Blind Prediction of Dispersion and Explosion Experiments Using CFD

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Abstract

Computational Fluid Dynamics (CFD) is used widely in safety assessments around the world and predictions often influence decisions on strength of structures. Since simulations are performed at scales and in scenarios where no experimental tests are available, it is essential that the predictive capability of the tools is acceptable. Frequently the predictive capability of CFD softwares is "proven" by simulating a couple of existing, well known, experiments which are usually at smaller scale than the scenario to be modeled. If the simulation tool is not reliable, the modeler has many possibilities to manipulate input and use tuning parameters to achieve good performance simulating the well known experiment. A more challenging and convincing way to validate CFD-softwares is to take part in blind prediction benchmark acitivities, where the experiments are either not performed at the time of prediction, or is made available after predictions are submitted. Over the past 2 years GexCon has used the CFD-software FLACS to blind predict a range of different scenarios, both dispersion and explosion, natural gas as well as hydrogen, with very good performance. The paper will describe some of the various experiments and blind predictions.

Keywords: CFD, FLACS, Validation, Explosion, Dispersion

Introduction

Computational Fluid Dynamics (CFD) tools have increasingly begun to play an important role in risk assessments for the process industry, be it oil and gas industry, hydrogen applications, and more. CFD is also employed for accident investigations as it can help understanding the chain of events that led to the accident. The models can also be used to identify and design protection measures after an accident. CFD tools have the potential to model the relevant physics and predict the effects of a certain incident. The CFD tool FLACS has been developed since 1980 [1,2]. Its inherent capability has been performing explosion and dispersion calculations to help in the improvement of oil and gas platform safety with initial focus on the North Sea.

Since simulations are performed at scales and in scenarios where no experimental tests are available, it is essential that the predictive capability of the tools is acceptable. Frequently the predictive capability of CFD software is "proven" by simulating a couple of existing, well known, experiments which are usually at smaller scale than the scenario to be modelled. If the simulation tool is not reliable, the modeller has many possibilities to manipulate input and use tuning parameters to achieve good performance simulating the well known experiment. Therefore, it is very important that extensive validation (with studies on variations of various important parameters that may affect explosion loads and hence risk) be carried out since physical processes that are relevant to safety are highly complex. Without proper user guidelines based on extensive validation work, very mixed prediction capability can be expected.

Significant experimental validation activity has contributed to the wide acceptance of FLACS as a reliable tool for prediction of natural gas explosions in real process areas offshore and onshore (e.g. [3]). Recent validation exercises performed in the area of hydrogen safety have led to FLACS becoming a well accepted tool in this area as well [4,5]. A more challenging and convincing way to validate CFD-software is to take part in blind prediction benchmark activities, where the experiments are either not performed at the time of prediction, or are made available after predictions are submitted. Over the past 2 years GexCon has used the CFD-software FLACS to blind predict a range of different scenarios, both dispersion and explosion, natural gas as well as hydrogen, with very good performance. The paper will describe some of the various experiments and blind predictions. These exercises have primarily been carried out as a part of our involvement in the European Union sponsored network of excellence HySafe and IEA Task 19. One example of natural gas work relevant to mining safety is also given.

1 Subsonic Hydrogen Jets

FLACS has been used to simulate gas dispersion experiments performed by INERIS in their gallery facility [6]. These simulations were carried out and reported blind two months before the experiments were carried out. The experiment is a hydrogen release (1 g/s for 240s) through a 20 mm orifice on top of a release chamber (26 cm above ground) with a 1-2 hour dispersion time thereafter in a 78.4 m^3 rectangular room. No ventilation is provided except 2 small openings near the floor on one of the walls. Concentration sensors are provided at various locations to monitor the hydrogen concentration. A comparison between FLACS blind predictions and observations is presented in Figure 1 for sensor 16, which was located on the jet axis 1.38m above the ground, and for sensor 12, which was located at a lateral distance of 1.4 m from the jet axis 88 cm above the ground. It can be seen that the blind predictions correlate very well with experimental data. Similar results were seen for all other sensors. 15 other partners in the HySafe project simulated the same experiment, and the results were presented at the International Conference on Hydrogen Safety (ICHS) in September 2007. A large scatter can be seen among the different predictions. The FLACS prediction is very good both for sensor 16 (jet dominated) and 12 (slow diffusion dominated), for sensor 12 none of the other predictions are near predicting the trend observed in the experiment. The results obtained by another company using FLACS were very consistent with our predictions (this simulation was stopped after 800s).

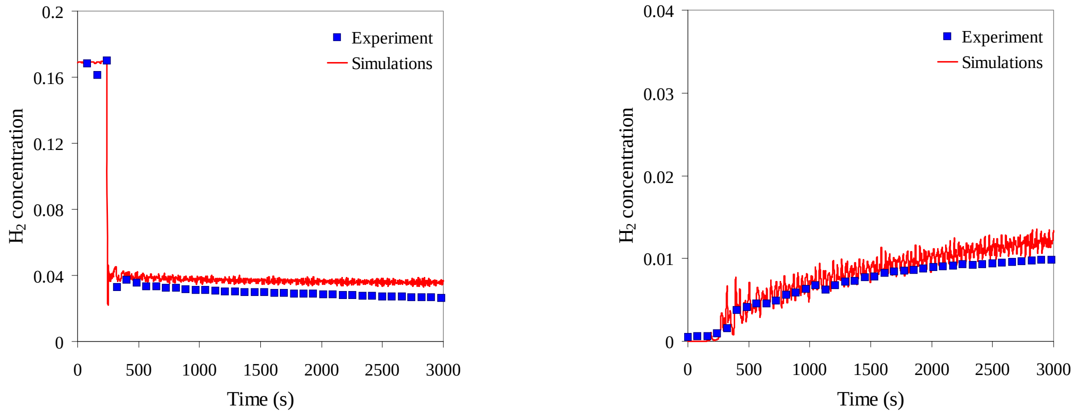

Figure 1. Comparison between FLACS blind predictions and experimental measurements for the INERIS gallery tests [6] for sensor 16 (left) and sensor 12 (right).

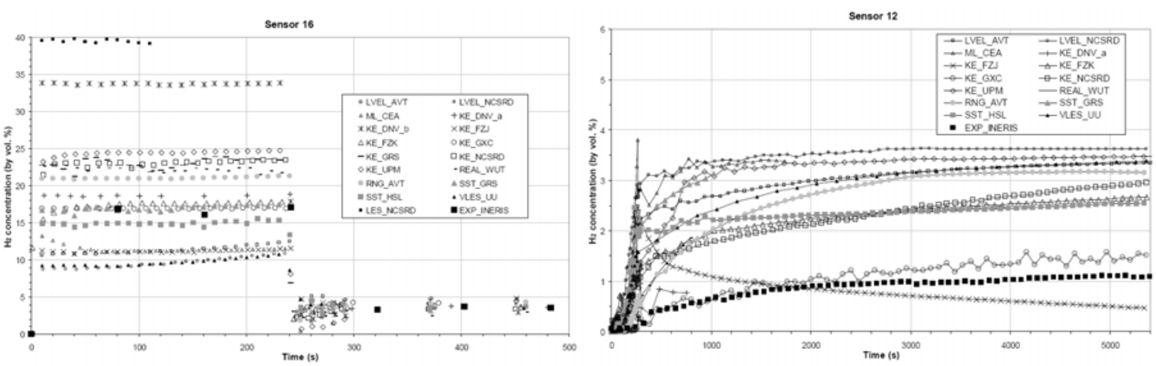

Figure 2. An overview of simulation predictions and experimental measurements for the INERIS gallery tests for sensor 16 (left) and sensor 12 (right) for all participating modelers. More details can be found in [6].

2 Hydrogen Refuelling Station

As a part of our involvement in the HySafe project, we have also been involved in the simulation of many other explosion benchmarks. These include experiments in a hydrogen refueling station carried out by Shell [7]. The experimental rig included a dummy vehicle, two dispenser units and a confining wall. The facility was surrounded by a metal frame, which was covered by a thin plastic film to retain a premixed almost stoichiometric hydrogen-air mixture. The mixture was ignited between the dispensers. A comparison of simulation and experimental results for two different measurement sensors is shown in Figure 3 and reasonable agreement is seen. The predictions using 2 different grid sizes were generally consistent with experimental results. However, the simulations with the finer grid predicted a too strong flame acceleration and pressures at two sensors in the turbulent wake behind the car. More details and information about simulations performed by other modellers can be found in [8].

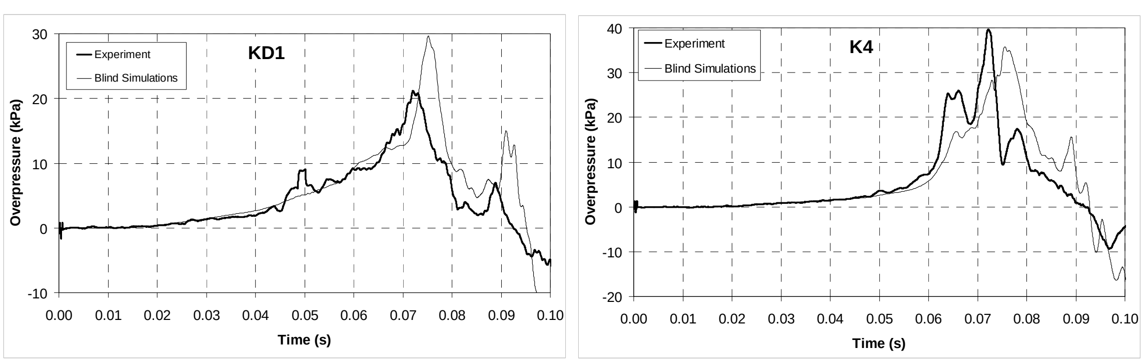

Figure 2. Experimental measurements and FLACS blind simulation results for two different sensor locations for the Refuelling Station experiment: KD1 (at the dispenser) and K3 (under the car).

3 Mining Safety

Thousands of people die globally in mine accidents every year. A significant fraction of the accidents are caused by explosions of methane. In 1997 FLACS was used to blindly predict methane explosions in two different mine tunnel test geometries. The South-African research institute, CSIR, thereafter performed the experiments and evaluated the blind predictions. Good results were seen for FLACS blind predictions for both scenarios. As a consequence of the Sago Mine accident in 2006, the US National Institute for Occupational Safety and Health, NIOSH started an activity evaluating the design of seals. One observation from the Sago accident was that the concrete seals applied were far from strong enough to withstand the explosion. In the research initiated by NIOSH, one activity included the simulation of existing NIOSH experiments (performed in the Lake Lynn experimental mine) to evaluate the ability to predict or reproduce existing experiments. Thereafter, potential mine explosions at larger scales were simulated to study the required seal strength as a function of separation distance of seals. Six different experiments with gas cloud sizes up to 18 m length in two different mine geometry configurations were simulated. The FLACS simulations were carried out prior to receiving information about the test results. Still very good results were obtained, with 8 out of 12 maximum overpressures (6 tests and 2 observation locations) predicted within 10% of observed values, and the worst prediction of the 12 with a deviation of only 24%. Figure 4 presents a comparison between observed and predicted overpressures for three different locations [9]. As a result of this work, new design criteria for seals have been established. The two studies mentioned have confirmed that the blind predictive capability of FLACS is very good for the situation with methane gas clouds in tunnel systems.

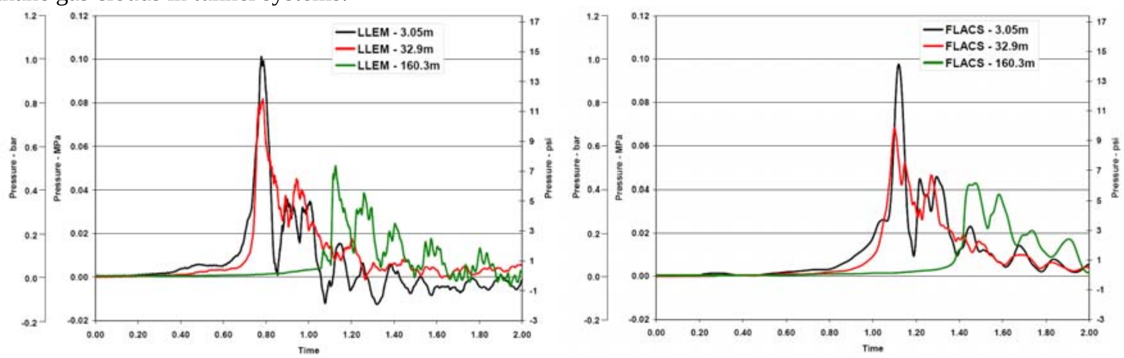

Figure 4. Comparison of FLACS blindly predicted pressures (right plot) and NIOSH test results from Lake Lynn Experimental mines (left plot) for three different locations [9]. The deviation in arrival time is a consequence of the strong ignition source used in the tests.

4 Impinging Jets (Low and high momentum)

Forschungzentrum Karlsruhe (FZK) has recently carried out an extensive study which can be used for model validation for jets of different momentum. As a part of this study, 9 different vertical hydrogen releases (varying nozzle size, release rate, and momentum) impinging on a plate 1.5 m above were studied in two geometrical configurations (plate and hood). The resulting gas cloud was ignited and overpressures were recorded at various different locations [10]. GexCon carried out and reported more than 200 blind simulations with FLACS before the experiments were conducted. Both release phase and ignition of jets were modelled. The predictions were evaluated against experimental data after the tests were completed. This kind of experiment is very important for developing risk assessment techniques for hydrogen applications, as it is possible to study the explosion loads resulting from a "realistic" gas cloud.

The simulated and observed concentration profiles for a 21 mm nozzle for both geometries for a release rate of 3 g/s are presented in Figure 5. It can be seen that the results compare very well. Good agreement was seen between the blind predictions and observations for all different release scenarios in terms of hydrogen centerline and lateral concentrations and the shape of the plume.

The gas clouds were further ignited as described above. The resulting overpressures from the combined dispersion and explosion scenario were reasonably well predicted. More details about this can be found in [10].

Conclusions

This article presents selected examples of the extensive blind validation activity for simulation of dispersion and explosion phenomena relevant to process safety. Modelling results are compared to experimental data, and in general, reasonable agreement is seen for many different kinds of scenarios. This points to the ability of FLACS to model scenarios relevant to safety and accident investigations. It should also be mentioned that during the extensive validation work with hydrogen safety we have identified some weaknesses in the modeling, which can sometimes lead to less precise results. Work has been initiated to improve these models. To detect potential weak models when doing model predictions, it is always recommended to perform a quality assurance, which should include grid sensitivity studies.

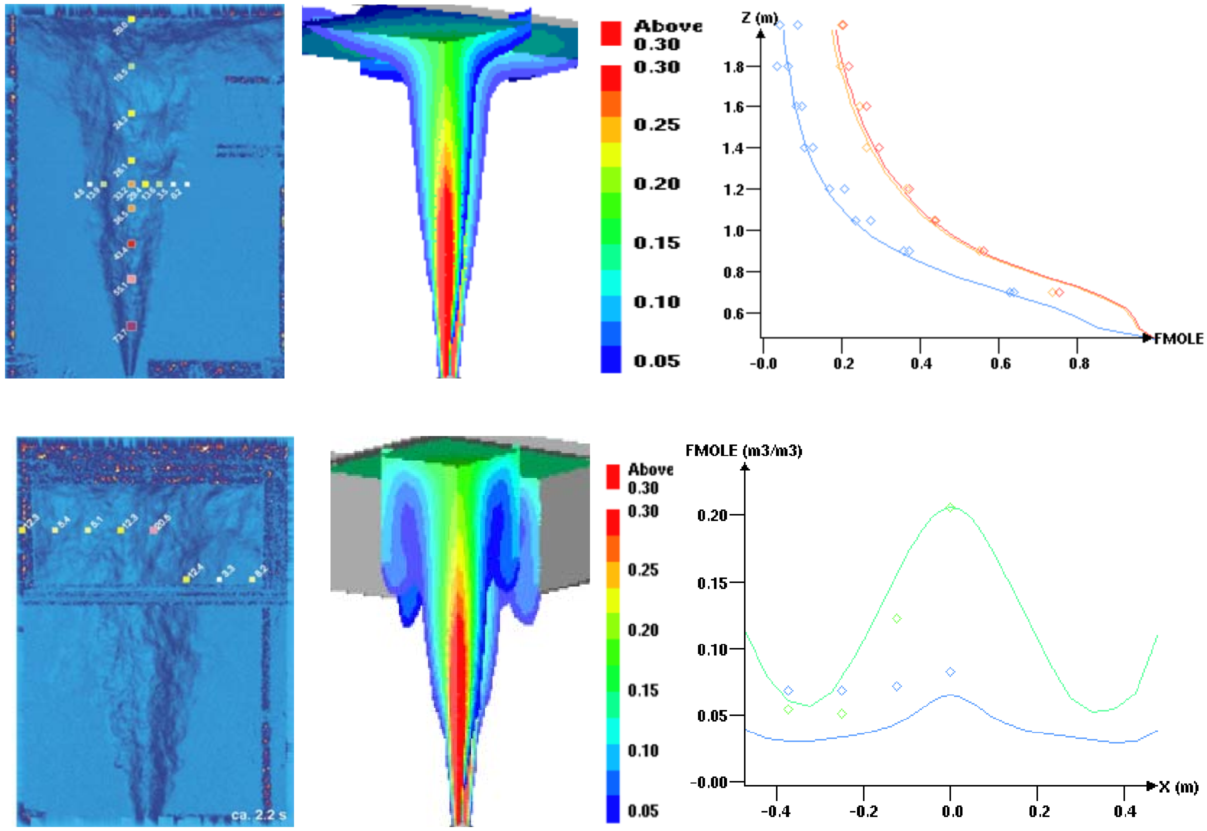

Figure 5. Comparison of experimental photograph/recording with FLACS predicted plume shape and concentrations for release from 21 mm nozzle (3 g/s) in the plate geometry (top) and hood geometry (bottom).

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