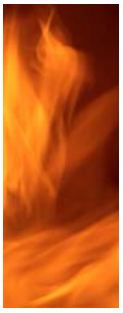
MINUTES OF MEETING

FLACS USER GROUP (FLUG)



Venue: Bergen, Norway, hosted by GexCon
Meeting: 23-24 May 2013
Issued: 18 July 2013
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Distribution: FLUG mailing list
Attachment: Safety Gap Notification

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FLUG meeting 23-24 May 2013

FLUG chair: Chris Savvides (BP)

FLUG Meeting – 23 May

Welcome

Erik Aadland (GexCon) and Chris Savvides (BP) welcomed the participants to Bergen and FLUG. There were no comments to the minutes from the previous meeting (available from the FLUG website). Erik commented that a few users have reported issues with network licences for FLACS v10, but that generally the new licence system is more stable compared to the old system.

GexCon Software: Activities and prospects

Erik Aadland (GexCon) presented the latest news from GexCon Software. The number of users has increased by 30 over the last 12 months, compared to 20 over the same period in 2012. The ambition is to grow further, and to double the 2012 revenue by 2015. Despite the positive trend, development of FLACS is still an on-going investment for GexCon. At the time of the meeting, GexCon Software and GexCon R&D have seven vacant positions. In addition to the basic FLACS training course, GexCon intends to add several more advanced courses to the portfolio.

GexCon R&D: Activities and prospects

Trygve Skjold (GexCon) presented the status for GexCon R&D. The implementation of Agile methodologies for software development continues. Two new co-workers have joined the department: Laurence Bernard, who will do a PhD on mist and spray combustion, and Sunil Lakshmipathy, who will work on testing and validation. Regarding organization, the department is in the process of defining the roles of technical leads for areas such as turbulence, dispersion, premixed combustion, and non-premixed combustion. It is foreseen that the role of a technical lead will cover modelling, validation, documentation, publication, training, and project management.

On-going R&D projects include NORCOWE (wind energy and atmospheric flow), CO2PipeHaz (release and dispersion of carbon dioxide; finalized in May), and IEA Task 31 on hydrogen safety (runs up to December). Trygve announced the forthcoming release of FLACS v10.1 (officially released 20 June 2013), in line with the goal to release new versions twice per year.

Trygve briefly summarized the plans for an integrated validation framework for FLACS, and Chris Savvides (BP) commented that the validation report is very important. Trygve agreed, but also emphasized the advantages of a web-based interface to the validation database, which will allow users to select validation cases for specific application areas based on selected criteria.

A new joint industry project (JIP), “Modelling Escalating Accident Scenarios and the Use of Risk-reducing technology for Explosion safety” (MEASURE), started on 1 July 2013 and is scheduled to run for two and a half years. The primary focus area will be fundamental improvements to the turbulence and combustion models in FLACS, with the direct application of improving the predictive capabilities with respect to vapour cloud explosions (VCEs) in complex geometries, and particularly safe design of critical separation distances, also referred to as ‘safety gaps’. The JIP includes experiments aimed at producing state-of-the-art validation data for flame propagation through repeated congested regions. Depending on the number of sponsors, the JIP may also include activities such as simulating detonations, distributed memory parallelization and adaptive mesh refinement. Potential participants may join the JIP up to 30 November 2013.

Trygve also mentioned a related JIP proposal, coordinated by Health and Safety Laboratory (HSL), concerning the application of sensitivity and uncertainty analysis to consequence modelling in the process industries. Interested parties should contact Simon Gant (HSL): simon.gant@hsl.gsi.gov.uk

Trygve concluded with some thoughts on a prospective tool for 3D risk management in FLACS, and mentioned the “Tenth International Seminar on Hazards, Prevention and Mitigation of Industrial Explosions” (X ISHPMIE). The conference will be organized by GexCon and the University of Bergen, and will take place in Bergen 10-14 June 2014. For further details: www.xishpmie.com

The effect of vegetation on gas explosions in a 1.5 m channel

Helene Hisken Pedersen (GexCon) presented recent experimental and modelling work at GexCon R&D/Labs on the influence of vegetation on gas explosions. The main motivation for the study was the Buncefield incident on 11 December 2005. The initial accident investigation concluded that very low wind speeds made it possible to generate a very large cloud within the flammable range, and that ignition most likely took place in the emergency pump house, before the flame propagated into bushes and trees along the nearby roads.

Helene showed videos from earlier experiments performed by GexCon on Sotra, with flame propagation through tents with and without vegetation. Explosions are much more violent with trees or bushes present, since trunks, branches, leaves and needles act as obstructions with components that cover a wide range of spatial scales. Helene pointed out that in a strong deflagration or deflagration-to-detonation-transition (DDT) event, trunks and branches of a tree will not have time to respond/deflect significantly.

The experiments were carried out at GexCon in a 1.5 m long channel with slightly over-stoichiometric propane air mixtures and several types of obstructions: Norway spruce (*Picea abies*) branches, with and without needles, steel models of the spruce branches without needles, as well as mugo pine and Thuja branches. Helene described the total length and diameter distribution of the spruce branches, as well as an approximate blockage ratio determined from photographs.

The experiments showed that even inserting a single branch into the channel results in significant flame acceleration. When the needles were removed from the spruce branches, the overpressures were reduced with approximately a factor of 3. Thuja branches gave the highest overpressures in these experiments, which is consistent with their high blockage ratio. Either the drag area or the volume of a typical tree/bush was used to model the influence on flame acceleration, using a lower cut-off scale for the smallest components of vegetation. In the simulation, an enhancement factor of 3.5 for the drag area accounted for the effect of the needles. Helene emphasized the importance of the finer geometrical details, and that it is not sufficient to account only for the tree trunks in the geometry model. For large unconfined scenarios, the effect of vegetation may be less pronounced than in the duct experiments, but evidence from accidents suggests that DDT may occur in dense vegetation.

Chris Savvides (BP) inquired about the modelling of large-scale experiments with flame propagation through vegetation, and Helene confirmed that this naturally would be done if/when such results are available. Henri Tonda (Total) inquired about the cell size used in the simulations, and Clément Lapierre (IRSN) asked about the sensitivity of the results. Helene answered that the results were obtained with 3 cm grid cells, and that simulations on a 5 cm grid indicated moderate grid dependence. Chris Savvides (BP) wondered about the validity of the results for different types of trees, and Helene suggested estimating the volume blockage from visual inspection. Olav R. Hansen (GL Noble Denton) raised a question regarding how the enhancement factor of 3.5 for the drag area was implemented. Helene commented that this was done by putting in more obstructions.

Pipeline releases of carbon dioxide – Experiments & simulations

Vagesh Narasimhamurthy (GexCon) presented results from the EU FP7 project CO2PipeHaz. The pipeline is the 'missing link' in the carbon capture and sequestration (CCS) chain, connecting the carbon dioxide (CO_2) production and storage sites. The CO2PipeHaz project focused on the potential hazard of pipeline ruptures, resulting in massive releases of CO_2 along the pipeline. The project split the modelling into four parts: thermodynamics, in-pipe and outflow conditions, near-field and far-field. GexCon coordinated the efforts related to far-field dispersion, and have developed a pseudo-source model for CO_2 release and a Lagrangian particle tracking model in an internal R&D version of FLACS. FLACS results were in good agreement with results obtained by HSL using ANSYS CFX, and the CFD results were in good agreement with small-scale experiments performed by INERIS and industrial-scale releases performed by Dalian University of Technology (DUT).

Olav R. Hansen (GL Noble Denton) commented that the CO_2 concentrations measured in the far field are expected to be less sensitive to the representation of the particles in the Lagrangian model.

FLACS-Fire: Status and prospects for the upcoming release

Deiveegan Muthusamy (GexCon) presented the status for the on-going development of FLACS-Fire, including selected validation cases: an impinging jet (SINTEF), an LNG flare, an LPG flash fire, a

compartment fire, and fires in an enclosure (SINTEF). Future validation work will include liquid spills with pool and flash fires, hydrogen fires, and improvements to the wall conduction model.

Parag Gupte (ExxonMobil) inquired whether GexCon has access to data from the fire experiments by Sandia National Laboratories, and Deiveegan replied that he would look into this. Masatake Yoshida (Explosion Research Institute) asked whether it is possible to use FLACS-Fire for large-scale LPG fires, such as the very violent events in Japan following the Tōhoku earthquake and tsunami on 11 March 2011. Deiveegan expressed that he anticipates that it will be possible, but that such scenarios have not been simulated yet. Masatake inquired about the anticipated release date for FLACS-Fire, and Deiveegan replied that the current plan is to release a commercial version in December 2013. Chris Savvides (BP) would like to see further comparison between FLACS-Fire to KFX, but Deiveegan stressed that the results he showed in his presentation were only representative for the specific validation cases. Jamie Thompson (Arcadis) inquired about the computing time for the SINTEF enclosure case, and Deiveegan estimated this to about three days on a single core using the Discrete Transfer Method (DTM). If the lower accuracy of the six-flux model is sufficient, the simulation time can be shortened to less than one day. Performance optimization and parallelization of FLACS-Fire are still to be carried out.

Pool fire smoke propagation towards urban areas

Camille Azzi (GexCon) presented a case study involving the propagation of smoke from a pool fire towards urban areas. Rather than modelling the fire directly, a specified source term represented the production of smoke in FLACS. The simulations show that topography, wind speed and wind direction are important factors influencing the results, and significant exposure to smoke may occur in the city centre under unfortunate wind conditions.

Overview of the new FLACS v10.1 release and the roadmap for FLACS

Djurre Siccama (GexCon) presented the new FLACS v10.1 release. The highlights include bug fixes in CASD, such as steady-state temperature and issues with surface area leaks in the leak wizard, and added feature such as the possible to specify fuel mass fraction in the “Create new gas cloud” option. The Porcalc version used for the porosity calculations is now stored in the cp-file. In the core simulator Flacs, it is now possible to define up to 8000 monitor points and panels for each simulation. Djurre listed a range of features in the beta release of Flowvis 5, and showed a preliminary roadmap for FLACS.

Djurre introduced the JIP on FLACS-Fire, scheduled for 2014-2016. The intention is to extend on modelling capabilities of the prospective December 2013 release, primarily jet and pool fires, multi-phase jet fires, parallelisation of the DTM model, adaptive radiation ray tracing, QRA methodology, and further validation.

Karim Osman (GDF Suez) asked whether the license system would change for FLACS v10.1, compared to FLACS v10.0. GexCon responded that the license system remains unchanged, including the hardware key (dongle).

Demonstration of Flowvis 5

Tommy Lea (GexCon) demonstrated a beta version of Flowvis 5. A question was raised whether it would be possible to have a different scale in z-direction, relative to x- or y-direction, for simulation domains with high aspect ratio. Djurre said that this is something GexCon would like to implement in the future. Olav R. Hansen (GL Noble Denton) was concerned whether you lose some functionality when running Flowvis 5 compared to Flowvis 4. GexCon responded that not all functionality from Flowvis 4 is available in the current beta version of Flowvis 5, such as the ability to show the ignition point or to visualize streamlines. However, most of the old functionality will be included in the official version. Python scripting will be possible in future version of Flowvis 5.

Demonstration of geo2flacs

Thomas Landvik (GexCon) presented the beta release geo2flacs, including improvements implemented thus far and plans for future development.

Daniel Mahoney (Atkins) asked whether the new representation of inclined objects leads to enhanced turbulence generation. Trygve Skjold (GexCon) responded that GexCon would have to look more into this to give a clear answer. Olav R. Hansen (GL Noble Denton) reported problems running geo2flacs2b: beams becoming cylinders, and crashes that caused the computer to hang.

Stian Jensen (Scandpower) asked about support for the DGN format. GexCon responded that there are improvements for both v7 and v8 of the DGN format. Masatake Yoshida (Explosion Research Institute) asked whether geometry in STL format can be imported using the new geo2flacs, and GexCon responded that this should be viable in a future version. Daniel Mahoney (Atkins) asked whether the import feature in the geo2flacs plugin in CASD could append geometries from different CAD formats, and Thomas replied that the input might consist of mixtures of different formats. A question was raised whether terrain import would be possible in geo2flacs, and GexCon responded that it is on-going work on this, and terrain import is planned to be available in a future version of geo2flacs. Masatake Yoshida pointed out that it would be more useful for certain geometries to be able to use tetrahedra, rather than a new CAD file format. Djurre Siccama (GexCon) pointed out that CP8s can be used to represent tetrahedra, but they do not generate sub-grid turbulence and take long time in the porosity calculation. Jamie Thompson (Arcadis) wanted to know how staircases can be more accurately imported than bounding boxes, which are also obtained when using geo2flacs2b. Helge Hestetræet (GexCon) pointed out that they at least look much better than previously.

Advanced visualization techniques for multivariate data sets

Ove Daae Lampe (CMR Computing) presented advanced visualization techniques for multivariate data sets. One application could be analysis of results from multiple CFD simulations, for instance during a probabilistic risk analysis. Interested persons may contact CMR Computing for further details.

Sensitivity study on mitigation measures: Weather cladding and water deluge

Josué Quilliou and Ingvild Lid (both GexCon Consulting) presented a sensitivity study on the effect of mitigation measures based on weather cladding and water deluge. Weather cladding protects equipment and personnel, but increases the degree confinement. Water deluge increases the initial turbulence intensity in the cloud and it is necessary to use waterproof equipment, but droplet break-up reduces the rate of combustion significantly. Removal of weather cladding enhances ventilation and reduces the size of the flammable clouds. This decreases the explosion loads resulting from relatively small clouds, compared to a slight increase caused by deluge. Deluge significantly reduces explosion loads of large flammable clouds, compared to a modest decrease for increased venting. Venting has the largest impact on the overall explosion risk, since the effect of deluge is most efficient for explosions in large clouds, i.e. low-probability high-consequence events. The combined effect of mitigation by venting and deluge showed significant reductions in explosion risk for all scenarios considered.

Chris Savvides (BP) commented that one should be careful applying mitigation measures, since they may introduce other risks.

FLUG Meeting – 24 May

Explosion in a turbulent jet

Karim Osman (GDF SUEZ) presented a case study involving explosions after igniting a turbulent jet resulting from a small leak (25 mm, 67.7 bar) in a natural gas transportation network. The overpressures were relatively low.

Djurre Siccama (GexCon) inquired whether simulations of stoichiometric clouds had been performed, and Karim replied that this resulted in even lower overpressures. Olav R. Hansen (GL Noble Denton) commented that the smallest dimension of the cloud was not always resolved by 13 grid cells, according to grid guidelines, and that this may explain some of the grid dependency.

Modelling of safety gaps in FLACS

Daniel Mahoney (Atkins) presented FLACS simulations of the RIGOS ('research to improve guidance on separation distance') and ERGOS ('extended research for guidance on separation distance') experiments from TNO. The purpose of the experiments was to generate empirical data for the critical separation distance (CSD), i.e. the minimum separation distance between two congested areas that still results in two separate blast waves. For these experiments, FLACS predicts the overpressures in the donor region reasonably well, but significantly over-predicts the pressure in the acceptor region.

Olav Sæter (Statoil) asked whether the measurements included flame speed when the flame exits from the donor region. Apparently, this was not the case. Olav challenged GexCon to prepare an official statement regarding the applicability of FLACS with respect to simulating this type of

phenomena, and describe how GexCon plans to approach this issue, both short-term and in a longer perspective. Trygve Skjold (GexCon) responded that GexCon will prepare such a statement (the statement is included as an attachment to this document), and that GexCon has investigated the cause of the over-prediction in the acceptor. The long-term solution entails a fundamental revision of the turbulence and combustion models in FLACS, in conjunction with rather extensive validation and sensitivity studies[1]. There are indications that a simple workaround may prove useful in a short-term perspective, but this approach does not address the root cause of the poor model performance, and the results are likely to depend on the user. Helene H. Pedersen (GexCon) commented that GexCon has very limited access to experimental results from the RIGOS and the ERGOS experiments, and there is limited information regarding the repeatability of the experiments. On a general note, GexCon is reluctant towards changing the modelling in FLACS in a less conservative direction unless there is sufficient experimental data to support this decision.

FLACS for onshore/FPSO/FLNG blast studies: weaknesses and potential model improvements

Olav R. Hansen (GL Noble Denton) gave a presentation on the use of FLACS for onshore/FPSO/ FLNG blast studies, with emphasis on weaknesses and potential model improvements.

The integral/empirical models normally used for onshore explosion studies have severe limitations. CFD models such as FLACS typically have fewer limitations, and validation studies show that FLACS generally predicts overpressure in full-scale explosion experiments well. However, in a few cases, such as tests 4, 19 and 22 in the BFETS Phase 3A series, the experimental results are significantly under-predicted. There are indications from both experiments and accidents that DDT may be more likely to happen than previously anticipated, and this is likely a contributing factor to the poor model performance some of the full-scale tests. The DPDX parameter, available from FLACS v10, indicates the likelihood of DDT during an explosion simulation. Simulation results show overpressures in good agreement with the experimental results mentioned above up to the point where detonation occurs, and the simulated DPDX values indicate a reasonably high likelihood of DDT in those cases.

It is possible to use a cn-file to reduce the time-step, and hence limit the numerical smearing, during far-field blast wave propagation, but Olav encouraged GexCon to develop automated features for controlling the time-step. For scenarios involving safety gaps, the simulated flame accelerates too much when entering the acceptor, resulting in overly conservative explosion pressures. A temporary workaround was proposed, but changes of a more fundamental nature are required for the future.

Trygve Skjold (GexCon) commented that GexCon will look into the short-term workaround for the ‘safety-gap’ problem, but the primary goal is to implement lasting improvements to the turbulence and combustion models. Chris Savvides (BP) commented that care should be taken when working with improvements to the model system, since many of the models in FLACS are interconnected.

Olav Sæter (Statoil) asked about the relevance of the blast solver in FLACS. Idar Storvik (GexCon) commented that blast blocks are available in FLACS, and that the flux corrected transport (FCT) solver is second order (same as the standard Flacs solver). The blast solver might be used as a supplement, if the computational resources are limited.

On the possibility of using FLACS for Hazardous Production Facility design in the territory of the Russian Federation

Denis Vladislavovich Degtyarev (STC Industrial Safety) gave a presentation on the possibility of using FLACS for hazardous production facility design in the territory of the Russian federation. The Russian design philosophy is in general to follow published standards and norms. Companies and authorities are used to the method of risk analysis, for instance by employing the tool Toxi+Risk (similar to Phast). It is possible to deviate from norms and standards by providing sufficient documentation for the alternative methodology, but this approach is not straightforward since the method of substantiation has to be authorized based on a project-specific technical specification and documentation. Hence, it is a goal to obtain a normative document for general use of FLACS, to avoid substantiation for each individual project.

Erik Aadland (GexCon) asked when it is expected that such a normative document can be prepared. Denis replied that help is needed from GexCon to develop such a document, and the approval process could take in the range of 3-6 months.

[1] This is the primary goal of JIP MEASURE project. The project started 1 July 2013, but additional partners may join the JIP consortium up to 30 November 2013. Please contact GexCon R&D for further details.

CFD dispersion modelling supporting the design of a potential oil shale field test

Parag Gupte (ExxonMobil) gave a presentation on CFD dispersion modelling supporting the design of a potential oil shale field test. It has been a concern during the study whether dispersion of pyrolysis gas potentially could represent a risk for personnel. The mitigating measures considered include a constructed barrier and a fan to lower the concentration. The potential for gas explosion was also considered. The simulation results imply that is highly unlikely that an explosive fuel-air cloud can build up.

Convergence, efficiency and accuracy

Stian Jensen (Scandpower) presented two studies of grid dependency, convergence, efficiency and accuracy from two offshore installations. Scandpower uses FLACS routinely for probabilistic explosion analyses. A typical offshore study involves 200-800 explosion simulations, and it is not practical to run all of them with the highest grid resolution. The aim is to obtain a good balance between accuracy and computational cost/efficiency. The results showed significant influence of grid resolution on the results, and differences between the compressible and non-compressible versions of FLACS.

A comment from the audience pointed out that certain parts of the geometry may be on-grid on a fine grid, and sub-grid on a coarser grid, which may explain some of the grid dependency. Values for the computing time when running the incompressible solver compared to the compressible solver, were presented for a set of test examples. For these tests, the compressible solver was actually marginally faster than the non-compressible solver in most cases[2].

Results for the accuracy when employing the incompressible solver compared to the compressible solver, were presented for a transient simulation case of a hydrocarbon gas release in an enclosed process module. It was found that the maximum flammable cloud (Q8) was obtained about 700 s (physical time) later with the incompressible solver compared to the compressible solver and about 10 % less maximum Q8 volume (test for high release rate, for low rate test, the arrival time is approximately the same and the volume is less different).

It was commented that the choice of boundary conditions might explain some of the difference between the incompressible and compressible solvers. Djurre Siccama (GexCon) commented that it might help to choose a fixed time-step for the incompressible solver[2].

An approach utilizing Computational Fluid Dynamics (CFD)-codes for the determination of acceptable risk level for helicopter operations exposed to hot gas emission

Olav Sæter (Statoil) presented a method based on CFD for determining acceptable risk levels for helicopter operations exposed to hot gas emissions. The approach adopted entails establishing tolerance criteria for the temperature at different elevations above the helideck. This leads to an operational restriction mode for helicopters. Analysis of two triggering events indicates that the approach is capable of addressing the risk of hot gas exposure.

Assessment of gas explosion parameters using FLACS and AutoReaGas

Vitaly Chizhevskiy (Krylov State Research Centre) gave a presentation on the assessment of gas explosion parameters using FLACS and AutoReaGas. For a case with relatively low congestion, FLACS simulations tend to give lower explosion pressures compared to AutoReaGas. The reason for this difference could be looked more into.

Formal issues – Next meeting and closing

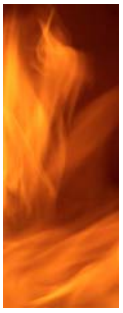
The date and venue for the next FLUG meeting was not confirmed during the meeting in May. However, the autumn meeting is scheduled for 7-8 November 2013, to be hosted by GL Noble Denton at the Spadeadam test site near Brampton in Cumbria, UK. GexCon will provide further information about the event in due time.

The chair thanked the participants for all contributions and closed the meeting.

[2] The explanation for the poor calculation speed and accuracy obtained with the non-compressible solver for this scenario is the high Mach number (about 0.67) used in the simulation. The maximum velocity in the CFD domain reaches values in excess of 300 m/s in the simulation using the 'compressible' solver (the user specified velocity at the leak is 300 m/s), which corresponds to a Mach number that is much higher than FLACS guidelines for the use of the incompressible solver. The primary advantage of the non-compressible solver is increased calculation speed for scenarios with low Mach numbers. The FLACS User's Manual for version 10.1 contains updated guidelines for the non-compressible solver.

NOTIFICATION

On the use of simulation results obtained with the CFD code FLACS for optimizing safety gaps between repeated congested regions



Issued: 18 July 2013
Prepared by: Helene H. Pedersen, Trygve Skjold
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Approved by: Trygve Skjold
Distribution: FLUG mailing list
FLUG web page

Background

The CFD code FLACS has been developed and validated for simulating gas explosions in complex geometries. One of the more recent application areas for the software is the optimization of critical separation distances, or safety gaps, between repeated congested areas in process facilities. The primary source of empirical data describing flame propagation and pressure build-up for this type of scenarios is the RIGOS (Research to improve guidance on separation distance) and ERGOS (Extended research for guidance on separation distance) experiments conducted by the Dutch Organization for Applied Scientific Research (TNO). Figure 1 illustrates the experimental setup.



Figure 1 Experimental setup for the RIGOS and ERGOS experiments.

The aim of the ROGOS and ERGOS experiments was to develop quantitative guidance with regard to the critical separation distance. The flammable mixtures were contained in tents that covered two separate blocks of pipe arrays. After ignition to deflagration in the centre of the primary block, the flame propagates from the primary (“donor”) to the secondary (“acceptor”) congested region.

Recent validation work shows that FLACS predicts the explosion pressure in the primary congested region well. However, FLACS significantly over-predicts the simulated rate of combustion in the secondary congested region, and hence the local over-pressure for several of the RIGOS and ERGOS configurations. Within a certain range of separation distances, FLACS predicts an increase in the explosion pressure in the acceptor for growing separation distance, whereas the available experimental results show a steady decrease in the pressure over the same range.

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Unfortunately, GexCon has only limited access to experimental data from the RIGOS and ERGOS experiments. The experiments were performed on relatively modest scales, compared to typical geometries encountered in industry, and the repeatability of the experiments is not known. Hence, it is not straightforward to quantify the severity of the over-prediction in the simulations.

From the available experimental data, the mechanism that causes the over-prediction appears to come into effect when the safety gap is in the range one to two times the dimension of the congested regions. The model system has been validated and optimized for numerous gas explosion experiments in geometries with varying degree of congestion and confinement, and the limitation with respect to reproducing deceleration and acceleration of flames in the space between repeated congested regions has thus far only been observed experimentally for RIGOS and ERGOS. The unsatisfactory representation of trends observed in these particular experiments is caused by the modelling of *flame instabilities* and the *turbulent length scale* used by the combustion model. However, GexCon has observed a similar tendency towards over-prediction of the explosion pressure in secondary congested regions in simulations performed as part of risk assessments for process plants.

Various actions have been initiated to remedy the situation:

- GexCon has contacted TNO in order to gain access to more detailed data from the RIGOS and ERGOS experiments. However, this may not be straightforward, since the results presumably belong to the consortium that financed the experiments.
- GexCon has contacted other companies, including Shell Global Solution, that have access to data from relevant large-scale experiments, but it is not clear if and when additional data will be published.
- GexCon has initiated the joint industry project (JIP) "*Modelling Escalating Accident Scenarios and the Use of Risk-reducing technology for Explosion safety*" (MEASURE)[1], where the primary objective is to implement and validate fundamental improvements to the turbulence and combustion models in FLACS, and hence to develop improved predictive capabilities with respect to optimizing safety gaps.

The validity of results obtained with FLACS for typical offshore scenarios, such as single congested geometries and confined congested geometries, remains unchanged, provided scenario and grid follow existing guidelines. At the same time, it is important to be aware that several large-scale gas explosion experiments, including tests with natural gas, have shown a propensity to undergo deflagration to detonation transition (DDT), which can result in severe over-pressures. It is therefore recommended to include the DPDX variable in all large-scale gas explosion simulations with FLACS, and to evaluate the results according to the latest guidelines provided in the FLACS User's Manual. Validation against large-scale experiments indicates that the DPDX criterion may not be an accurate predictor of DDT if the rate of combustion during the initial phase of flame propagation is under-estimated, for instance if the effect of initial turbulence is neglected in the simulation.

In summary, users of FLACS should **exercise caution** when optimizing safety gaps between repeated congested regions with limited degree of confinement based on results from explosion simulations. The unphysical over-prediction will not dominate the results for all configurations and grid resolutions. If FLACS is used in a safety gap study, and the level of overpressure in the second congested region unexpectedly starts to increase at separation distances around one to two times the dimension of the congested region, the overpressures in the acceptor are most likely overly conservative. In the absence of such a trend, the accuracy of the FLACS results is expected to be acceptable.

Please refer to the FLACS User's Manual and the FLUG pages for updated information.

[1] JIP MEASURE started on 1 July 2013, and is scheduled to finish 31 December 2015. The financial contribution per participant depends on the number of participants, and additional participants may join the consortium up to 30 November 2013. The R&D activities include an experimental programme aimed at providing high-quality validation data for gas explosions in repeated congested regions, turbulence and combustion modelling in FLACS, and extensive validation of the improved model system. The duration and extent of the project reflects the complexity of the required modelling and validation work. For further details, please contact GexCon R&D.