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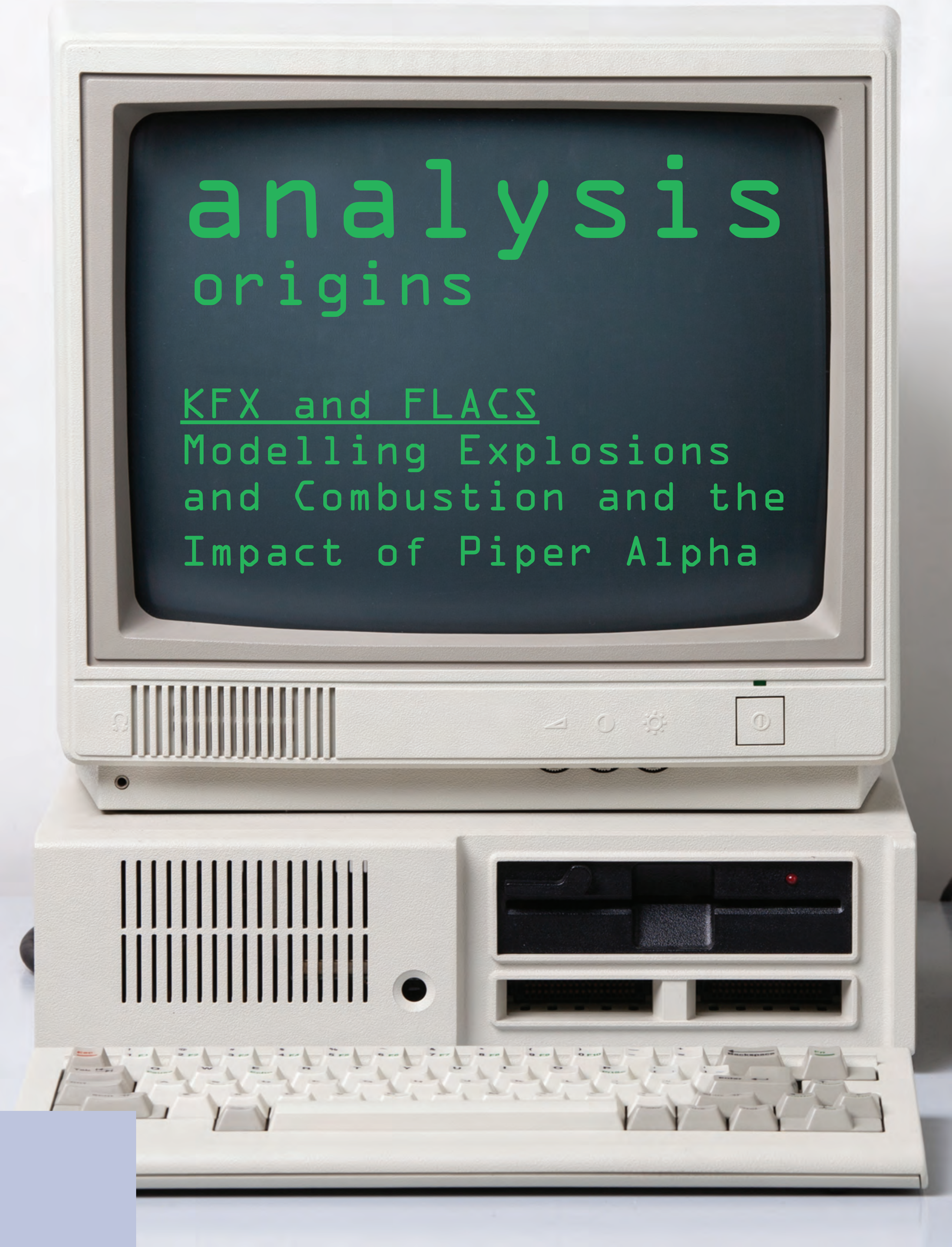
Artificial Intelligence & Machine Learning


analysis
origins
KFX and FLACS
Modelling Explosions
and Combustion and the
Impact of Piper Alpha

Introduction by Steve Howell

The catastrophic loss of the Piper Alpha platform claimed the lives of 167 people. On 6 July 1988, a small explosion caused secondary damage that resulted in a second larger explosion and then a sustained major fire. With a total insured loss of £1.7 billion (US$3.4 billion) it remains one of the costliest manmade disasters in history. Lord Cullen led the subsequent public inquiry into the tragedy, and his report outlined 106 recommendations for changes to safety procedures in the UK sector of the North Sea. In the aftermath of Piper Alpha and the Cullen Inquiry, a new focus was placed on modelling approaches for predicting fire and explosion events, including the use of computational fluid dynamics for mitigating the risk of fire and explosion damage. This feature considers the origins of two of the leading CFD codes for simulating fires and explosions in the offshore industry: KFX/Exsim and FLACS.

The Piper Alpha disaster was one that none of us wishes to repeat, but the lessons learned following the event through validation of numerical tools via experimental programmes have greatly improved our understanding of explosions and mitigation methods, which has helped to make our offshore facilities safer places to live and work. However, we mustn't be complacent. As the physical size and complexity of some of the new offshore facilities grow, we need to be aware of new associated risks – specifically DDT (deflagration detonation transition), where a subsonic explosion (a deflagration) may accelerate to the point where it can transition to a supersonic detonation. This is what is understood to have happened at Buncefield in 2005, and it is important because the level of damage is much more severe for a detonation.

There remain important challenges for the industry, specifically for the simulation tools in terms of their predictive capability and how they are used in practice. None of the CFD tools can yet robustly simulate detonations, but there are at least some measures relating to local pressure gradient that can be used to check for the onset of DDT. It is important, as an industry, that we remember the lessons of Piper Alpha and continue to develop the simulation tools for the new challenges ahead.

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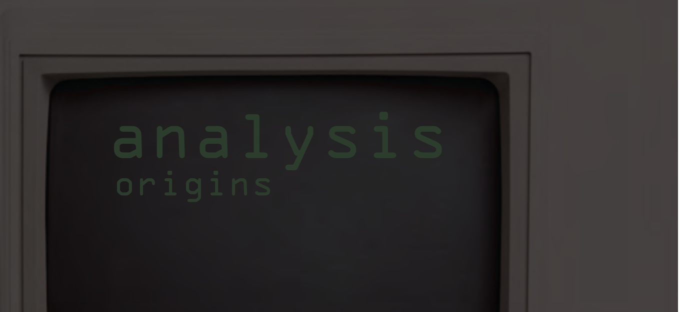
KFX



In 1976 Professor Bjørn F. Magnussen and his first doctoral student, Bjørn H. Hjertager, presented a seminal paper on modeling of turbulent combustion for numerical simulation at the Combustion Institute. This paper introduced the Eddy Dissipation Concept (EDC) and is by far the most-cited paper on fire modeling from the Combustion Institute. The concept turned out to be a very efficient and robust model, which has subsequently been implemented in most commercial CFD codes dealing with turbulent combustion.

The paper was the culmination of years of research at the Norwegian University of Science and Technology, NTNU (formerly NTH), in Trondheim, Norway. Since the 1960s, Magnussen had experimented with flames in the university laboratory, trying to understand the process of combustion and soot formation taking place in turbulent flows. After seeking an understanding of the physics, he started work on a mathematical model to calculate and incorporate the effects of turbulence.

Mathematically, the EDC is simple, though the physics are complex. It couples the turbulent flow with the combustion process through the reaction zones in the flow, the fine structures. The basic philosophic concept is that the turbulent eddies in the flow are broken down to fine structure zones where the chemical reactions take place. Magnussen's original hand sketch of the reactive zones was later confirmed through laser technique in the laboratory, where it was shown that the reaction zones in the real flow appeared in a similar way (see Figure 1).

In the 1970s, Magnussen and Hjertager were early adopters of practical 3D CFD. The two Bjørns continued their work on turbulent combustion modeling until around 1980 when their paths diverged: Magnussen remained at NTNU in Trondheim focusing on fire modeling and the development of the Kameleon CFD code, while Hjertager returned to his hometown of Bergen to focus on explosion modeling and the development of the FLACS CFD code.

Collaboration with industry

A substantial research group built up around Professor Magnussen at NTNU and SINTEF, the biggest independent research foundation in Scandinavia, also located in Trondheim. The group continued its research on fires and fire modeling. Collaboration with industry started in the late 1970s with simulation of flares, and continued with gas dispersion and fire development, including simulation technology for fire mitigation by various water-based systems. The research group provided advanced consultancy, working in close cooperation with oil and gas industry partners to solve specific problems, while also developing simulation tools. This close interaction between academia and industry is perhaps a significant reason for the industrial success of the methods and tools from this group, which has always had a practical approach.

Magnussen's CFD code was named Kameleon to indicate its adaptability as a general CFD code that could be used for many different applications. Later, having developed into a dedicated simulator for fire analysis, it became Kameleon FireEx, and eventually KFX. 'I had to decide where to focus,' Magnussen says. 'If I could make a contribution where I could save people's lives, that was what I wanted to do. So I decided to focus on what we could improve on offshore facilities from a safety point of view.'

For industrial safety applications, a major challenge for the CFD approach is to capture both the complex physics of combustion and the important effects of congested complex geometries typically found in process and offshore facilities. In KFX this is achieved through the use of a structured orthogonal mesh, a distributed porosity technique and other sub grid models. This approach makes it possible to simulate complex combustion events very efficiently. The physics can include gas or multiphase leaks, dispersion, liquid spreading, droplet sprays with rainout, evaporation, combustion, soot formation and smoke dispersion and radiation in congested geometries, even with complex surrounding terrain (Figure 2).

Ongoing development

Throughout its existence, KFX has been adapted and developed. 'In the early years, models had to be built manually, a little like LEGO on a computer,' says Trond Evanger, Managing Director of ComputIT. Simulations were necessarily coarse and simplified because of limited computing resources. Now the program is much more user friendly: it's easy to import large CAD models of offshore platforms or electronic maps showing the terrain of a larger area to automatically create the CFD model, while modern computing power means the models can be much more refined. Development of the

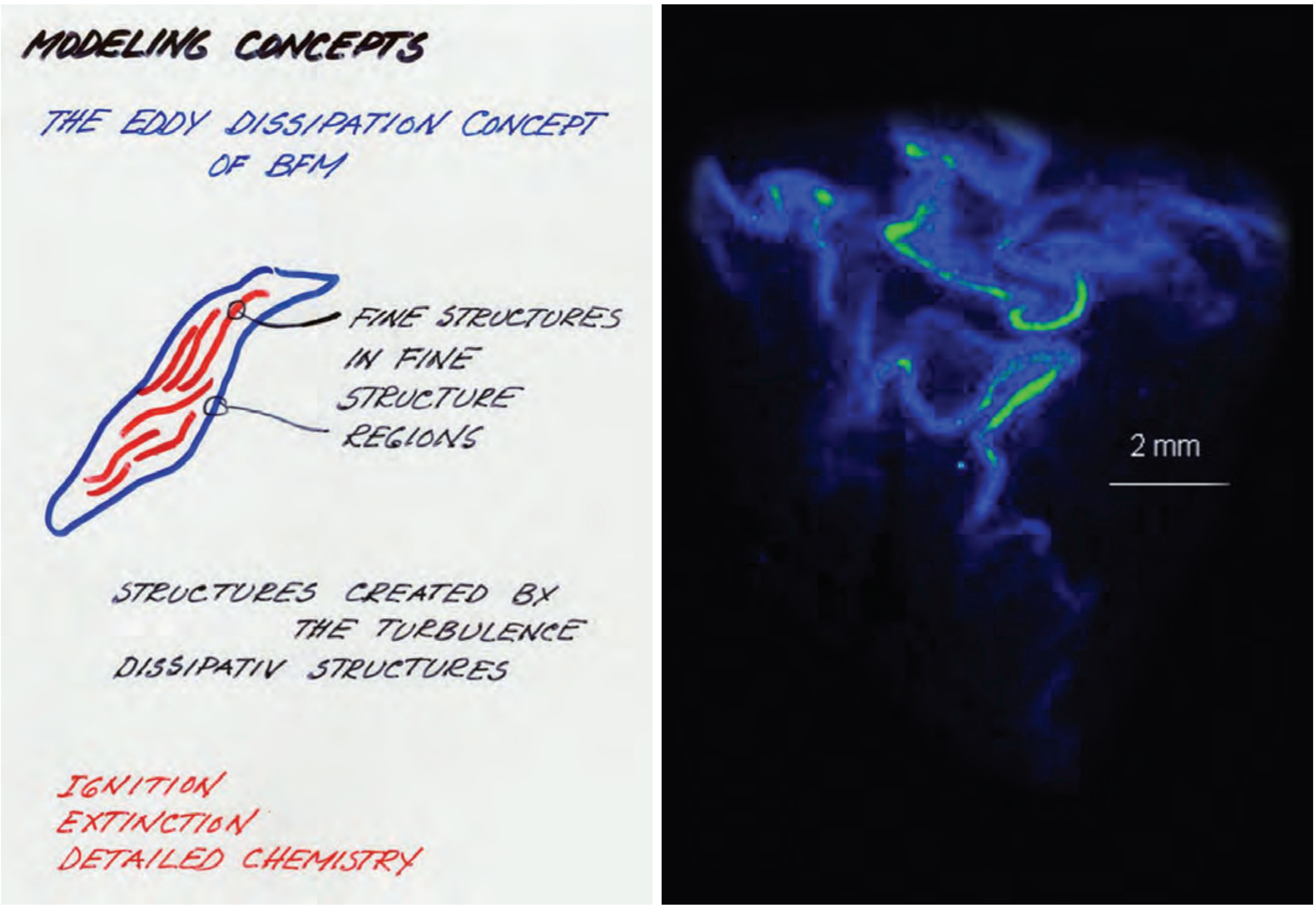


Figure 1: Magnussen's original hand sketch of the reactive zones (left) and the subsequent confirmation using laser photography (right).

code is still ongoing, and the collapse of the oil price in the last few years has strongly actualized the technology, as optimized design that can be achieved by detailed modeling is a key to production at lower cost.

The code is validated against large-scale experiments in terms of flow, heat transfer and radiation. One of the major test sites is the RISE Fire Laboratory, formerly the Norwegian Fire Laboratory at Sintef in Trondheim, where a huge outdoor test rig built like an offshore module for large-scale fire experiments was built by ComputIT and the fire lab with industry funding. Measuring systems on the rig make it possible to compare realistic fire events with simulations, including also a real-scale deluge system. Such tests are important not only for validation, according to Evanger, but also so engineers who simulate fires can actually experience them firsthand and feel the heat for themselves.

Industrial safety

Major industrial accidents onshore and offshore throughout the 1980s, including the loss of the Piper Alpha platform due to the devastating and sustained fire in 1988, focused attention on the development of more accurate simulation methods to better predict and understand the consequences of major toxic and flammable hazards in the process industries, in order to improve the accuracy of risk predictions and design of equipment, processes and safety barriers.

The petroleum industry realized the requirement for technology that could capture the interaction between accidental leaks and the complex geometries of industry plants both onshore and offshore, and that the rapid development of computer capabilities would facilitate this in the foreseeable future. The development of KFX since 1980 has been driven through JIPs with a total industrial funding of about US$20–25 million, in addition to a large number of related PhD theses. The impact of the CFD methodology on safety, design and cost in the petroleum industry has been astounding. In recognition of this, in 1995 Professor Magnussen was awarded the Statoil research price for 'significant contributions to the Norwegian oil and gas industry'.

Figure 2: Fire simulation visualisation

An Expert Witness

When lawyers were looking for a technical expert witness on combustion in an insurance trial deciding liability for Piper Alpha, Professor Bjørn Magnussen was an obvious choice. 'Even at that time I was a little bit famous,' he says. Professor Brian Spalding of Imperial College London gave evidence on gas dispersion at the same trial.

The basis for Magnussen's evidence was a series of photographs taken by a bystander on another platform. 'The sequence of pictures could tell us the evolution of the fire,' he says. 'I used a certain technique to look at the pictures, using a magnifying glass in a particular way to restructure it into a 3D view.' A key question at the trial concerned the size of a fireball: judging by the light emission on the rising structures that he could see in this almost-3D perspective, Magnussen says, it was by no means as big as it had been estimated.

The team at NTNU had previously been working with simulation of fires to calculate how long it might take to cause a rupture in a high-pressure pipe, but Magnussen's offer to simulate the Piper Alpha incident was declined. 'My vision has always been that if you have a real accident, you should go in and learn from what really happened,' he says. 'You should learn what to do in the future to make a safer structure and a safer operation.'

'The importance of the Piper Alpha accident was to put more focus on safety for offshore workers and offshore constructions,' says Magnussen. 'There had been many early warnings about leakage of gas, which were not properly taken into consideration. Today there is no chance that so many warnings would be ignored.'

Commercializing the code

ComputIT was established in 1999 to industrialize KFX. Trond Evanger had joined Magnussen's group at SINTEF in 1982, working in research and as a project manager on various joint industry projects. When Evanger learned of a business development opportunity, he contacted Magnussen and they seized the chance to make the KFX technology more widely available to industry. Since this time, KFX has taken a leading position internationally, especially for dispersion and fire simulations.

KFX now also covers gas explosions and structural integrity to explosion loads – and the fruitful collaboration between the two Bjørns has been re-established. Bjørn Hjertager had continued with explosion modeling as a professor at Telemark University College, and together with Shell Research he developed the Exsim software, which has been Shell's preferred explosion tool for more than 20 years. In 2014 ComputIT agreed with Shell and Hjertager to take over the full responsibility of Exsim, and has since then integrated Exsim into KFX as an explosion module.

The Exsim model is based on the Eddy Dissipation Concept, using the same modeling concept as KFX. The philosophy for KFX-Exsim is thus based on only one concept for modeling turbulent combustion covering both fire and explosion. This is important from a philosophic point of view, and provides assurance that industrial solutions are based on a consistent and coherent modeling concept.

A new chapter in the KFX history began in 2017 when DNV GL acquired ComputIT with the ambition to make CFD technology available for a larger part of the industry worldwide. KFX-Exsim is already being used by a large number of companies and universities around the world, but as a part of DNV GL new opportunities arise for CFD development and applications, and for the industry. The company's industry-leading test facilities at Spadeadam in the UK also represent unique opportunities in this respect.

'None of the codes can handle detonations at the moment,' Magnussen points out, but he and Evanger believe the EDC could be well suited to handle detonation simulations. Although this is an avenue they would like to explore, it would require a great deal of funding. Bjørn Magnussen is close to 85 years old but still comes into the office every day and has an eye on the future, 'because still there are a lot of things that can be improved.'

ComputIT would like to acknowledge Equinor (Statoil), Total, Eni, ConocoPhillips, Gassco, GRTgaz (Engie), and the Research Council of Norway for funding the development through many, many years.

Article written by **Trond Evanger** with support from **Fiona Shearer** and input from **Bjørn Magnussen**. Magnussen and Evanger are the co-founders of ComputIT. Shearer is a writer and editor.

Figure 3: Piper Alpha Memorial Garden at Hazlehead Park, Aberdeen, Scotland