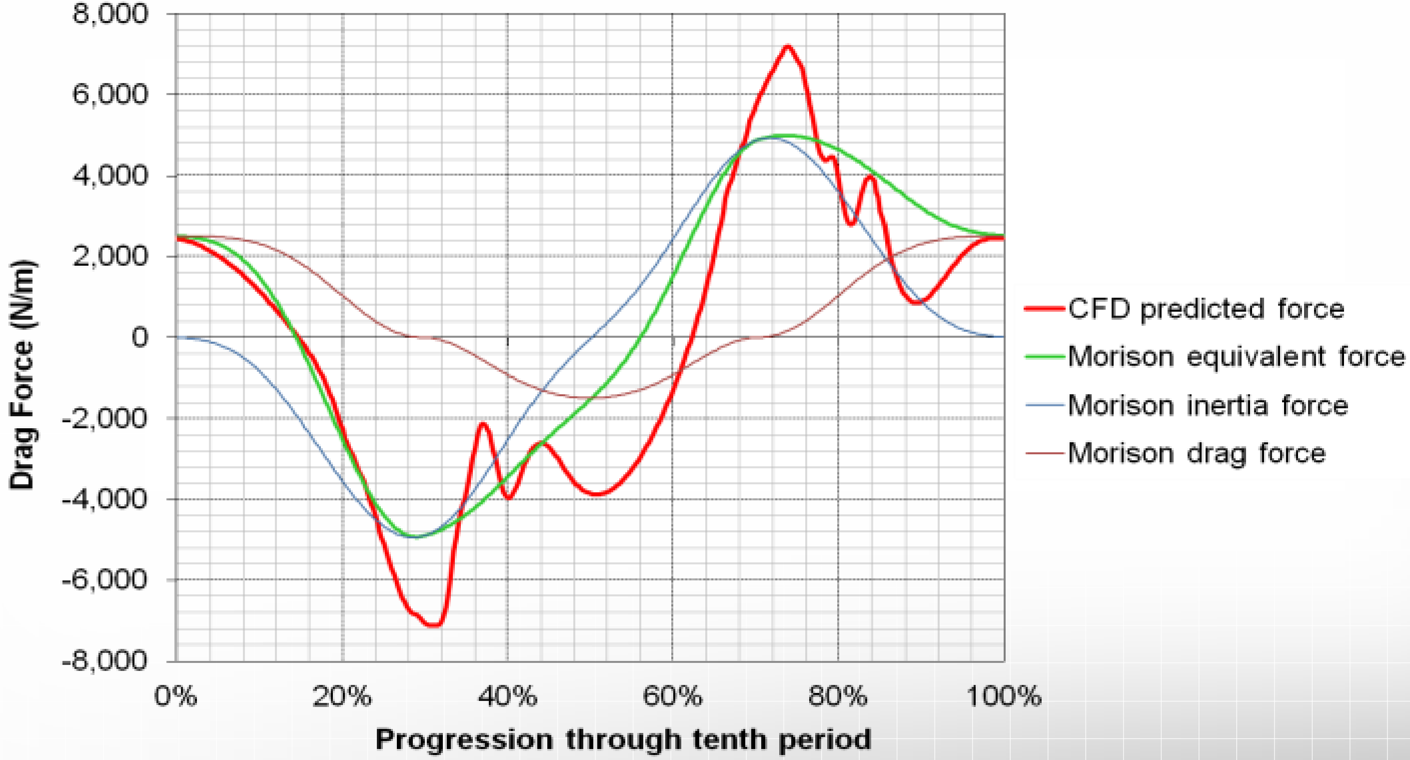
Morison equivalent force

- An approximate Morison equivalent force was fitted to the CFD predicted force in order to allow the drag and added mass coefficients for the mattress to be determined (see overleaf)
- However, it is clear that the agreement between the Morison equivalent force and the CFD predicted force is limited, which demonstrates that **the Morison equation is probably not valid for the mattress geometry considered**
- (But engineers prefer to use tools that are familiar to them, such as the Morison equation/approximation).

Case studies – hydrodynamics

On-bottom stability of a concrete mattress

Morison equivalent force



Case studies – hydrodynamics

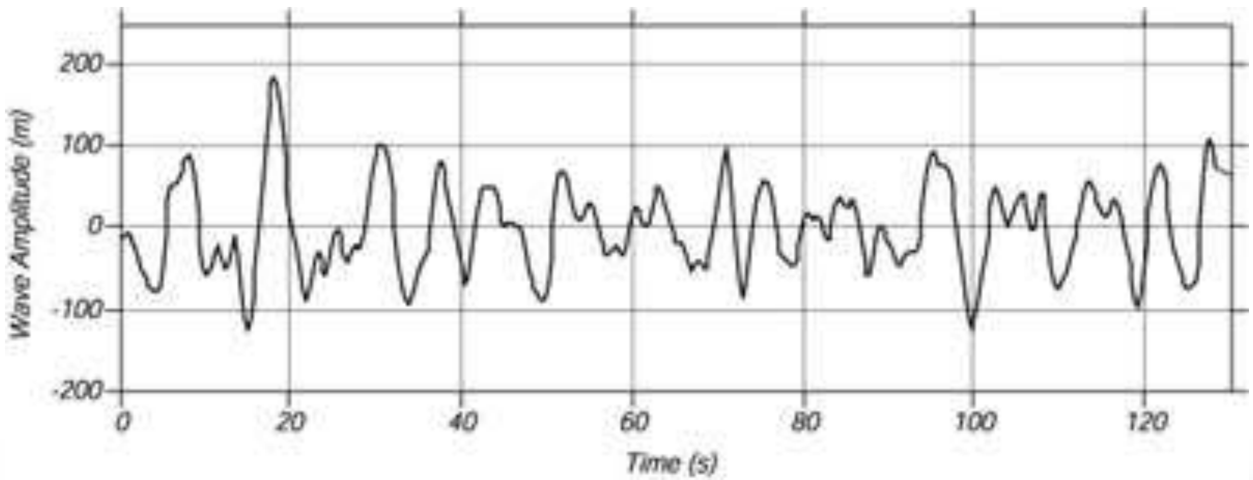
On-bottom stability of a concrete mattress

- Fitness for purpose?
  - Two-dimensional approximation – three-dimensional simulation would include additional gaps between mattress elements, which should relieve pressures and reduce lift
  - Fixed CFD mesh cannot capture dynamics effects and movement of individual mattress elements – even if the instantaneous lift exceeds the submerged weight of an individual element, it may not be sustained for long enough to displace it significantly
  - Wave loading – should a realistic wave train have been used? How likely is it for ten 1/100yr waves to arrive in sequence?

Case studies – hydrodynamics

Loading/boundary conditions – realistic wave trains

- Generally a sequence or train of identical waves do not occur
- Realistic wave trains are chaotic and combine waves through a continuous spectrum of length scales



http://www.wikiwaves.org/Waves_and_the_Concept_of_a_Wave_Spectrum

Case studies – hydrodynamics

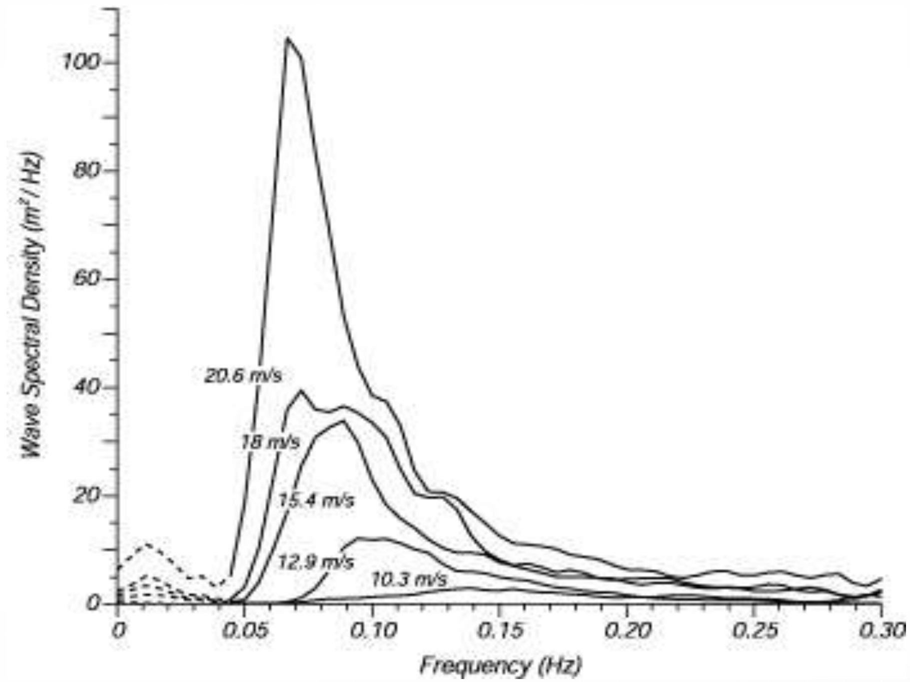
Loading/boundary conditions – realistic wave trains

- Generally a sequence or train of identical waves do not occur
- Realistic wave trains are chaotic and combine waves through a continuous spectrum of length scales
- Realistic wave trains are typically described by an energy spectrum that describes the wave spectral density and its frequency of occurrence:
  - Pierson-Moskowitz Spectrum (1964)
  - JONSWAP (1973)
- From these wave spectra it is possible to generate realistic wave behaviour and impose it upon a CFD model.

Case studies – hydrodynamics

Loading/boundary conditions – realistic wave trains

Pierson-Moskowitz (fully-developed sea)

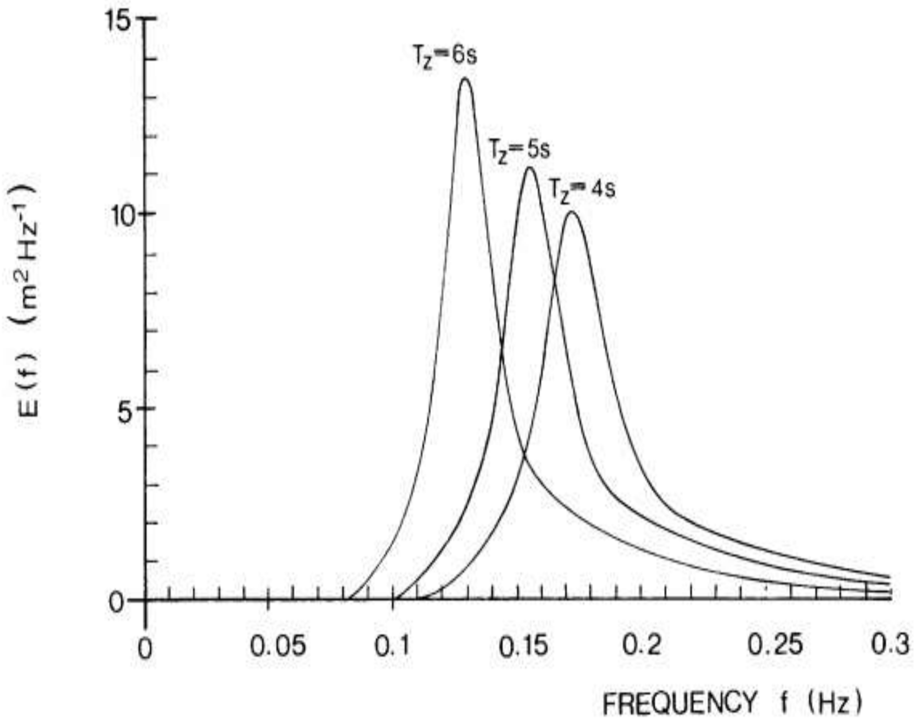


http://www.wikiwaves.org/Ocean-Wave_Spectra

Case studies – hydrodynamics

Loading/boundary conditions – realistic wave trains

JONSWAP – (JOint North Sea WAve Project)



Estimation of wave spectra from wave height and period, Institute of Oceanographic Sciences (1982), http://eprints.soton.ac.uk/14556/1/14556-01.pdf

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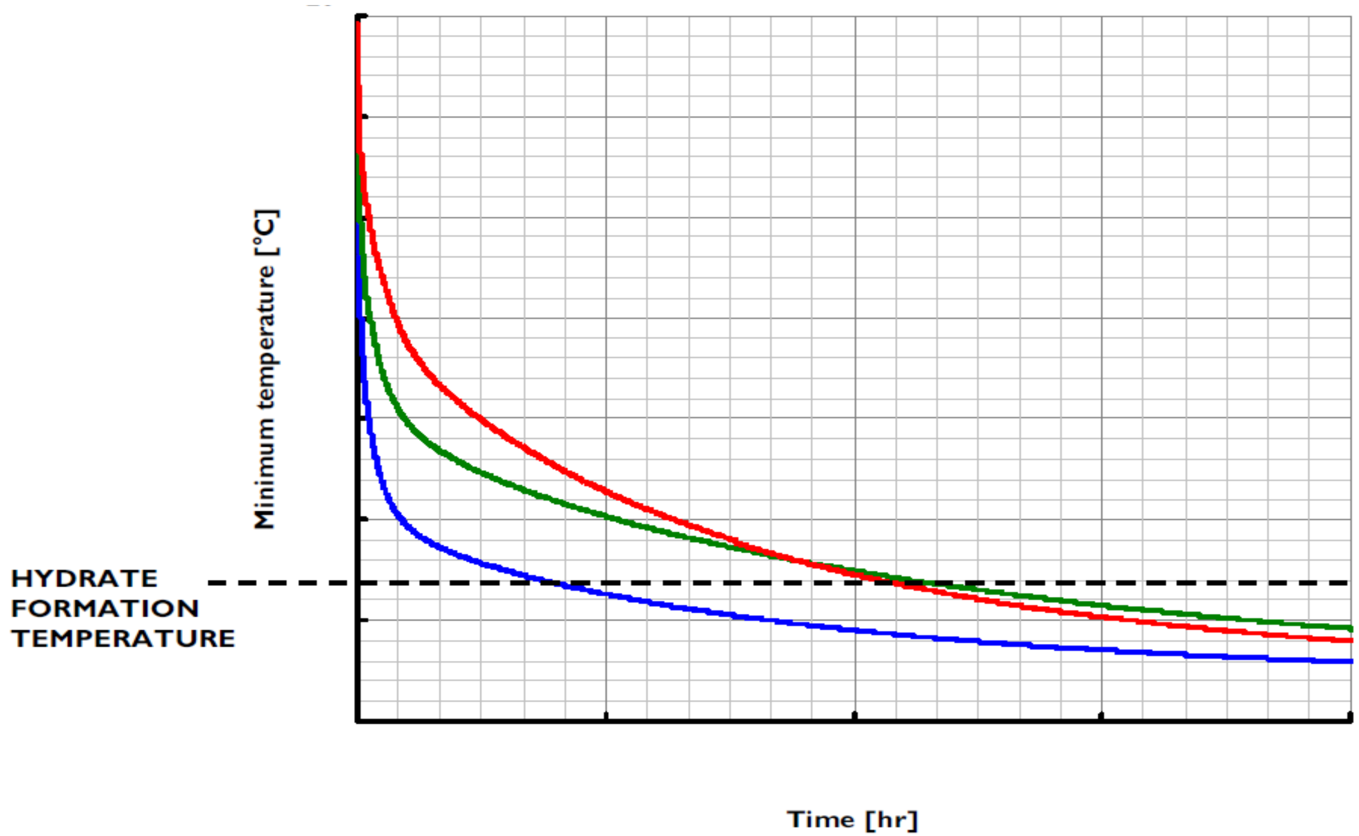
Case studies – thermal performance

Hydrate/wax avoidance

- CFD can be used to predict the thermal behaviour of subsea equipment to assess the risk of hydrate/wax formation
- Usually the temperature field is predicted and compared to the hydrate/wax formation envelope (rather than predicting the actual hydrate/wax formation processes)
- Typically the minimum temperature anywhere within the fluid domain is monitored with time to construct cool-down curves

Case studies – thermal performance

Hydrate/wax avoidance



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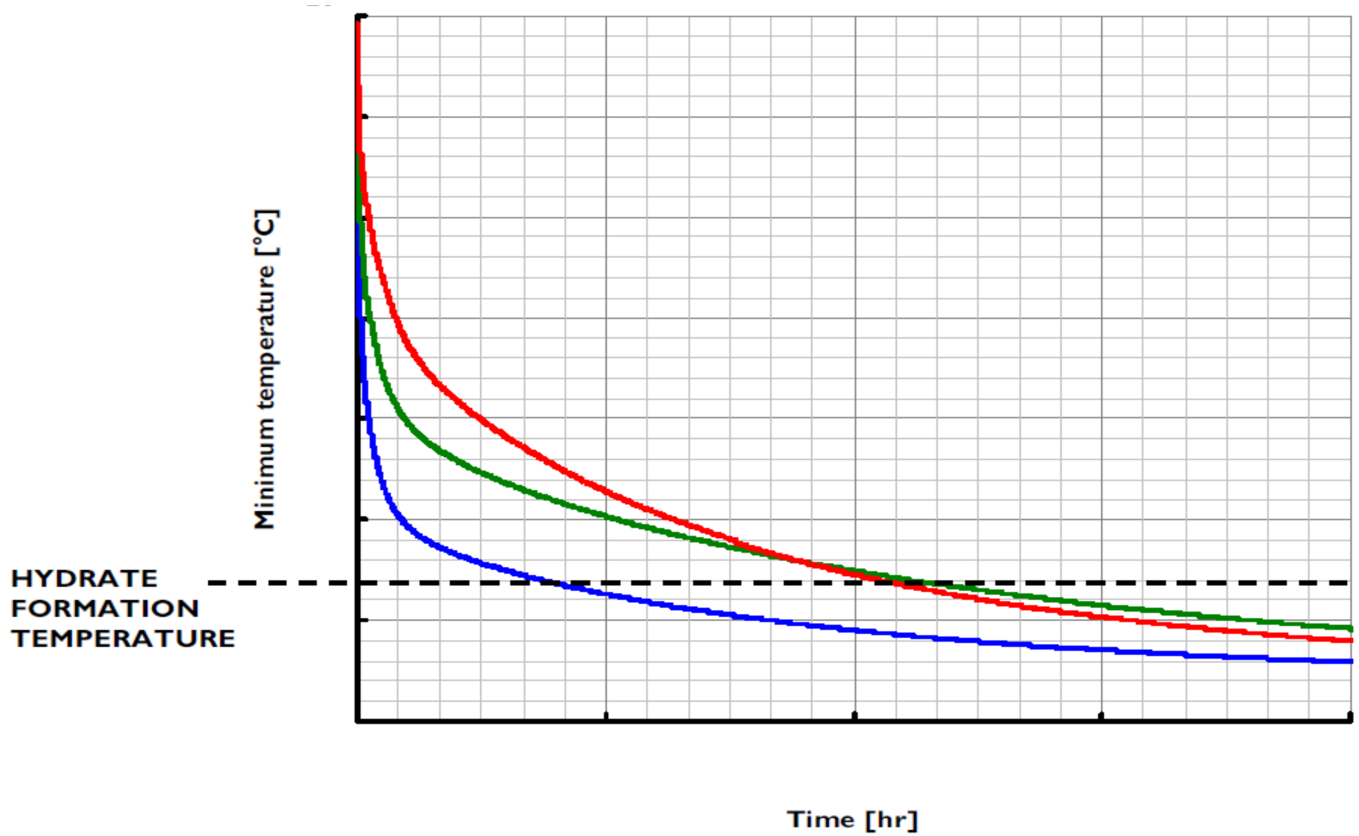
- Typically the minimum temperature anywhere within the fluid domain is monitored with time to construct cool-down curves
- Monitoring the instantaneous volume of fluid below the formation temperature may also provide useful insight.

Case studies – thermal performance

Hydrate/wax avoidance



Case studies – thermal performance

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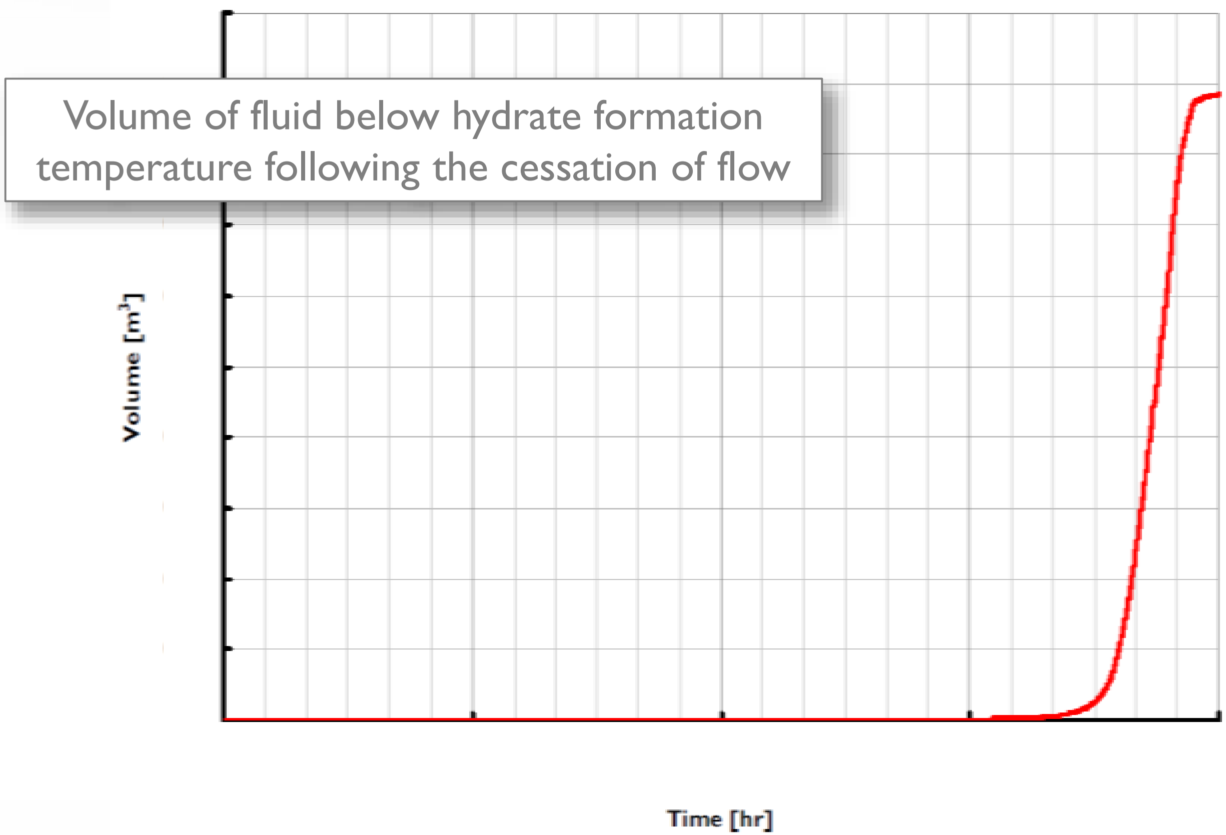


Case studies – thermal performance

Hydrate/wax avoidance

- The following example shows the level of geometrical complexity that can be captured within a CFD model
- Although the *F* in CFD stands for fluid, CFD can also capture solid regions – in fluid regions it is necessary to solve for conduction and convection (and perhaps radiation) but in solid regions only conduction is solved for.

Case studies – thermal performance

Hydrate/wax avoidance

Gasket materi
Casing materia

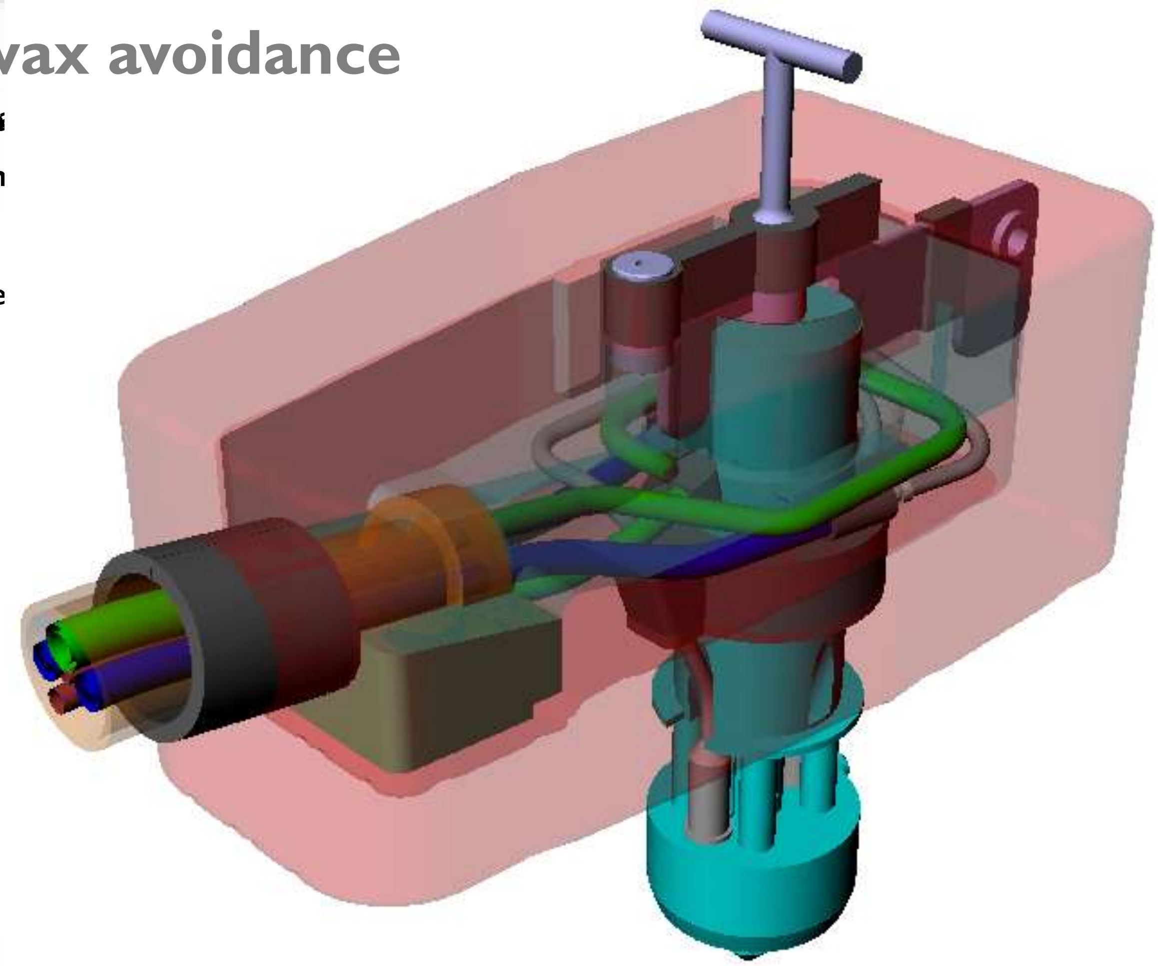
Hot stab chassis n

Carrier pipe

Material – Stainless s

Material – Nylo
with stainless s

Hot stab unit

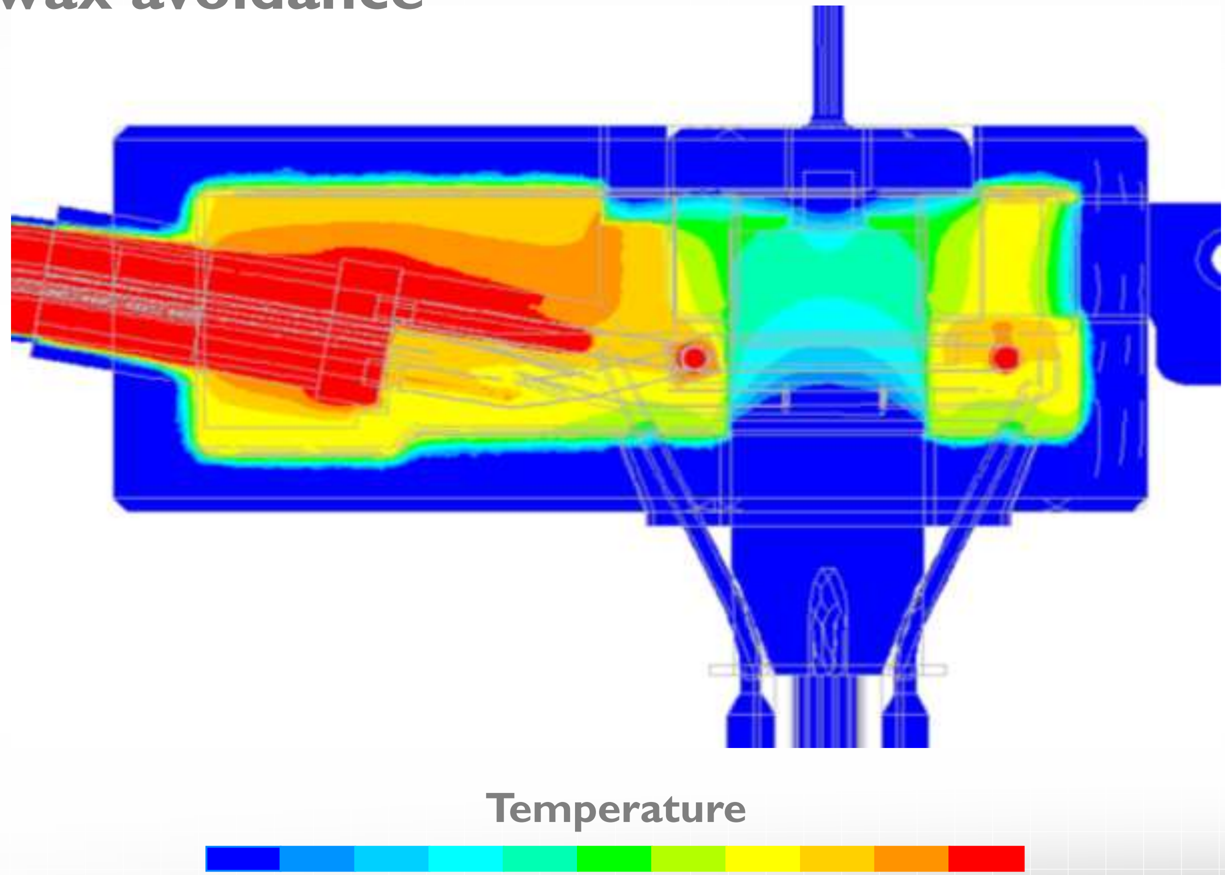


al – Stainless steel
r tube

n

Case studies – thermal performance

Hydrate/wax avoidance



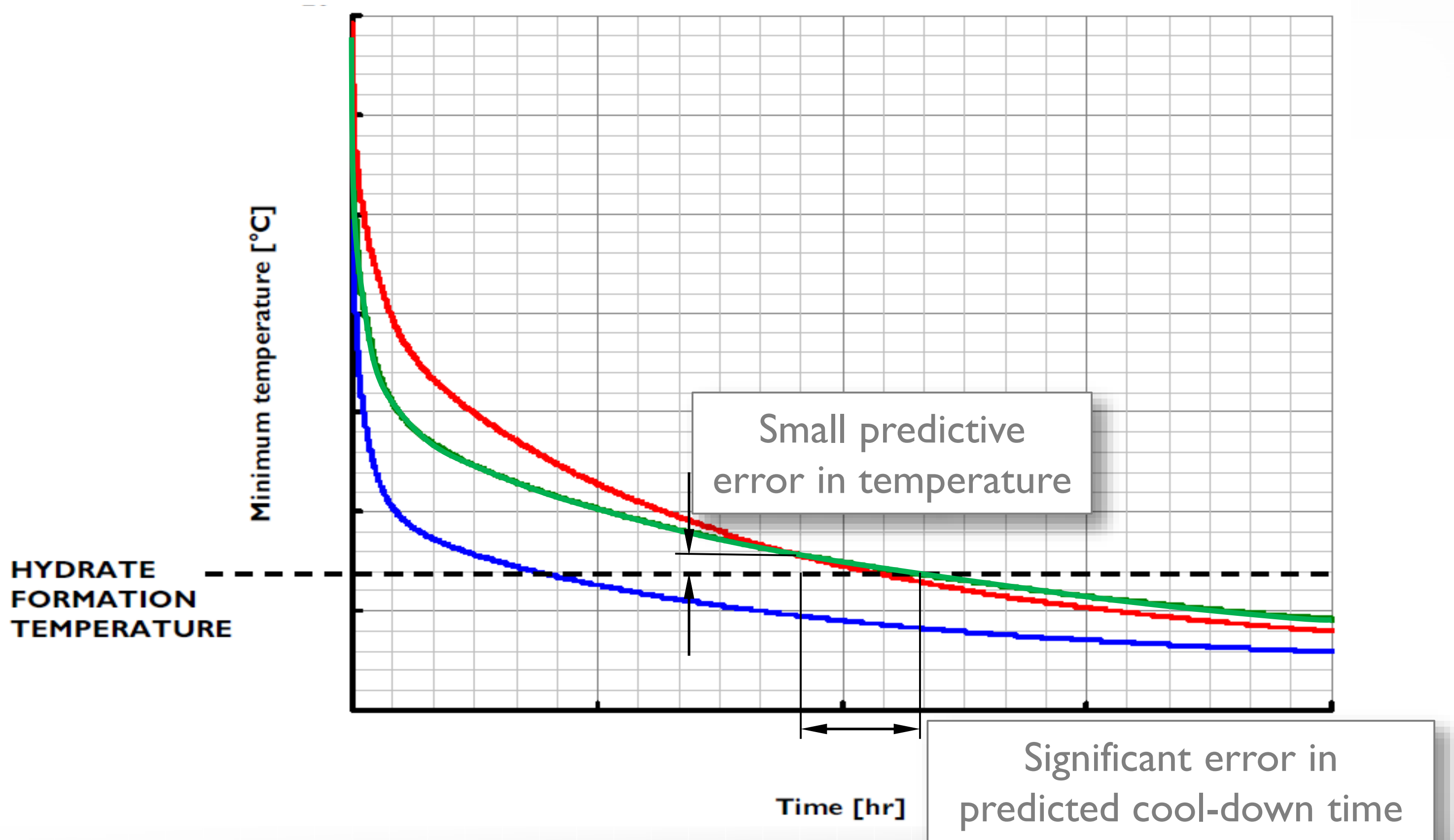
Case studies – thermal performance

Verification and validation

- Hydrate and wax formation represents a significant risk to the operation of subsea equipment
- Often, after the initial cooling period, the rate of cooling can be slow, so a relatively small predictive error in the temperature could correspond to a large error in the predicted cool-down performance

Case studies – thermal performance

Verification and validation



Case studies – thermal performance

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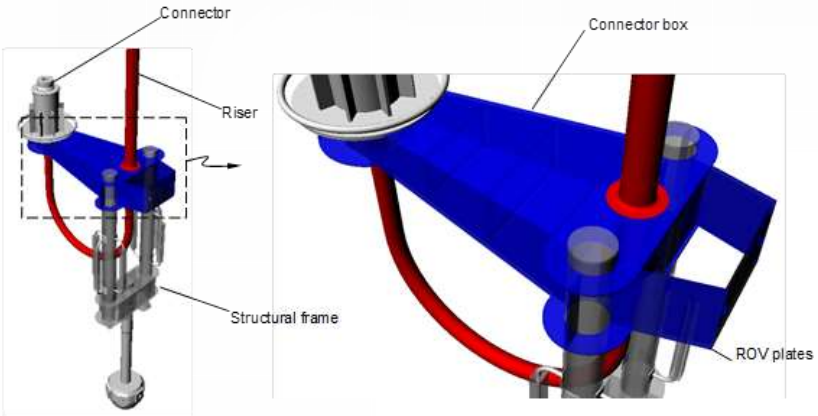
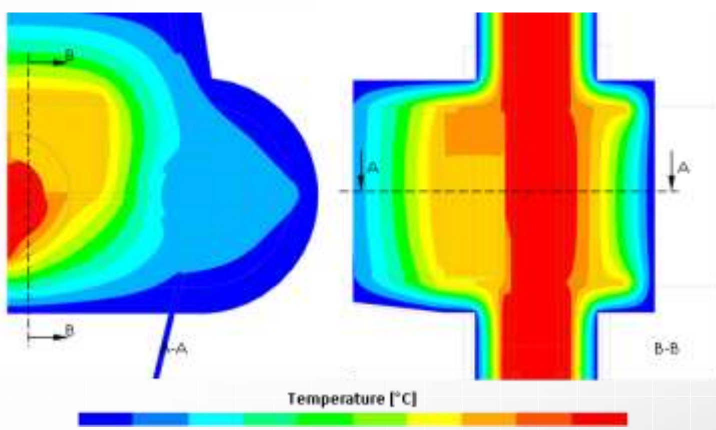
- Full-scale testing is often required to validate CFD for subsea installations

Case studies – thermal performance

Verification and validation





Case studies – thermal performance

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- Full-scale testing is often required to validate CFD for subsea installations *but the experimental data is typically archived within the project – perhaps it could be put to better use?*
- **More benchmark data in the public domain is required.**

Case studies – thermal performance

Verification and validation

- Issues with full-scale testing
  - Hydrocarbons cannot necessarily be tested at field pressure due to safety concerns during the experiments, so high-pressure gas may be replaced by either water or air – is this reliable?
  - Are thermal radiation effects important? – if a gas is replaced by water then heat transfer due to thermal radiation is neglected
  - There may be additional thermal bridging due to the presence of the monitoring equipment – a thermocouple installed through a layer of insulation provides a path for heat transfer through the insulation, therefore affecting what it is trying to measure
  - Is the inclination of the full-scale test piece important?

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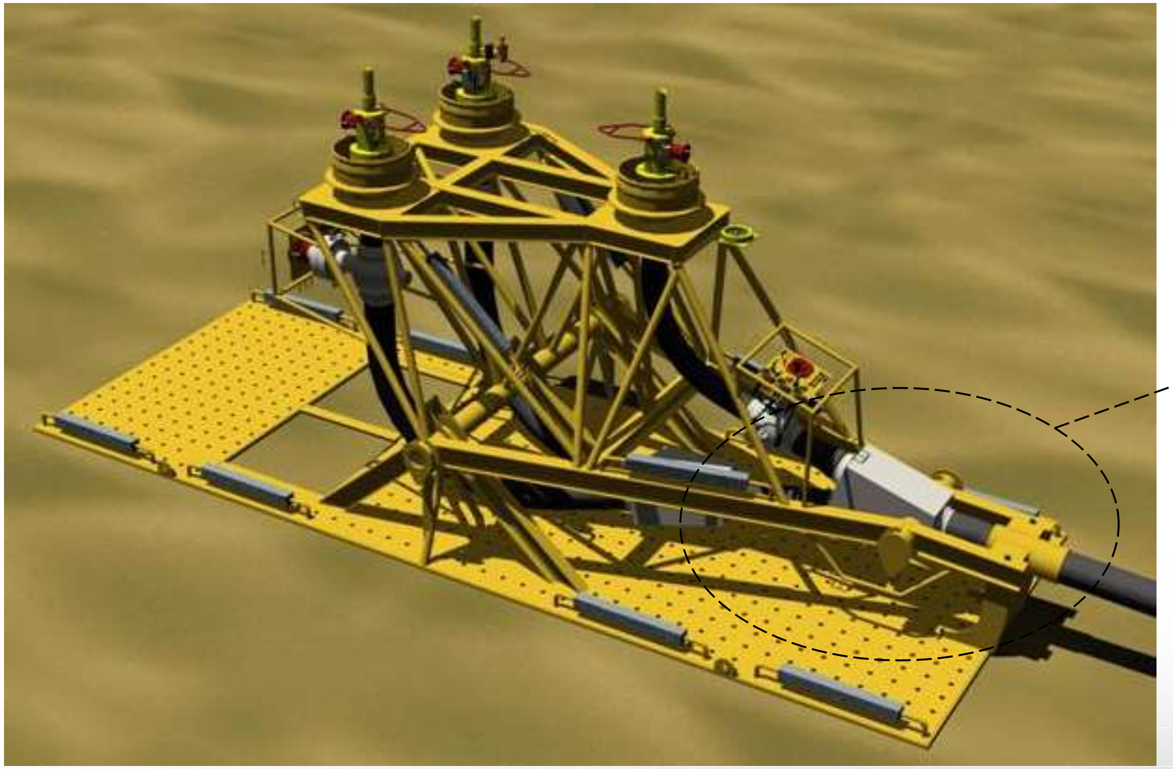
Case studies – pigging/sphering

- Pigs are used to both inspect pipelines and to clear out accumulated liquid hold-up (in a gas pipeline) and solids
- The CFD approach was used for the following case study where an over-inflated sphere is used in an existing subsea pipeline, to assess whether there is a risk that a sphere could become stranded within the wye-piece once the new tie-in is installed.

Case studies – pigging/sphering

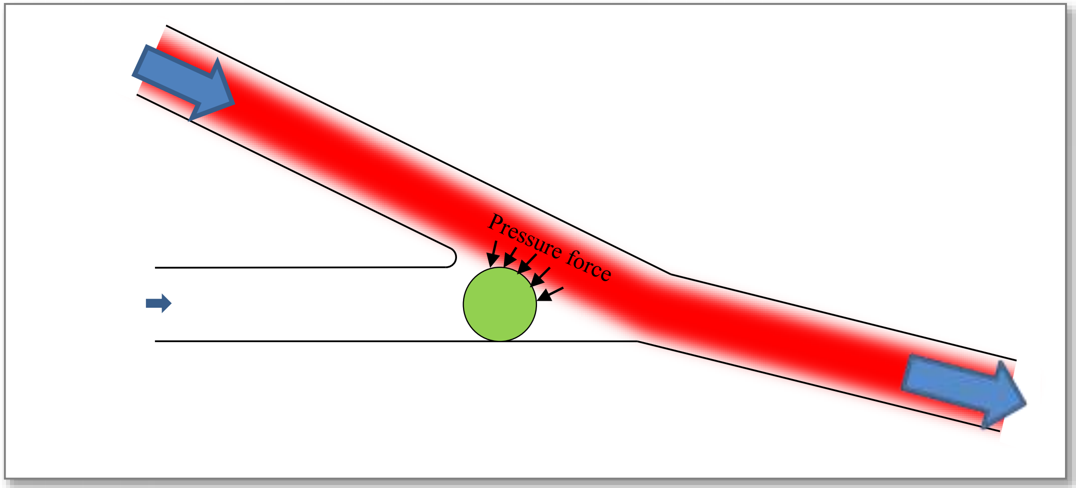
Pigging

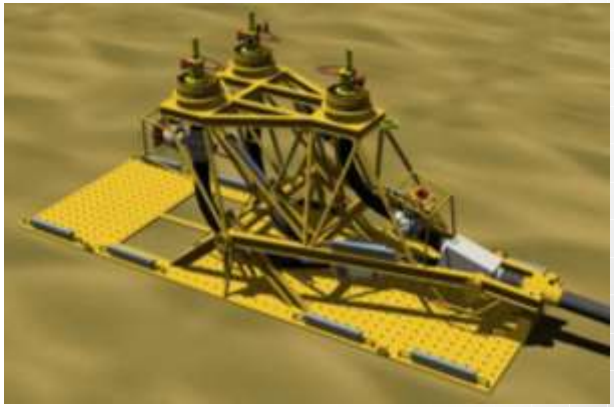


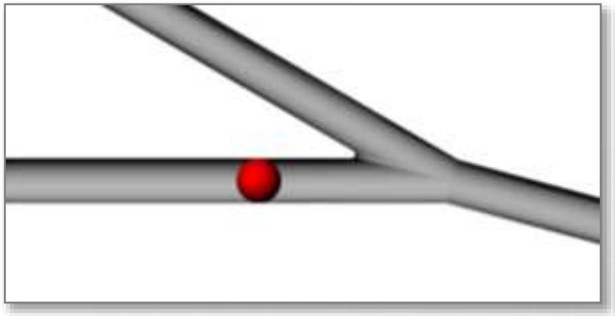
Wye-piece at new tie-in

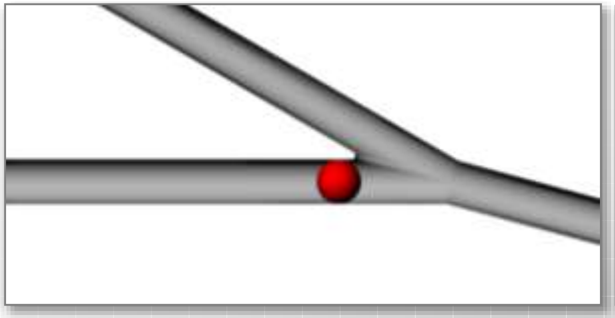
Case studies – pigging/sphering

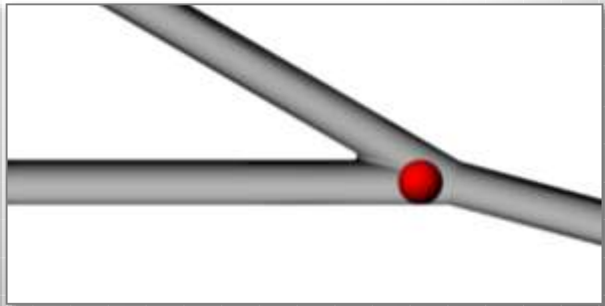
Pigging





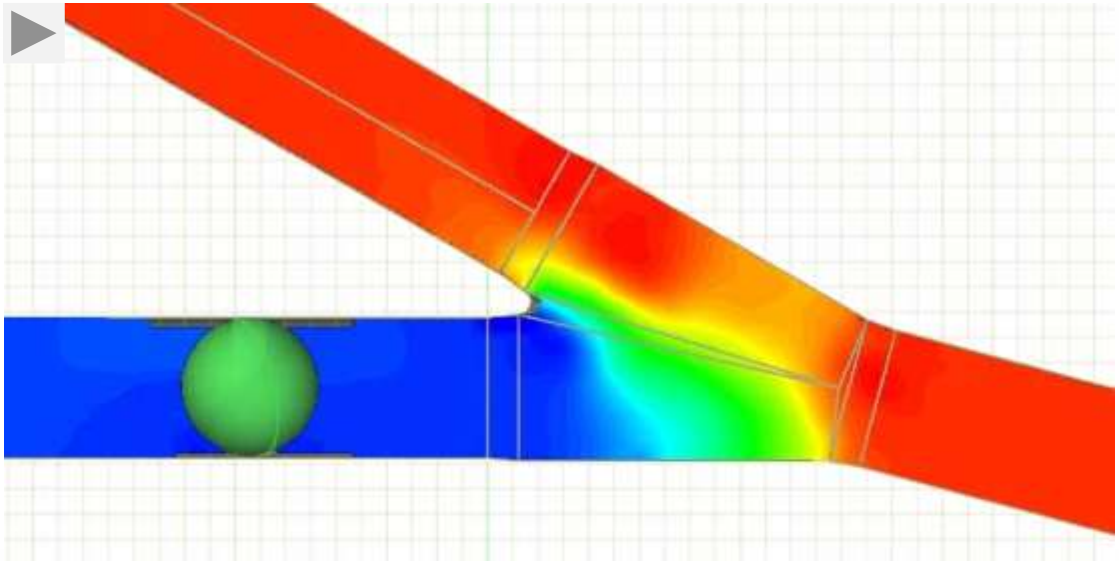






Case studies – pigging/sphering

Pigging



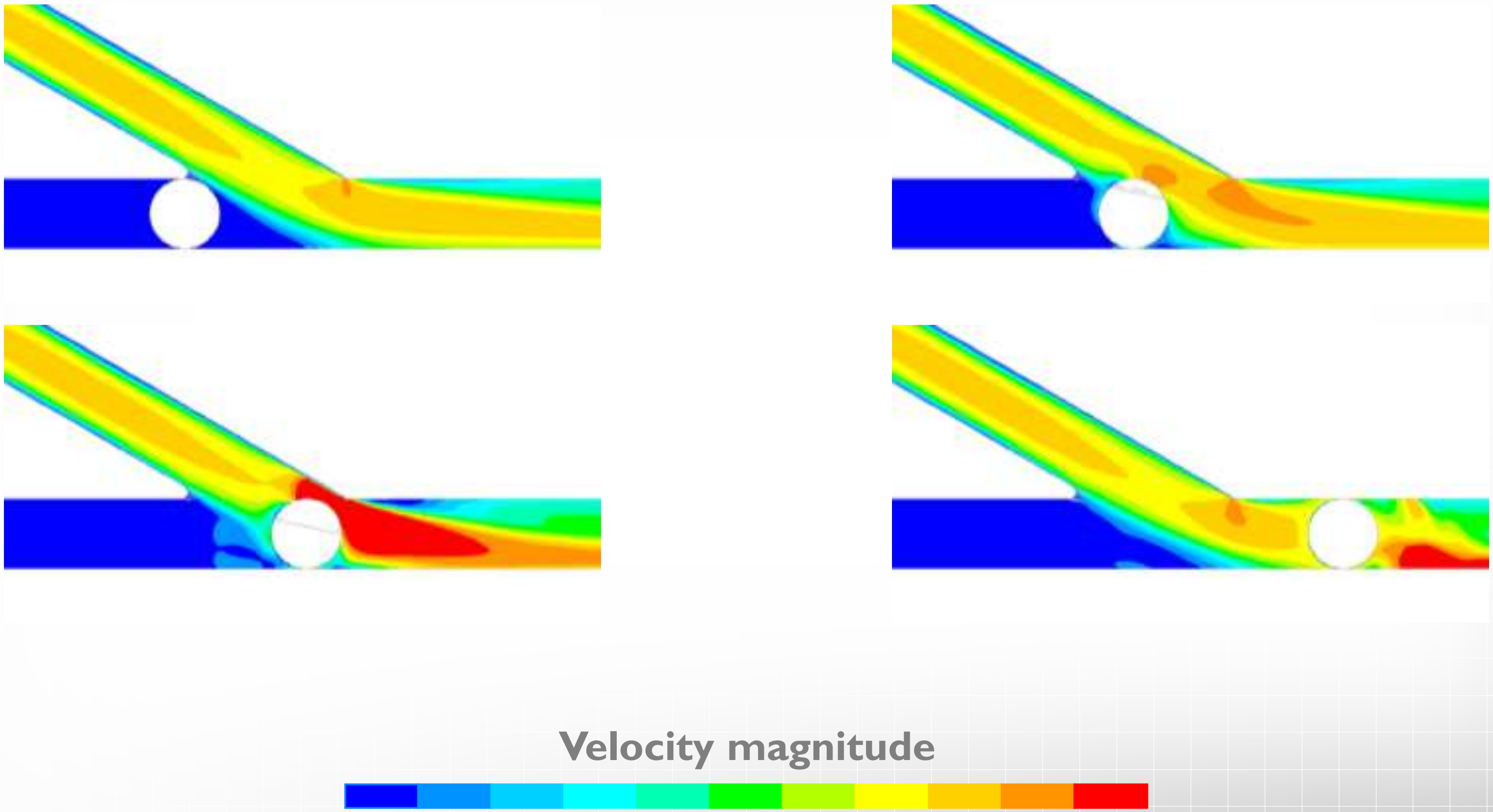
Velocity magnitude

Case studies – pigging/sphering

- The CFD codes STAR-CCM+, Ansys FLUENT, Ansys CFX and XFlow were used for the project
- The small gaps within the contact regions caused difficulties with STAR-CCM+, Ansys FLUENT and Ansys CFX – these codes use the FV approach which can struggle to mesh small fluid gaps
- XFlow is based on an SPH type meshless approach, which is suited for moving geometries with small gaps
- However, Abercus had concerns about the accuracy of SPH
- Abercus therefore undertook quantitative comparisons with FLUENT for an linearised wye (which could be easily simulated using a sliding mesh approach within FLUENT).

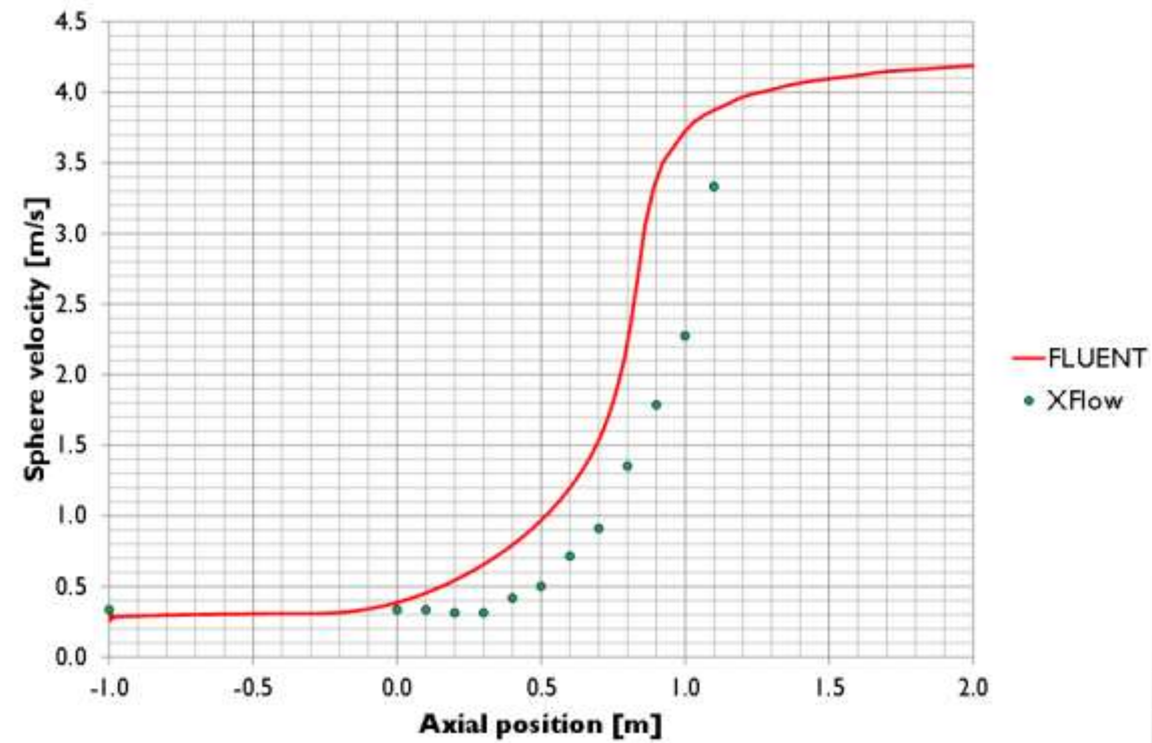
Case studies – pigging/sphering

Verification of XFlow by comparison to Ansys FLUENT using a linearised wye geometry



Case studies – pigging/sphering

Verification of XFlow by comparison to Ansys FLUENT using a linearised wye geometry



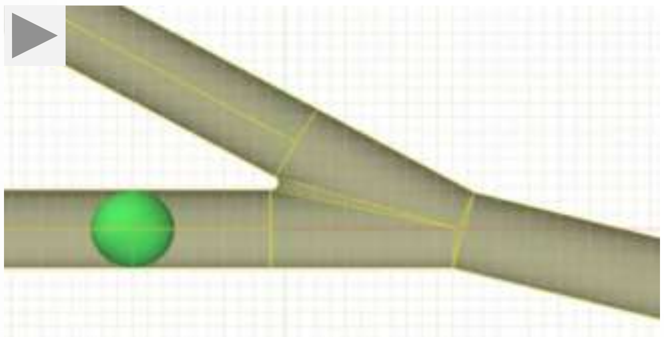
Case studies – pigging/sphering

- The quantitative agreement between XFlow and FLUENT was not perfect, but it was considered to be close enough to have confidence in XFlow
- XFlow was then used to simulate the actual wye geometry
  - (Which was not linear and, therefore, could not be simulated using a sliding mesh approach in FLUENT)

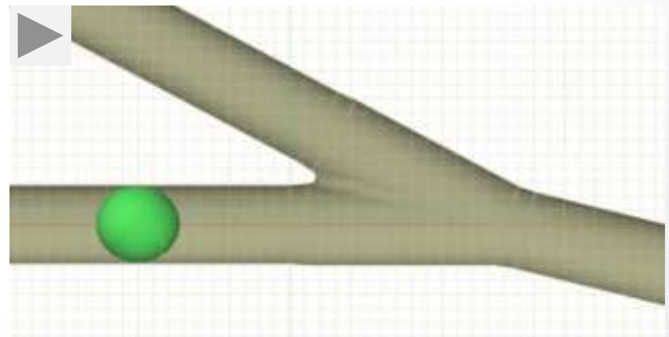
Case studies – pigging/sphering

Pigging

Without undercut



With undercut



Case studies – pigging/sphering

- The quantitative agreement between XFlow and FLUENT was not perfect, but it was considered to be close enough to have confidence in XFlow
- XFlow was then used to simulate the actual wye geometry
  - (Which was not linear and, therefore, could not be simulated using a sliding mesh approach in FLUENT)
- Recommendations to the project – an undercut within the wye-piece will relieve frictional resistance at the tie-in, allowing the sphere to progress freely through the wye.

Agenda

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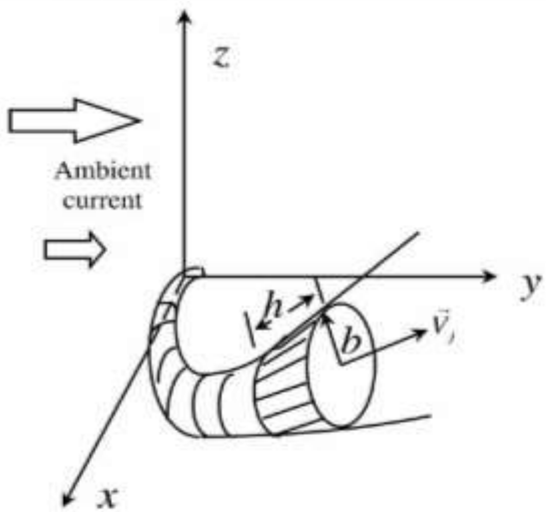
Case studies – subsea bubble plumes

- In the event of a rupture of a gas pipeline, the released gas will form a rising bubble plume which may present a hazard at the surface
- The physics of bubble plumes are reasonably well understood and can be described by simple plume modelling approaches based upon the entrainment hypothesis:
  - Morton, Taylor and Turner (1956)
- Extensions to the simple models have been proposed to account for starting plumes and to incorporate the effects of crossflow and gas dissolution.

Case studies – subsea bubble plumes



Entrainment hypothesis leads to plume theory for a steady plume without cross-flow (Morton, Taylor and Turner, 1956)

→ Transient starting plumes for single phase (Turner, 1971)

→ → Starting plumes for bubble plumes (Bettelini and Fannelop, 1993)

→ JETLAG model incorporating the effects of cross-flow for steady plumes (Lee and Cheung, 1990)

→ → DEEPBLOW model incorporating the effects of gas dissolution and hydrate formation for steady bubble plumes (Johansen, 2000)

Case studies – subsea bubble plumes

- For the current case study, our client (a marine contractor) was concerned about dropping a riser during a riser removal operation – in which event, a bubble plume could result
- In advance of the removal operation:
  - The riser and subsea pipeline would be depressurized to just a few bar above ambient at the sea bed
  - The system would be isolated so that the inventory of hydrocarbons that could be released would be finite
- Any release would, therefore, be over a relatively short duration
- The simple plume modelling approaches do not extend to this sort of pulsed release, so CFD was used to model the behaviour.

Case studies – subsea bubble plumes

- The work was completed using transient particle tracking
- The case without crossflow was considered:
  - This is the most conservative scenario, since crossflow will extend the path of the submerged plume, thus diluting the plume at the surface
  - This simplification allowed an axisymmetric framework to be used, which allowed the simulations to be undertaken more speedily
  - Crossflow can be captured using CFD but requires a three-dimension framework to be used, with an associated increase in computational effort
- The gas density and size of each bubble was modified to allow for expansion due to the reduction of pressure with height
- Gas dissolution and gas hydrate formation were neglected – this is a conservative assumption.

Case studies – subsea bubble plumes

- The transient starting plume was simulated using CFD, and compared quantitatively against the simple plume theory:
  - Bettellini and Fannelop (1993)

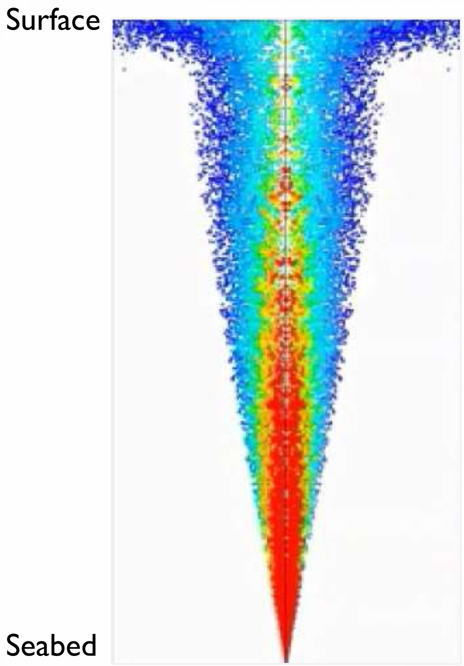
Case studies – subsea bubble plumes

Transient starting plume
(continuous release)

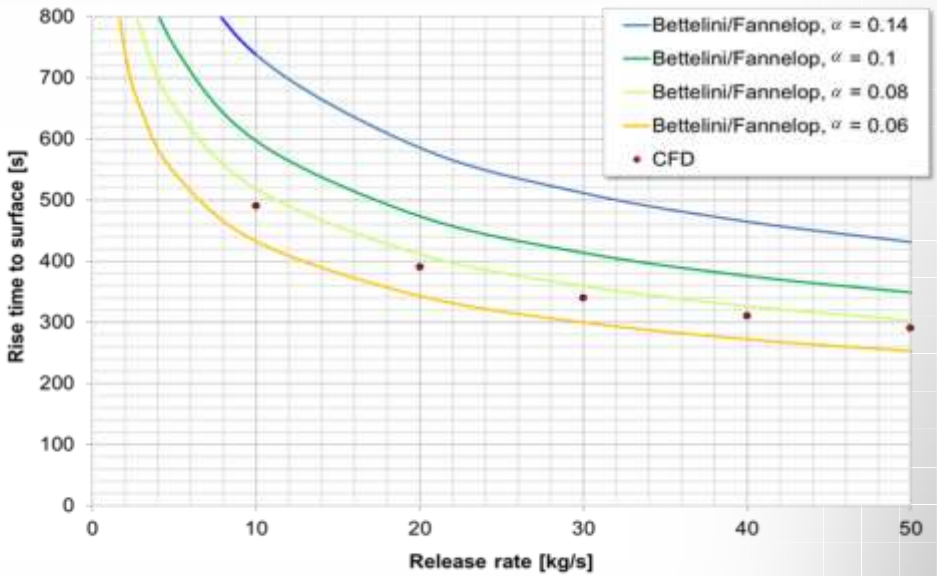
Gas concentration [% volume at atmospheric pressure]

Case studies – subsea bubble plumes

Transient starting plume
(continuous release)



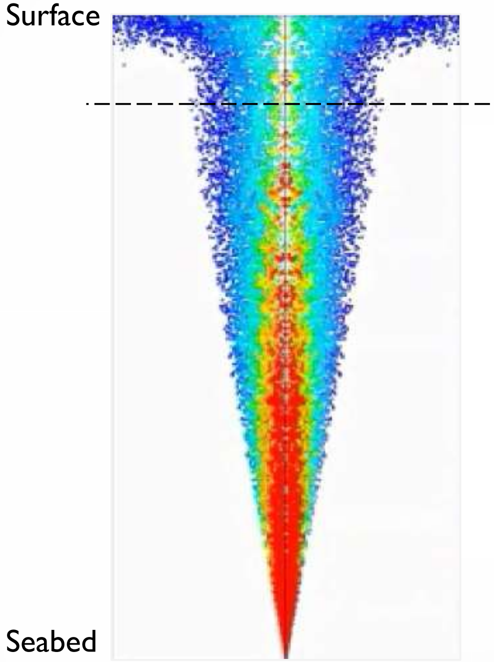
Rise time to surface



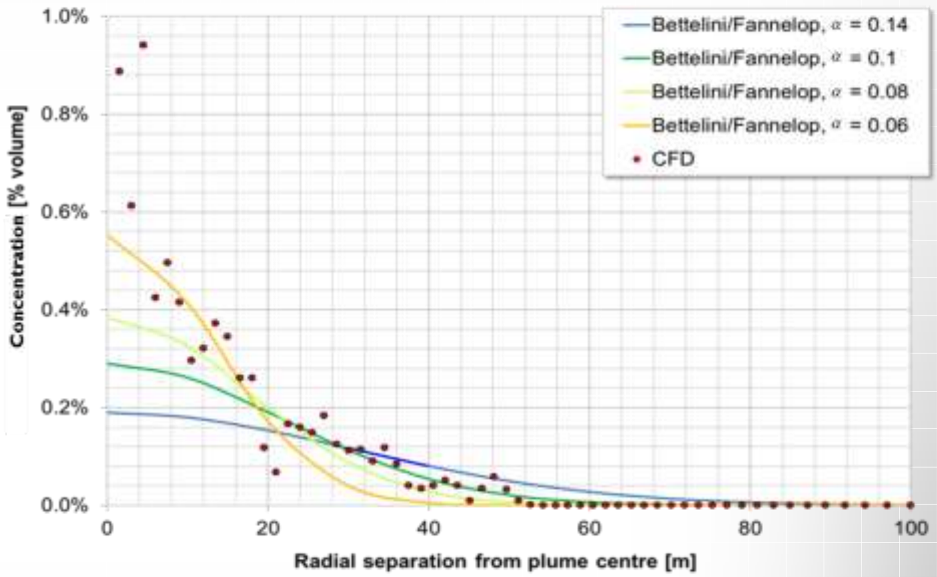
Gas concentration [% volume at atmospheric pressure]

Case studies – subsea bubble plumes

Transient starting plume
(continuous release)



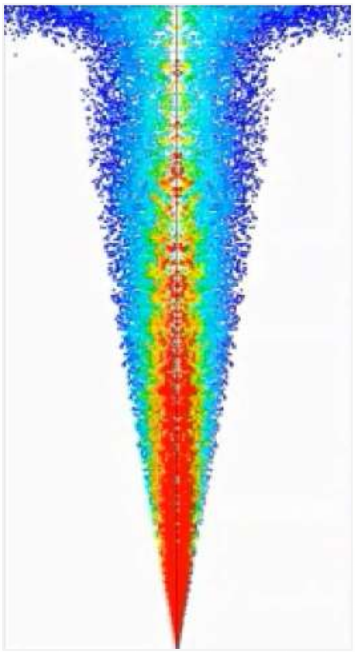
Concentration below surface



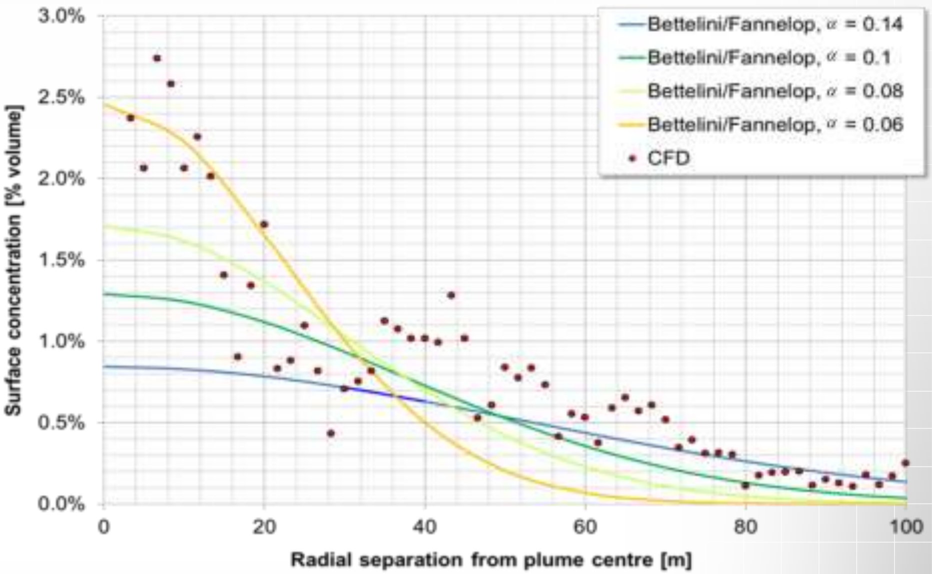
Gas concentration [% volume at atmospheric pressure]

Case studies – subsea bubble plumes

Transient starting plume
(continuous release)



Concentration at surface



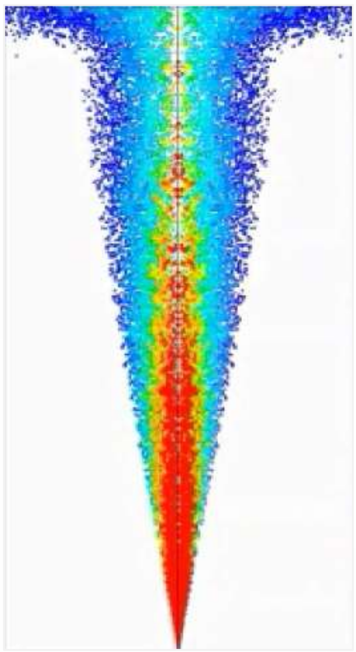
Gas concentration [% volume at atmospheric pressure]

Case studies – subsea bubble plumes

- The transient starting plume was simulated using CFD, and compared quantitatively against the simple plume theory:
  - Bettellini and Fannelop (1993)
- With the simple theory there remains uncertainty about the precise value of the entrainment coefficient α that should be assumed – it is generally considered to be in the range 0.08–0.1
- The CFD predictions agreed well with the simple theory for an entrainment coefficient in this range and was, therefore, used with confidence for the pulsed release.

Case studies – subsea bubble plumes

Transient starting plume
(continuous release)



Pulsed release

Gas concentration [% volume at atmospheric pressure]

Case studies – subsea bubble plumes

- The behaviour for the pulsed release is predicted to be significantly different from that for a transient starting plume
- The CFD predicted that for the pulsed release, the risk to operations at the surface would be negligible
  - (Even neglecting the mechanisms of gas dissolution and gas hydrate formation within the rising bubble plume, both of which would act to reduce the risk at the surface)
- Since the completion of this project, full-scale experimental data from SINTEF has become available to provide further benchmark data for CFD validation.

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- Lower cost and open source simulation tools
- Verification and validation
- Simulation data management
- Summary.

Lower cost and open source simulation tools

- Traditionally CFD and FEA tools have perhaps been considered as high cost, niche simulation tools
- The widely used general-purpose commercial codes have been developed over decades, primarily for use in other industries, and contain a huge amount of functionality that may not be used for many day-to-day applications in the subsea sector
- There is now a growing range of lower cost and open source simulation tools emerging that are accessible to everyone and are fit for purpose for many subsea applications.

Lower cost and open source simulation tools

- Abercus has developed ORTHOFLO, a structured orthogonal CFD code which is used for some niche applications and as a CFD training tool
- Abercus has also developed a suite of flow assurance tools FAST which is able to massively outperform the likes of OLGA for some basic applications but at a fraction of the cost
- Open source CFD tools include: OpenFOAM, Code_Saturne, TELEMAC, REEF3D, FEATFLOW
- Open source FEA tools include: CALCULIX, code_aster, OpenSees.

Lower cost and open source simulation tools

- It is Abercus' expectation that open source simulation tools will become increasingly used in future and this will accelerate the democratisation of advanced simulation methods
- Whilst this is a massive opportunity for our industry, we need to be rigorous with respect to **verification and validation**

- **As an industry, now is the time to be developing and improving our advanced simulation capabilities**
- **Low cost and open source tools will enable the democratisation of advanced simulation methods.**

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Verification and validation

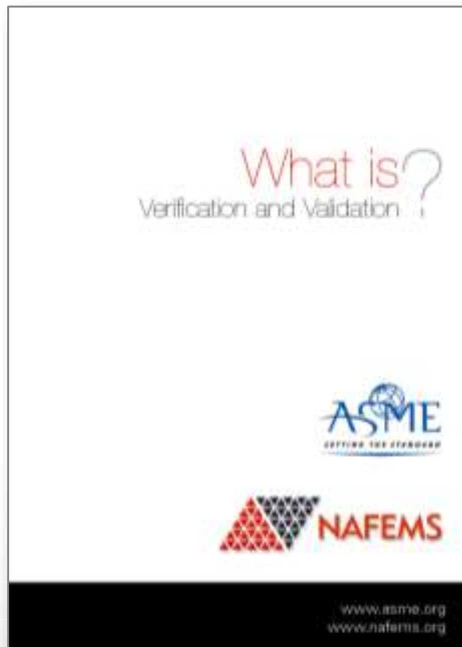
"All models are wrong but some are useful"

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.

- Verification and validation are the processes we must employ to gain confidence in our models, to ensure that they are useful and fit for purpose.

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

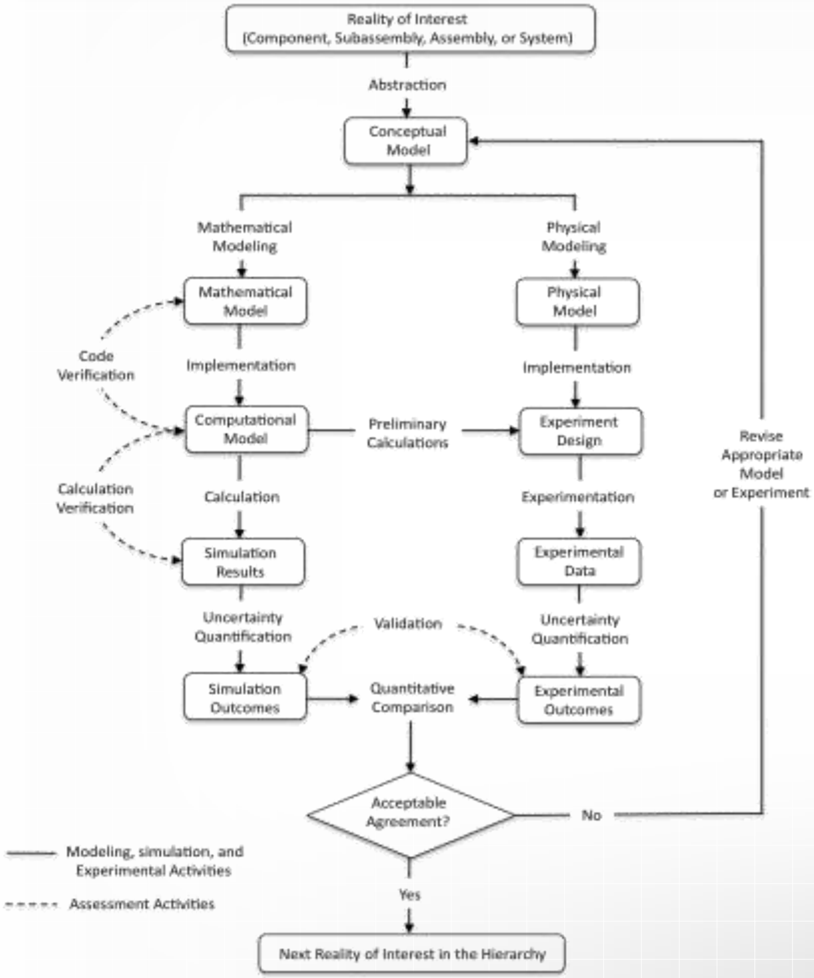
- NAFEMS is the International Association for the Engineering Modelling, Analysis and Simulation Community
- NAFEMS focuses on the practical application of numerical engineering simulation techniques such as finite element analysis, computational fluid dynamics, and multibody simulation
- There are a number of key strands to NAFEMS:
  - Teaching and training
  - PSE Scheme – to demonstrate competence
  - Verification and validation of simulation methods
  - National/international conferences to promote exchange of ideas
- http://www.nafems.org/.

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

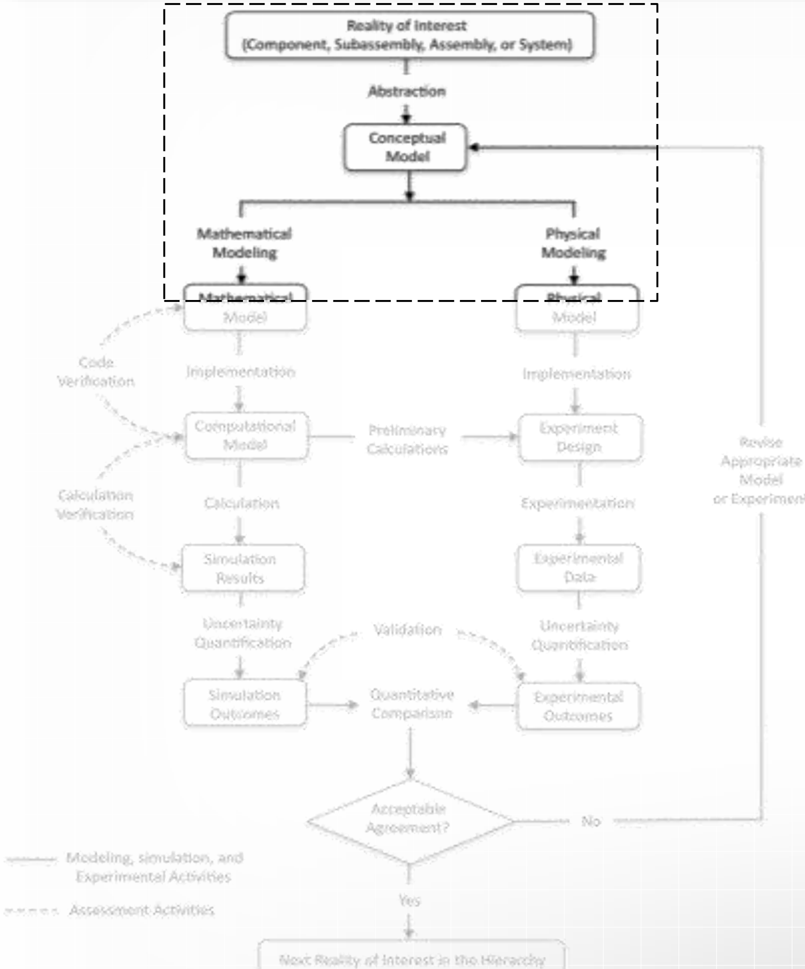
- Verification is the domain of mathematics and validation is the domain of physics.

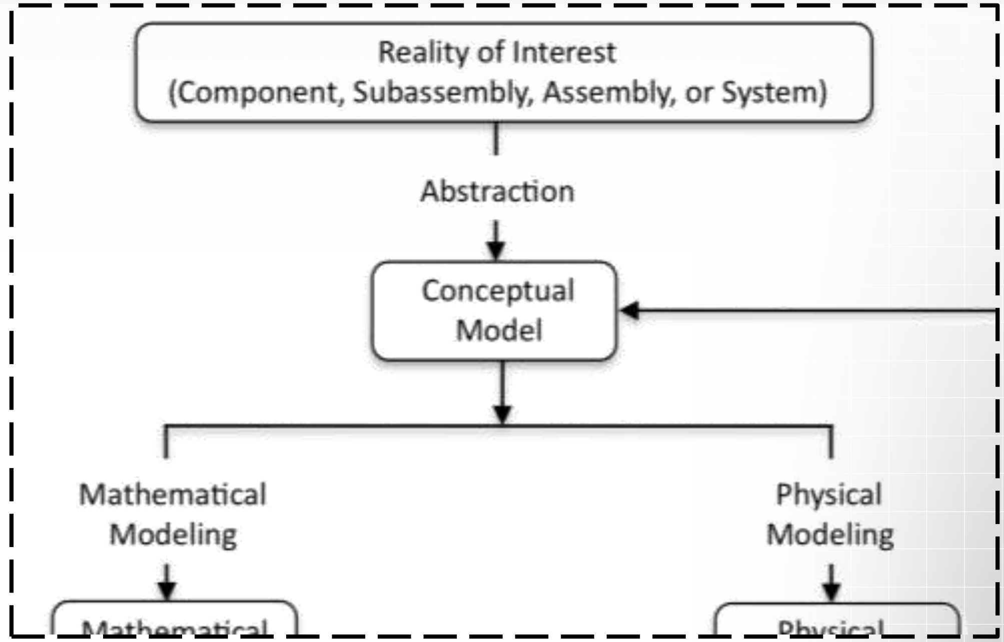
Verification and validation



From ASME/NAFEMS *What is?* Guide.

Verification and validation





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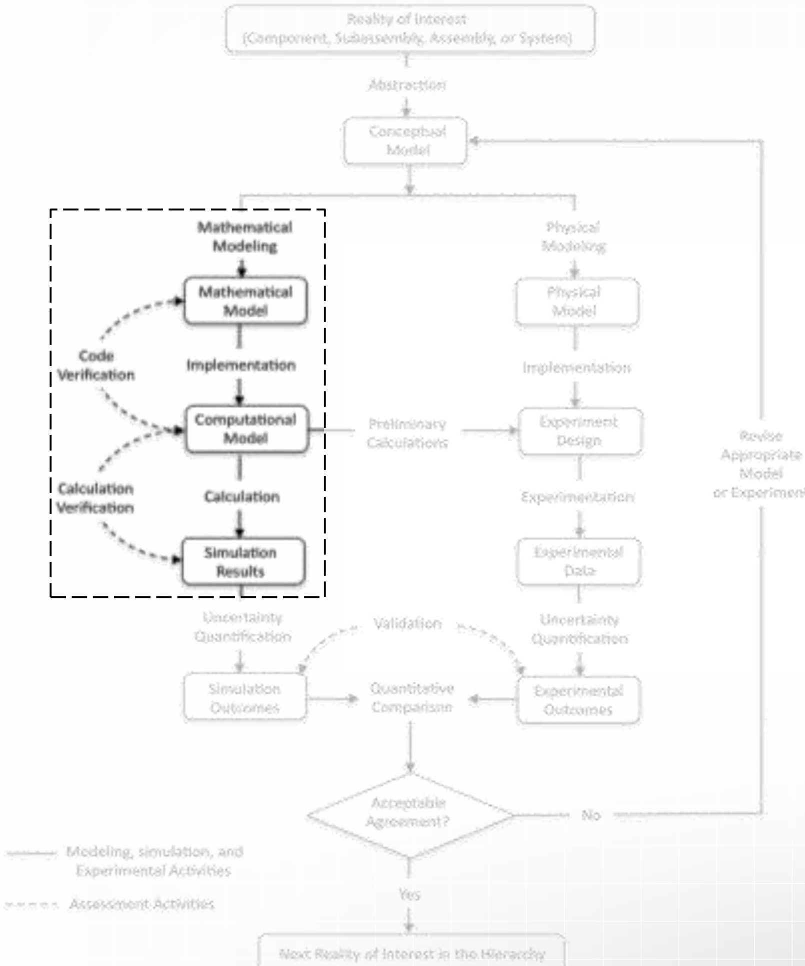

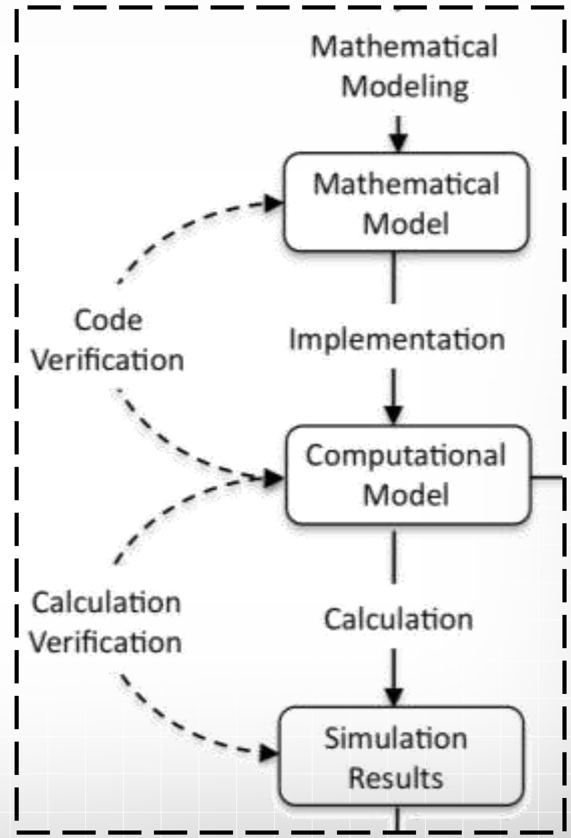

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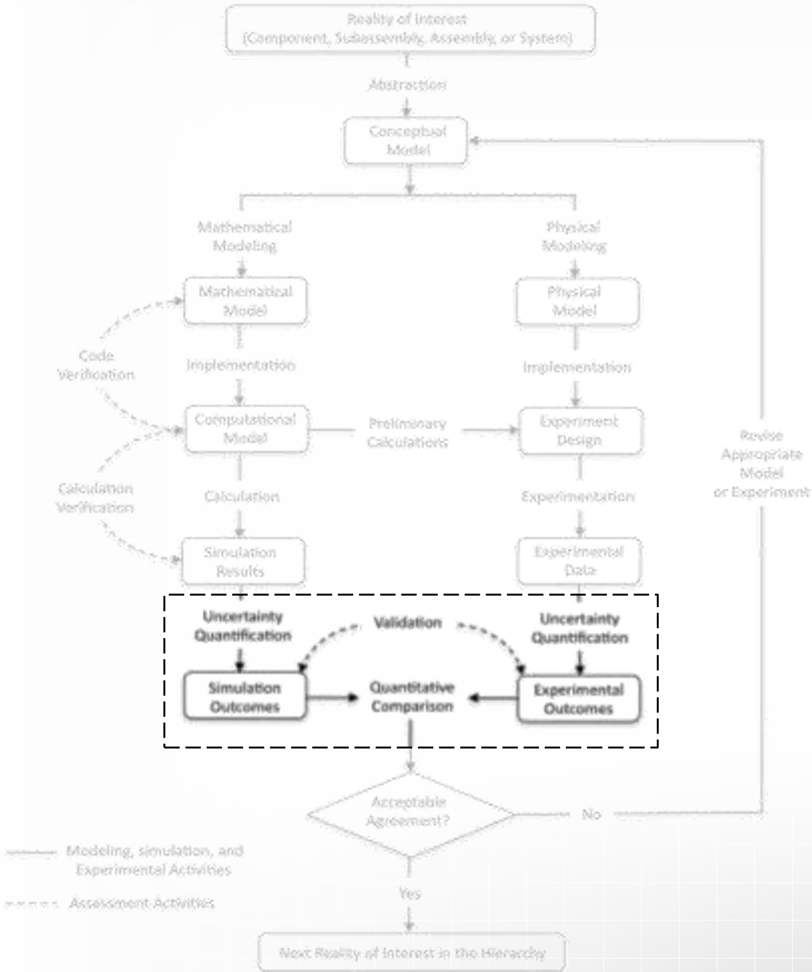

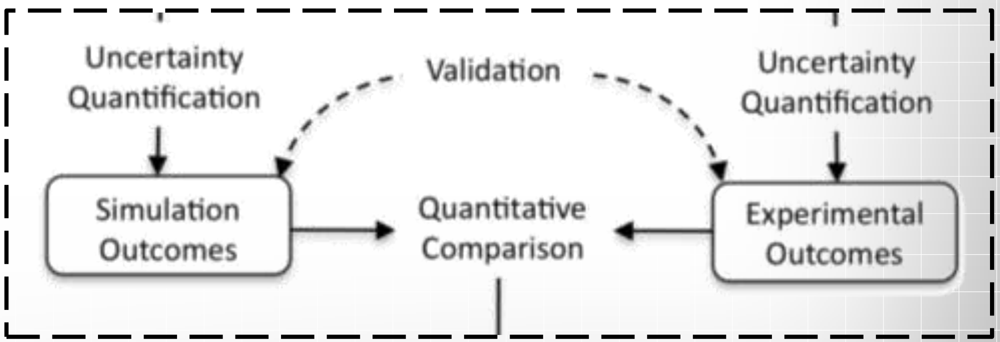

From ASME/NAFEMS *What is?* Guide.

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
- CFD and FEA can be misused
- The abstraction and derivation of the mathematical model is entirely down to the analyst/engineer
- The issue of verification and validation is hugely important for gaining confidence in the CFD and FEA approaches.

Verification and validation

- With other industry-specific *black-box* simulation tools, the abstraction and derivation of the mathematical model has generally been undertaken by the software vendor
- This is the main benefit of the black-box approach – it's consistent, repeatable and robust for the application for which it's been developed
- This is also sometimes a limitation of the black-box approach – engineers may use the software inappropriately, beyond the envelope for which the tool has been validated (perhaps through ignorance and a lack of training, or because it's the only software tool they have to hand).

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
- Combining the first-principles flexibility of CFD and FEA with the benefits of a black-box approach is an attractive way forward
- 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 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.

Verification and validation

- Benchmark data is incredibly important for the purpose of validation activities and there is always a need for more reliable benchmark data, particularly for subsea engineering
- There are some repositories of benchmark data to be aware of:
  - NAFEMS (http://www.nafems.org/)
  - ERCOFTAC (http://www.ercoftac.org/)
  - QNET (http://uriah.dedi.melbourne.co.uk/w/index.php/Main_Page)
  - MARNET (https://pronet.atkinsglobal.com/marnet/)
  - CFD-online (http://www.cfd-online.com/Wiki/Main_Page)
- **We need more public sources of benchmark data.**

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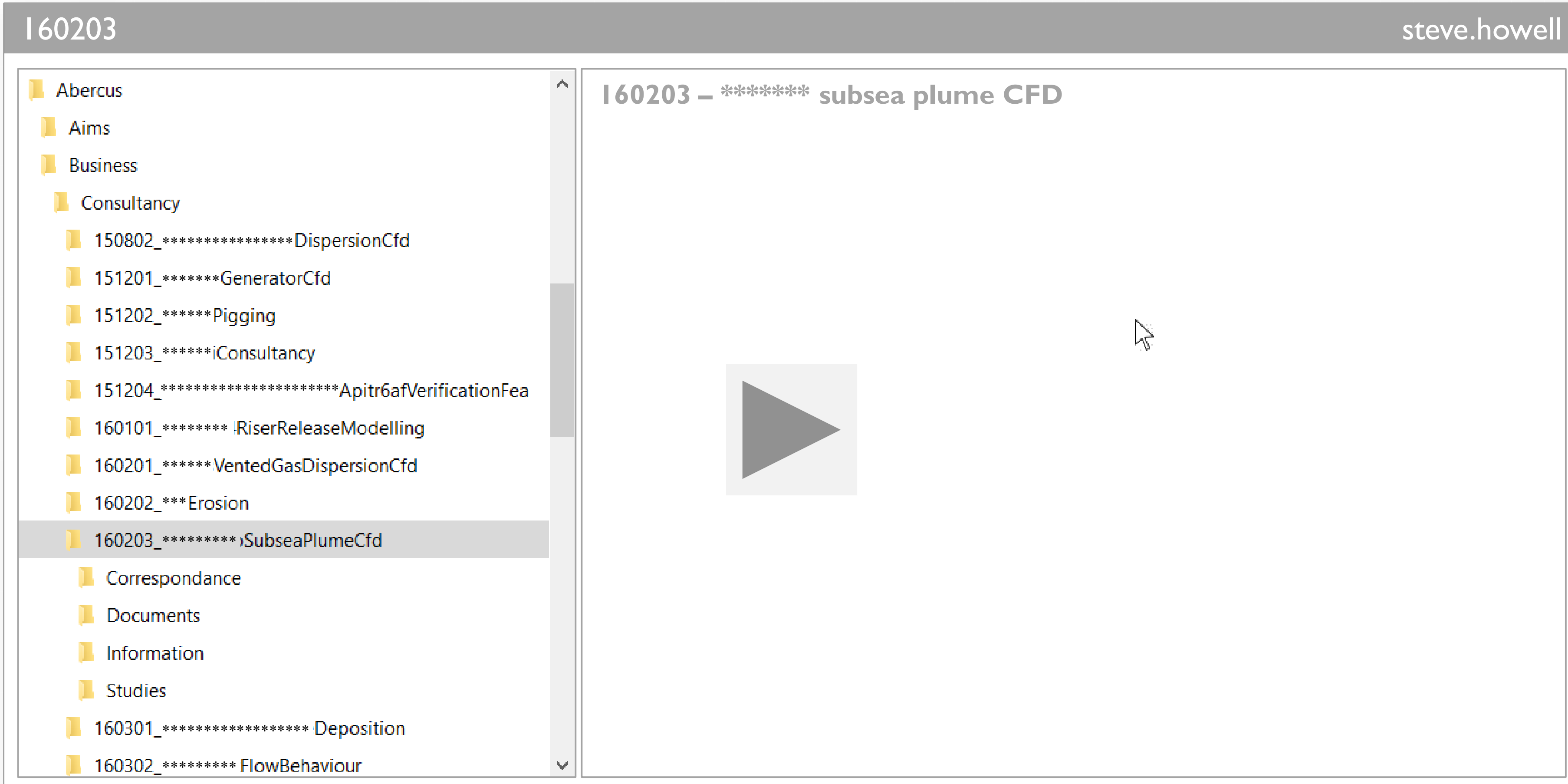
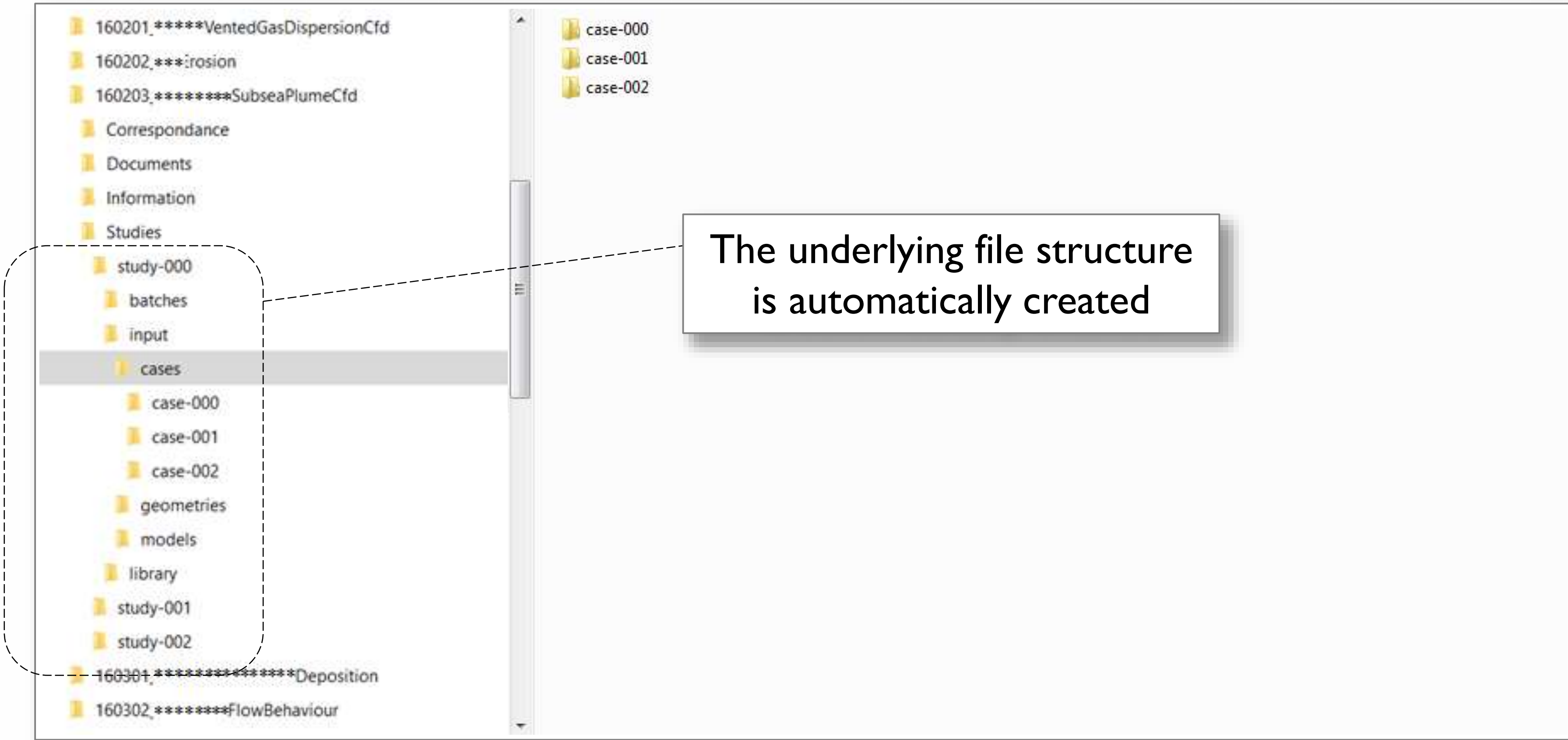
Simulation data management

- Engineering simulation is well suited to process automation and the use of simulation data management (SDM) tools
- Every simulation undertaken within Abercus is scripted so that a precise record of the simulation is stored
  - Each simulation is run as a background process without needing to interact with the GUI of the simulation tool
  - Abercus uses JET, an in-house SDM tool that was originally developed in 2002 to automatically create the simulation scripts
  - The use of JET has saved us time and effort at the point of use – the act of entering information into JET to create our simulation scripts also acts as the records required for our QMS, minimising duplication of effort
  - Work is consistent, efficient, and follows a validated workflow.

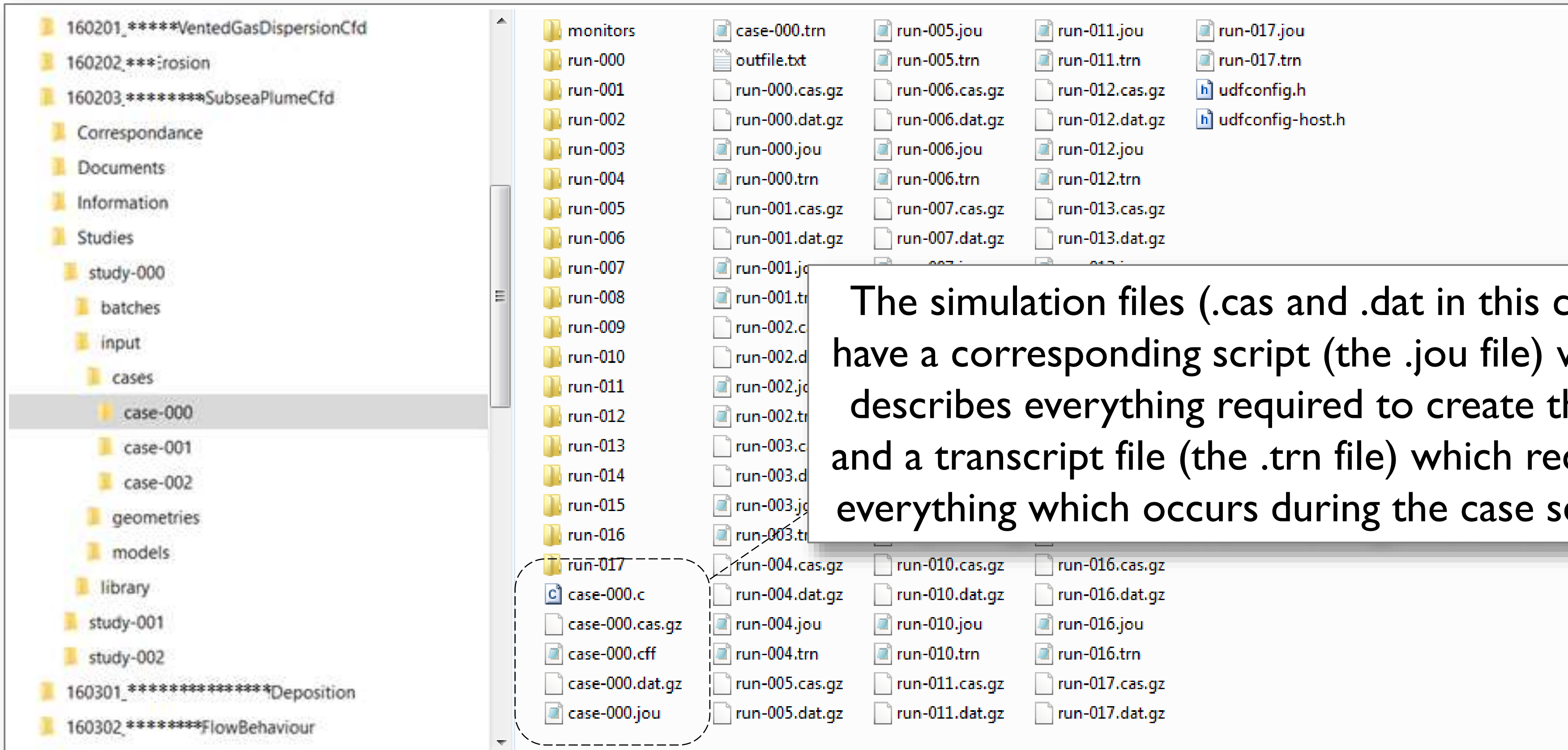
Simulation data management



Simulation data management



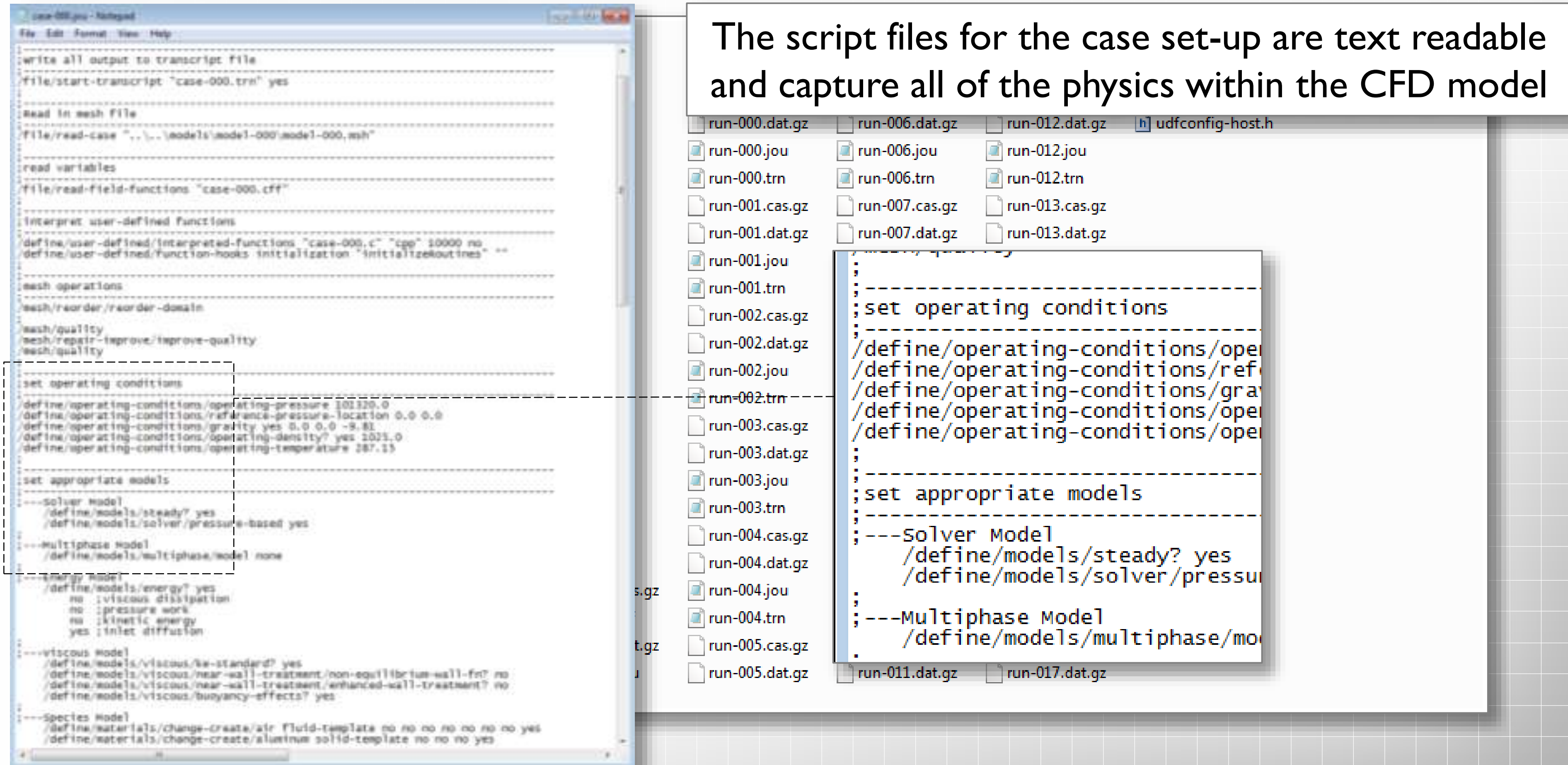
Simulation data management



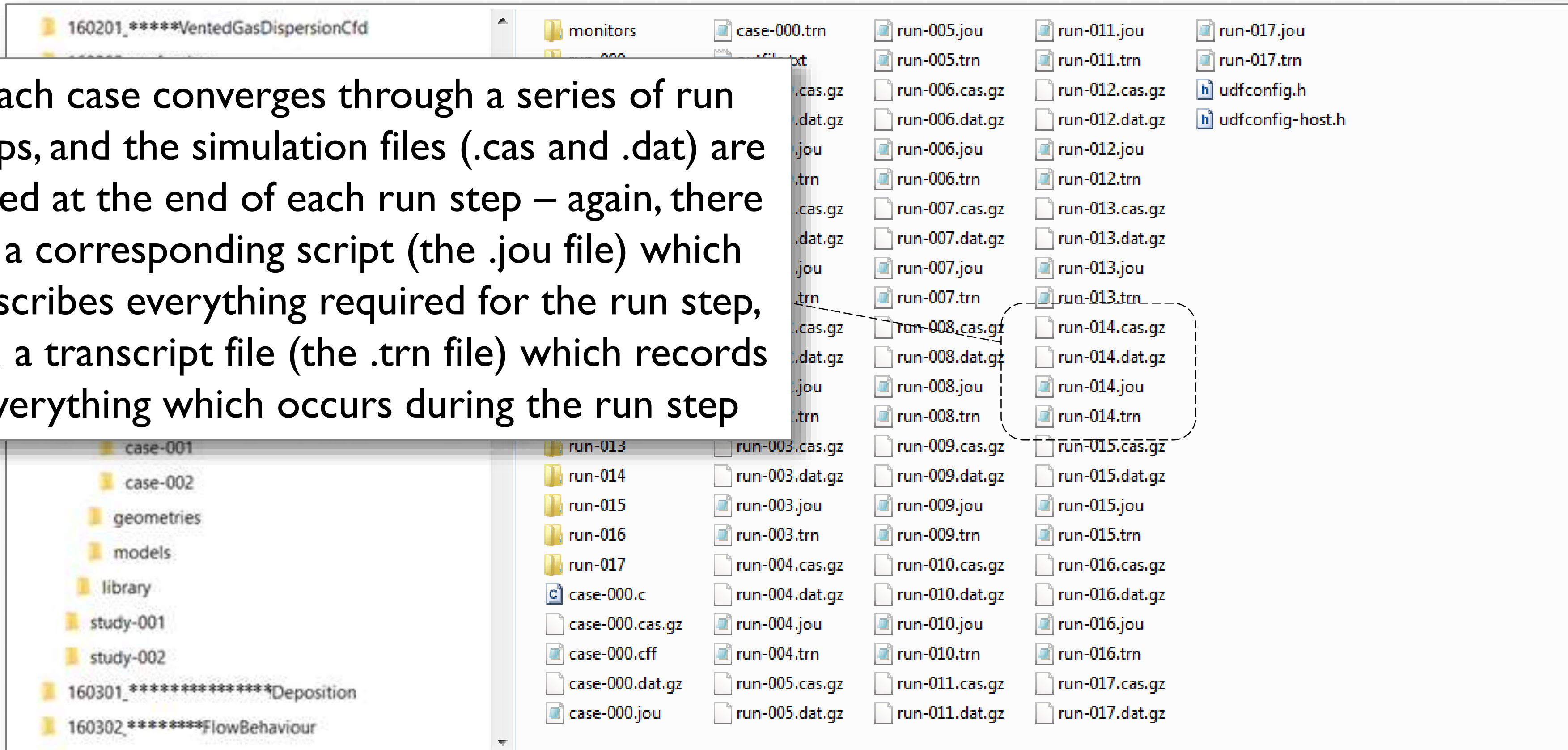
The simulation files (.cas and .dat in this case) have a corresponding script (the .jou file) which describes everything required to create them, and a transcript file (the .trn file) which records everything which occurs during the case set-up

Simulation data management

The script files for the case set-up are text readable and capture all of the physics within the CFD model



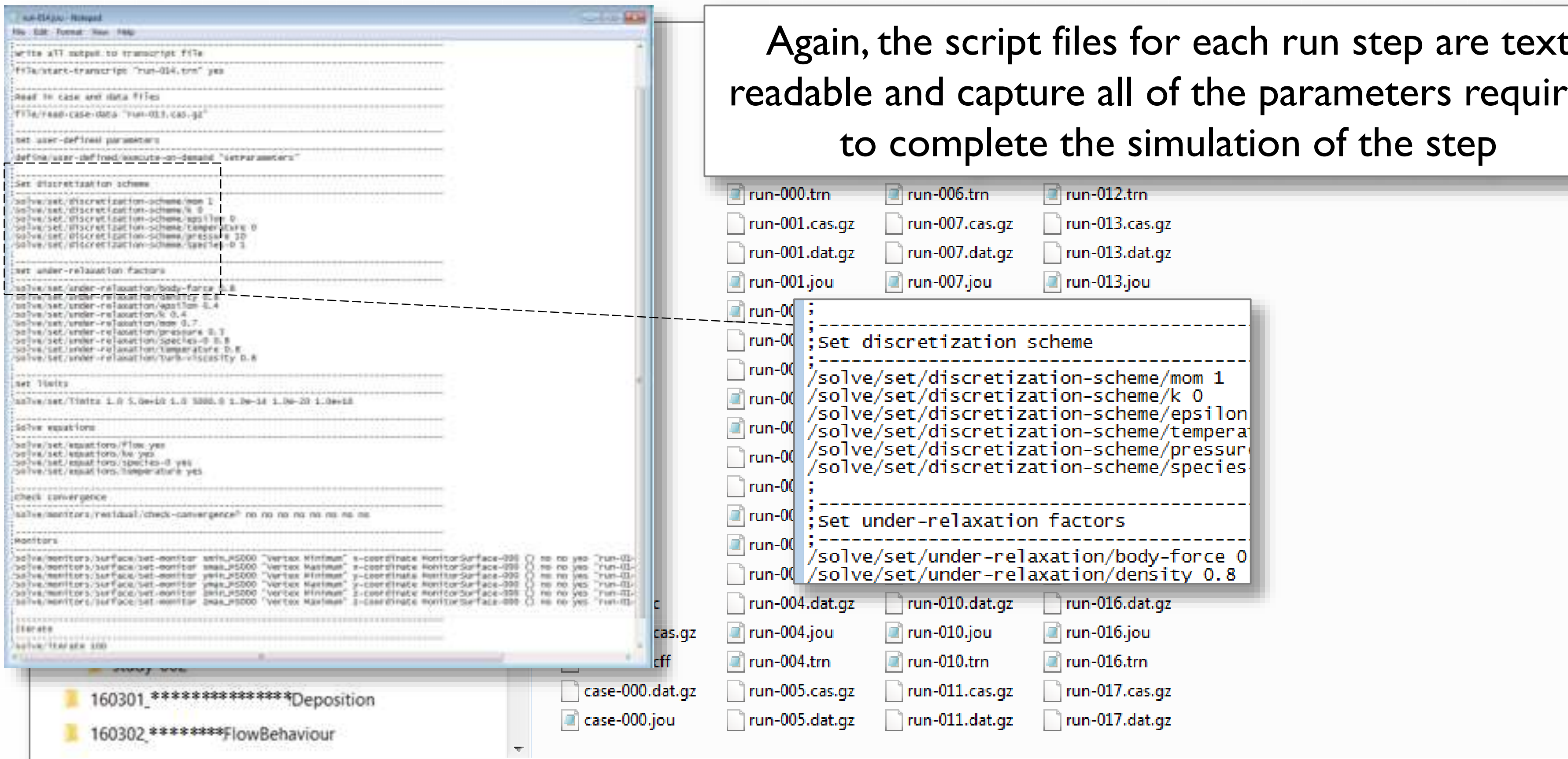
Simulation data management



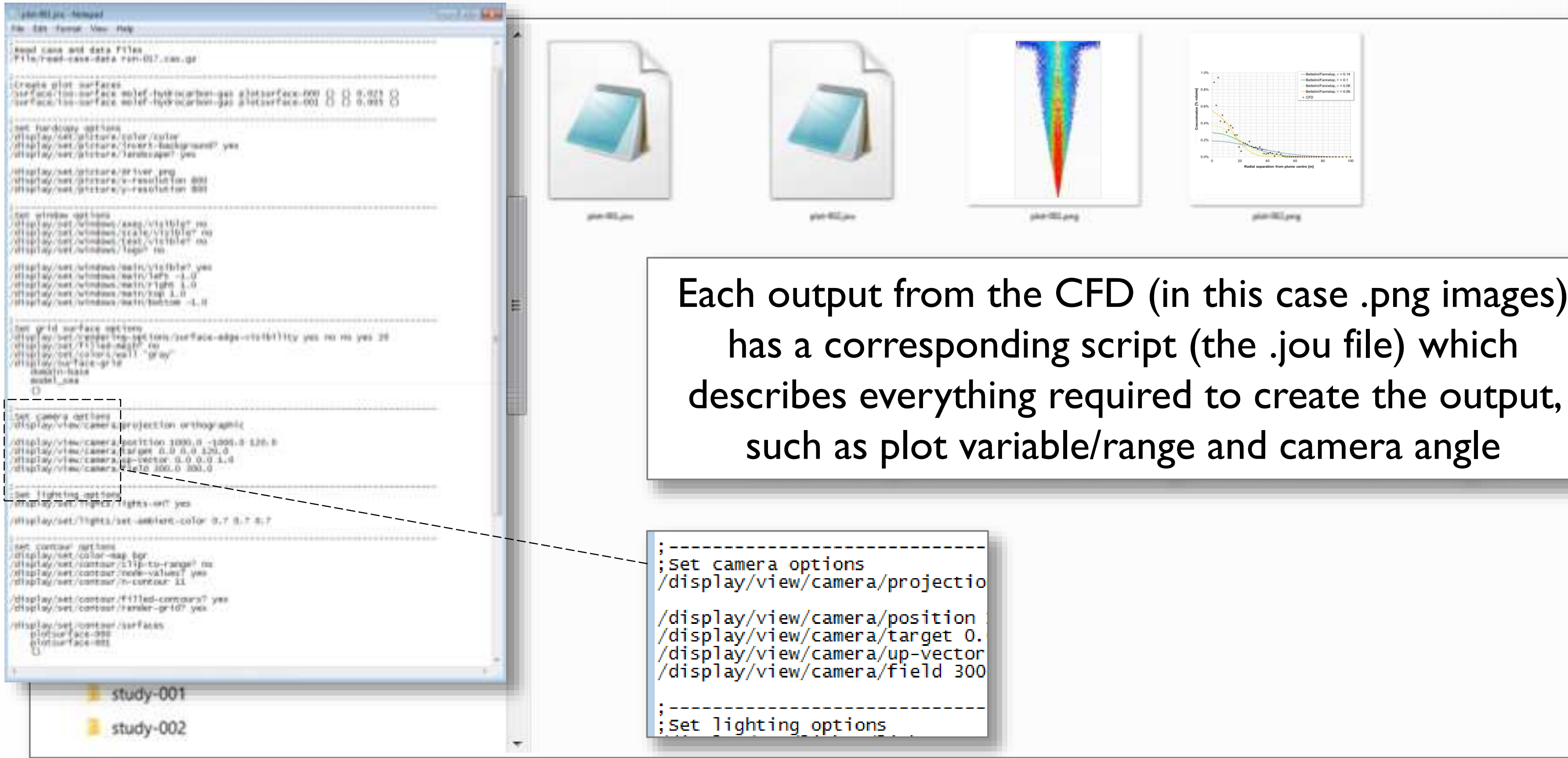
Each case converges through a series of run steps, and the simulation files (.cas and .dat) are saved at the end of each run step – again, there is a corresponding script (the .jou file) which describes everything required for the run step, and a transcript file (the .trn file) which records everything which occurs during the run step

Simulation data management

Again, the script files for each run step are text readable and capture all of the parameters required to complete the simulation of the step

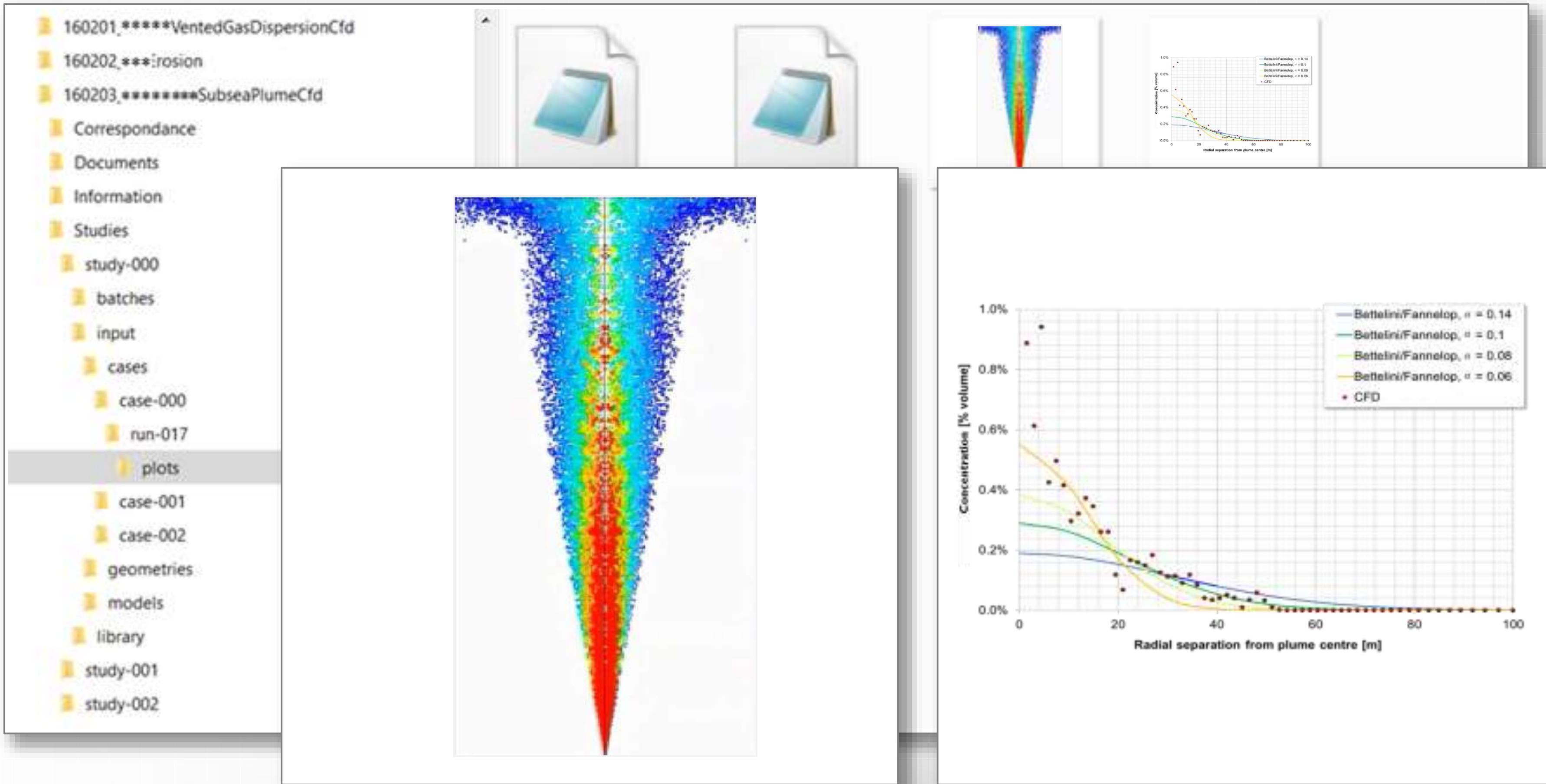


Simulation data management



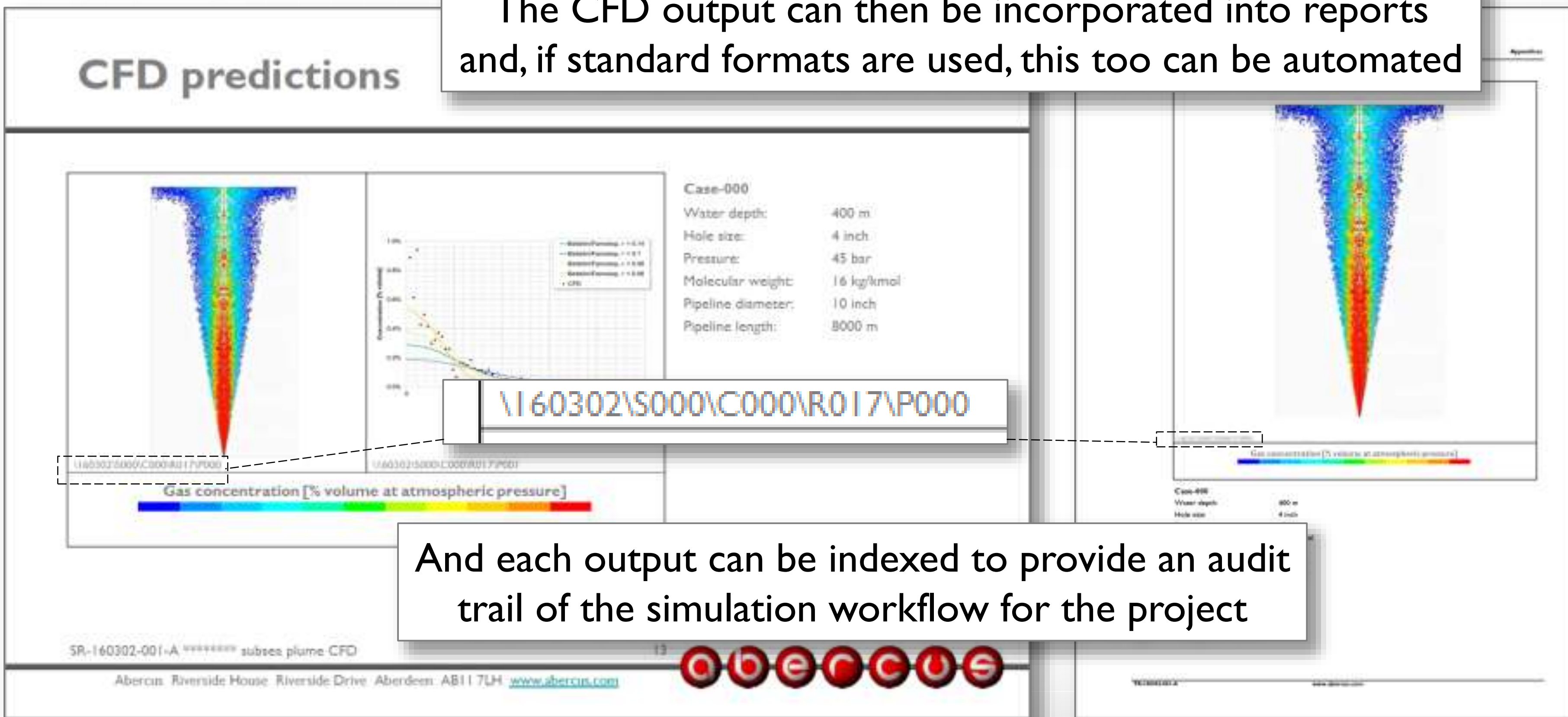
Each output from the CFD (in this case .png images) has a corresponding script (the .jou file) which describes everything required to create the output, such as plot variable/range and camera angle

Simulation data management



Simulation data management

The CFD output can then be incorporated into reports and, if standard formats are used, this too can be automated



And each output can be indexed to provide an audit trail of the simulation workflow for the project

Simulation data management

- SDM tools can provide an efficient, consistent framework for undertaking simulation projects
- The use of SDM tools doesn't mean that simulation predictions no longer need to be checked – an experienced eye is still required to check any simulation prediction, but at least the SDM tool can ensure a consistent approach is used by all simulation users, thus minimising user variability.

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Summary

- In the current lower oil price environment it is increasingly necessary for companies to collaborate and innovate to reduce capital and operating expenditures
- Now is the time to invest in research and development to deliver improved performance and reduced costs
- CFD and FEA are being increasingly used:
  - To deliver valuable insight at the design stage
  - To provide improved understanding of installation and operational issues
  - To demonstrate technology readiness for novel products and approaches
- Be mindful that CFD and FEA may not always be appropriate – if there are simpler methods that are fit for purpose, use them!

Summary

- Traditionally CFD and FEA tools have perhaps been considered as high-cost niche simulation tools
- There is now a growing range of lower cost and open source fit for purpose simulation tools emerging that can be successfully employed within the subsea sector
- It is Abercus' expectation that open source simulation tools will become increasingly used in future and this will accelerate the **democratisation of advanced simulation methods**.

Summary

- CFD an FEA are first-principles approaches
  - This is part of their attraction but also part of the risk
  - Whilst the further use of advanced engineering simulation tools offers a massive opportunity for our industry, we need to be rigorous with respect to **verification and validation**
- Be aware of NAFEMS
  - PSE scheme
  - Teaching and training
  - Verification and validation, uncertainty quantification, predictive capability
  - Working groups/conferences to promote exchange of knowledge/ideas
- **We need more public sources of benchmark data.**

Summary

- CFD and FEA are well suited to scripting and automation, so consider exploiting this through the use of SDM tools
  - SDM tools can provide an efficient, consistent framework for undertaking simulation projects
  - The creation of validated workflows which clone experience and capture best practice can minimise user variability
- The use of SDM tools doesn't mean that simulation predictions no longer need to be checked – an experienced eye is still required to check any simulation prediction, but at least the SDM tool can ensure a consistent approach is used by all simulation users, thus minimising user variability.

Summary

- We hope that our case studies have shown the kind of information and value you can get through the use of advanced simulation, and perhaps this presentation will act as an incentive for you to investigate these methods further for yourselves

- **As an industry, now is the time to be developing and improving our advanced simulation capabilities.**