Fluid Dynamics Modelling for Offshore Oil and Gas Applications

Dr Simon Gant, Health and Safety Laboratory, UK

Contents

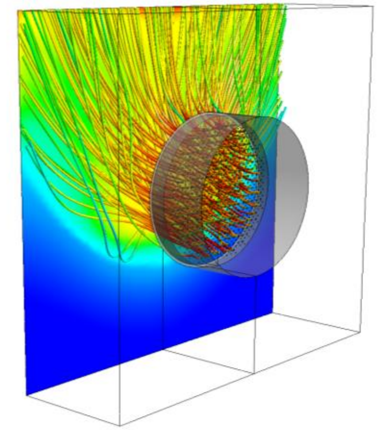
HEALTH & SAFETY LABORATORY

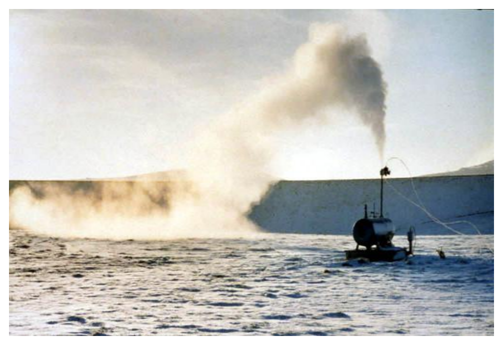
- Introduction to HSL
- Smoke infiltration
- Gas dispersion
- Flammability of gas mixtures
- Oil mist explosions
- Reviews of fire and explosion models
- Ongoing work…

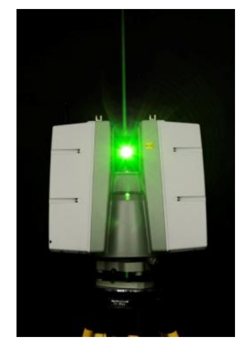
Health & Safety Laboratory

HEALTH & SAFETY LABORATORY

- Multi-disciplinary:
  - Fire and process safety
  - Computational modelling
  - Exposure control
  - Toxicology etc.
- 370 staff (90 PhD, 70 MSc)
- 550 acre test site
- Fire galleries and burn hall
- Impact track
- Anechoic chamber
- Thermal test chamber
- 3D laser scanner
- Imaging/sampling from UAV



Who do we work for?

HEALTH & SAFETY LABORATORY

london
AIRBUS
AN EADS COMPANY
ASDA
e·on
Home Office
Rolls-Royce
Unilever
AstraZeneca
Nestlé
defra
Department for Environment Food and Rural Affairs
HSE
TOYOTA
Pfizer
NHS
POST OFFICE
bp
HIGHWAYS AGENCY
BAE SYSTEMS
energy technologies institute
Sellafield Ltd
Environment Agency
CPNI
Centre for the Protection of National Infrastructure
DH Department of Health
FOOD STANDARDS AGENCY
SCOTTISHPOWER
Ford

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Smoke Infiltration into TRs

Background

- Cullen Report into the Piper Alpha disaster: Temporary Refuge (TR) must be provided on all offshore installations
- TR performance standards: survivability when exposed to a Major Accident, including ingress of smoke, flammable and toxic gas
- Air tightness of TR measured using blower door tests
- Current guidance based on TR endurance time recommends 0.35 ACH

Offshore Information Sheet No. 1/2006 “Testing Regime for Offshore TR-HVAC Fire Dampers & TR Pressurisation Requirements http://www.hse.gov.uk/offshore/trhvac.pdf

Smoke Infiltration into TRs

HEALTH & SAFETY LABORATORY

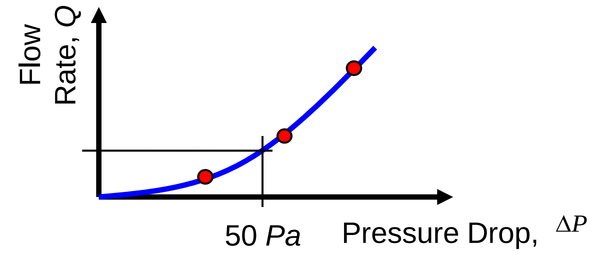
Project aims

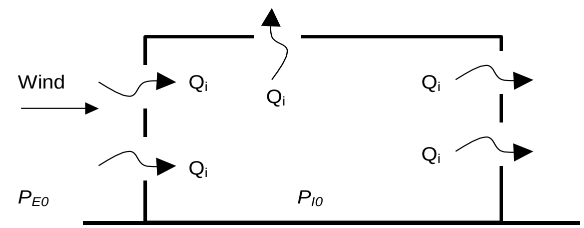
- To develop a model to predict the time to impairment in the TR (infiltration, toxic effects)
- To understand model sensitivities and identify important factors
- To collaborate with MMI who are developing EI standard for blower-door testing

Smoke Infiltration into TRs

Model Components

- Determine TR leakage areas using blower-door measurements
- Model infiltration, accounting for wind and buoyancy effects
- Account for effect of occupants respiration
- Calculate impairment time from effect on occupants of CO_2, CO, O_2 depletion



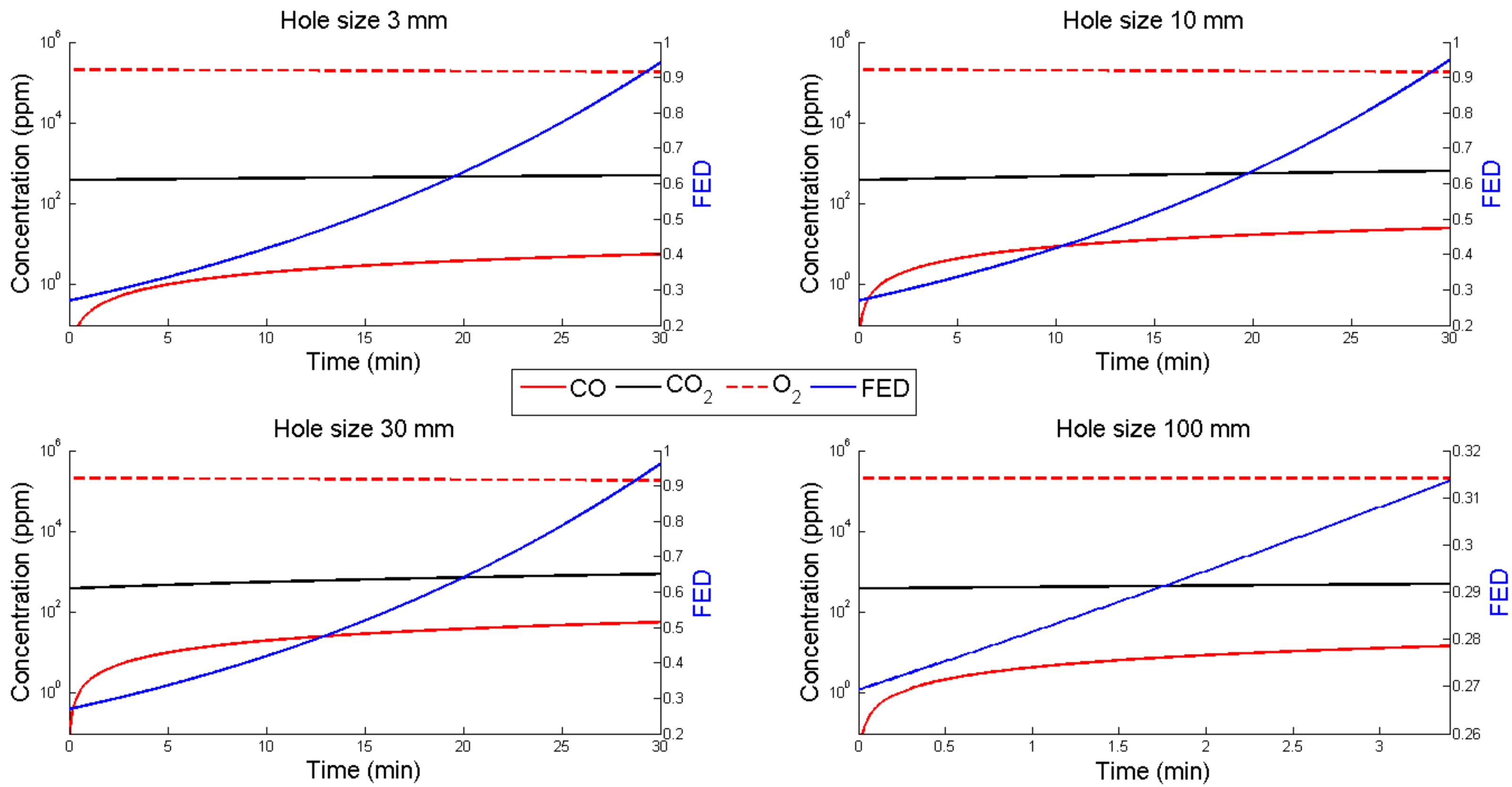


Fractional Effective Dose $$FED = \underbrace{\frac{TL}{SLOT}}_{CO_2} + \underbrace{\frac{\%COHb}{30}}_{CO} + \underbrace{\frac{Drop\ in\ SaO_2}{10}}_{O_2}$$

Smoke Infiltration into TRs

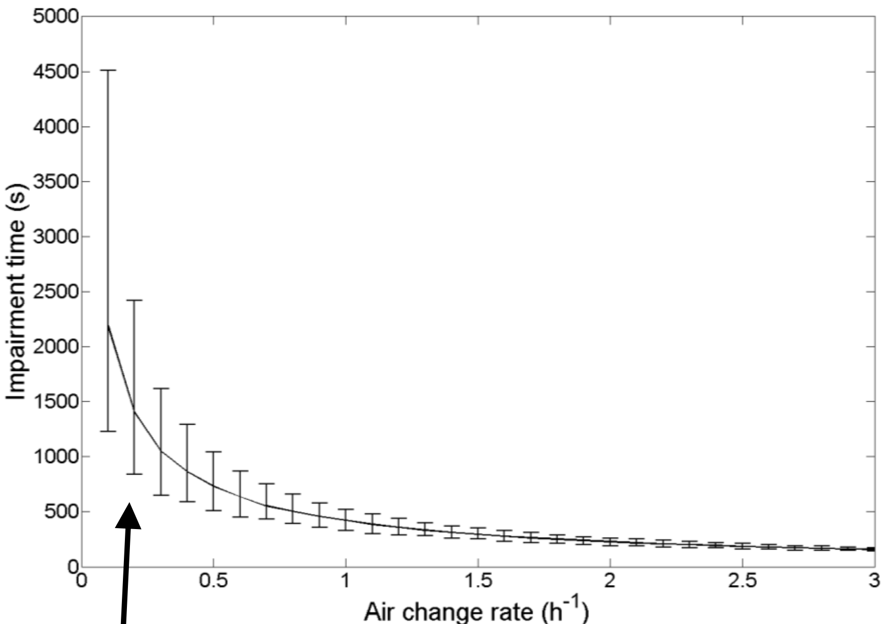
Sample results

- Smoke plume engulfing TR (Phast predictions)
- Representative ACH and wind-speed assumed

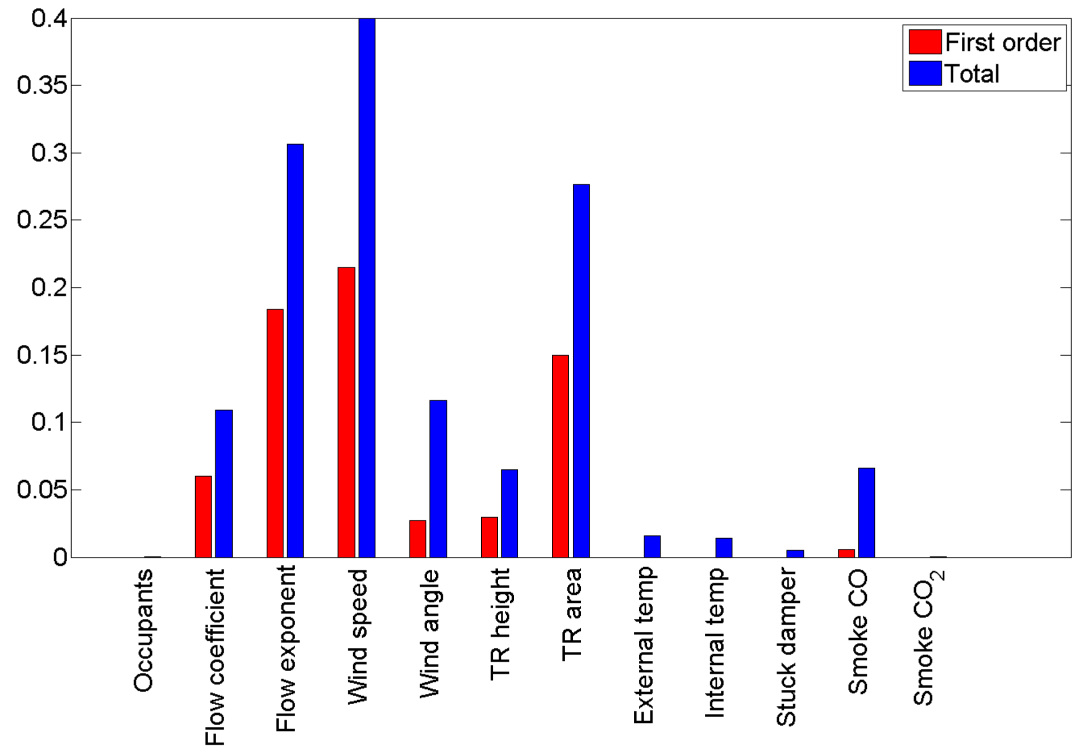


Smoke Infiltration into TRs

Sensitivity analysis



Buoyancy, respiration etc. have greater effect at low air change rates



First order sensitivity: influence of each input

Total sensitivity: includes interactions between inputs

Smoke Infiltration into TRs

Conclusions

- Model developed to predict impairment times due to smoke ingress into TRs
- Impairment times:
  - sensitive to wind-driven infiltration
  - insensitive to thermal/buoyancy effects
- Toxic effects mainly controlled by carbon monoxide and oxygen depletion – important to model respiration rates

Smoke Infiltration into TRs

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- Coldrick S. (2013) “Modelling smoke and gas ingress into offshore temporary refuges”, HSL Report MSU/2012/24 – in press
  - To be presented at FABIG “Risk management of ageing facilities”, 4-5 June 2013
- MMI Engineering (2013) Guidance on Integrity Testing for Offshore Installation Temporary Refuges, Energy Institute
  - To be presented at SPE Conference on Health, Safety, Environment and Social Responsibility in the Oil and Gas Exploration and Production Industry, 16-18 April 2013
- HSE (2010) “Indicative human vulnerability to the hazardous agents present offshore for application in risk assessment of major accidents,” SPC/Tech/OSD/30 (http://www.hse.gov.uk)
- Deevy & Garrard “Assessment of mathematical models for the prediction of smoke ingress and movement in offshore installations”, HSL Report CM/06/10, 2006
  - examined capabilities/limitations of CSTR/multi-zone/CFD

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Gas Dispersion

- Incident Investigations
  - Brent Alpha, 3.3t gas release (2000)
  - Brent Charlie gas releases, 1.2t gas release (2002)
  - Shell Stanlow, 20t isobutane 100kg HF (2003)
  - Leman Golf, visible plume seen from helicopter (2009)
  - Claymore Alpha, 90kg gas release (2009)
  - Piper Bravo, 36t liquid amine solution (2009)

- Research Projects
  - Natural ventilation of offshore modules (2003)
  - Gas releases in gas turbine enclosures (2004)
  - Area classification of low-pressure gas releases (2009)
  - Gas sensor networks (2013-)

Natural Ventilation in Offshore Modules

Objectives

- To identify stagnant areas in offshore modules over a range of wind speeds and directions
- To correlate local velocity / ventilation-rate measurements and CFD predictions against wind conditions
- To evaluate use of CFD to predict effectiveness of natural ventilation
- To investigate remedial measures to mitigate poorly ventilated areas

Natural Ventilation in Offshore Modules

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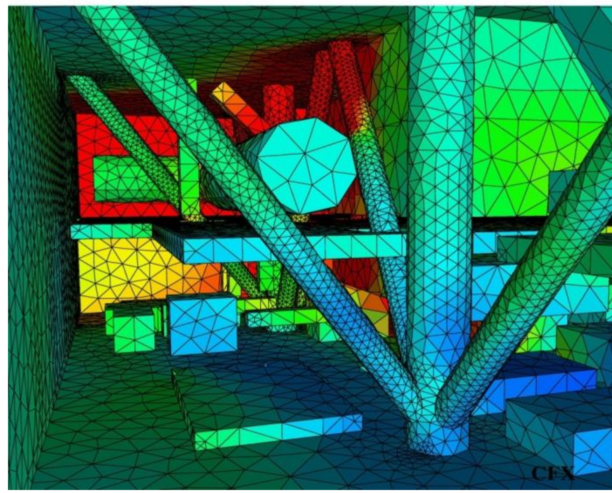
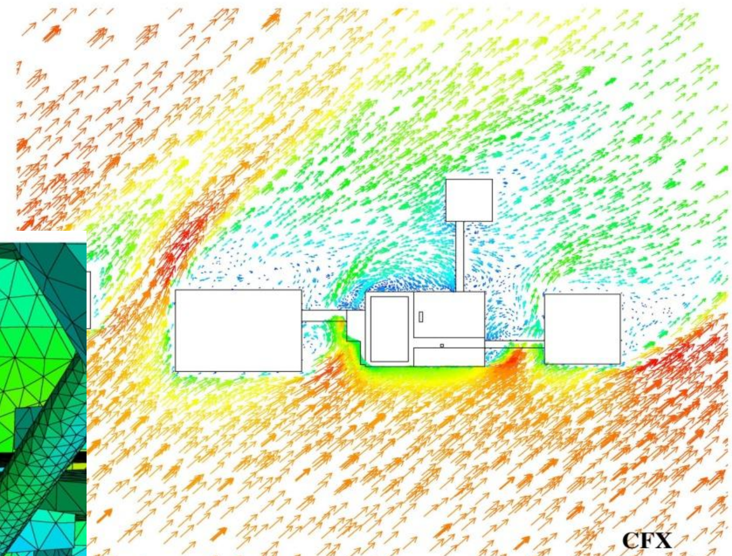
- 3D velocity measurements using ultrasonic anemometers



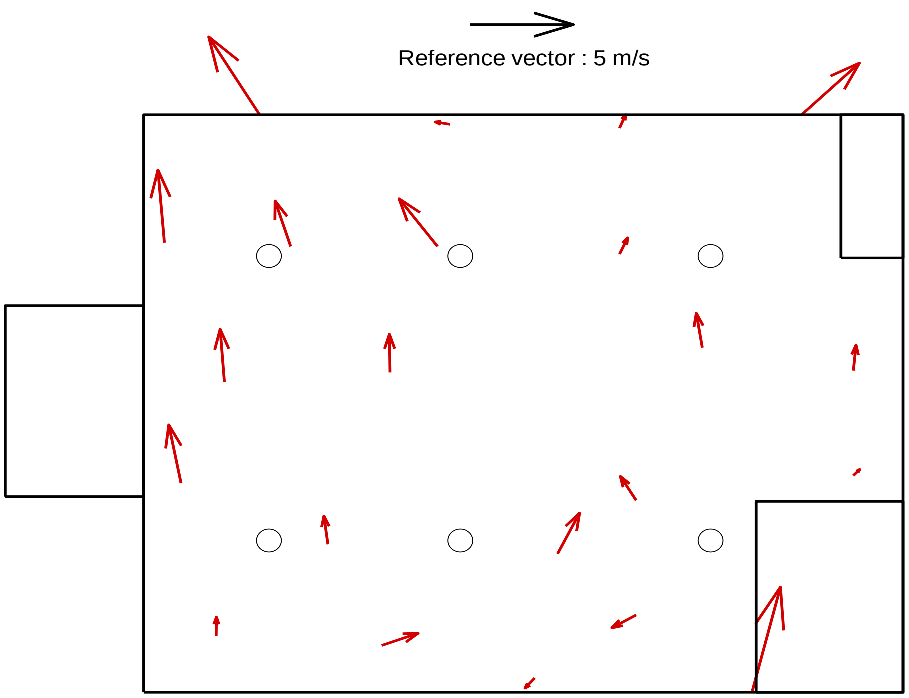


- CFD simulations of external and internal flow

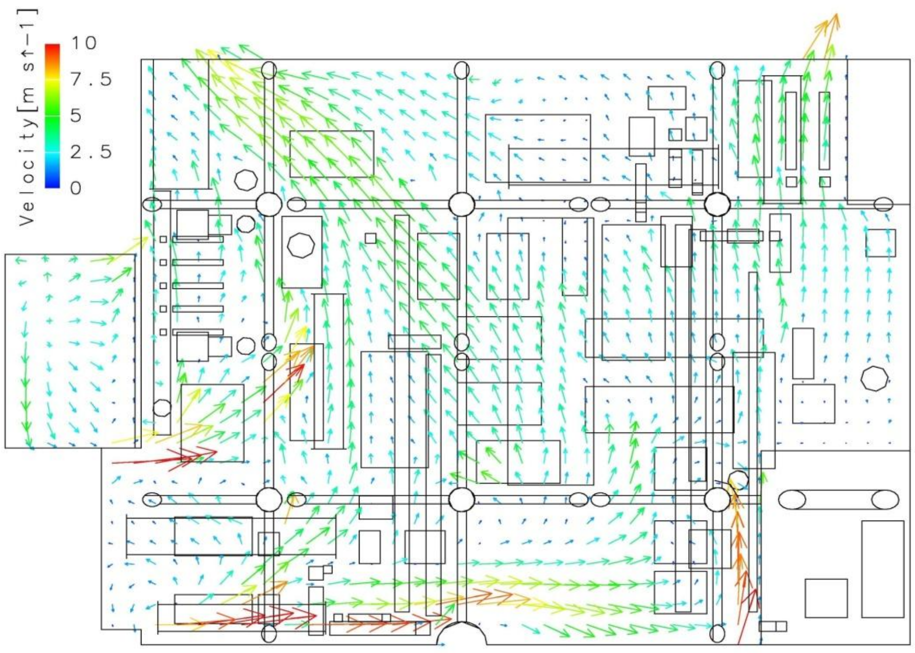
Natural Ventilation in Offshore Modules

HEALTH & SAFETY LABORATORY

CFD model validation



Measurements



CFD

Natural Ventilation in Offshore Modules

Conclusions

- Effectiveness of natural ventilation highly dependent upon external wind conditions
- Flow patterns complex – not intuitive
- ACH provides inaccurate indication of local ventilation effectiveness
- Recommended local ventilation assessments to be based on measurements and CFD
- Proposed improvements to IP15 standard (now EI15)

Gas Turbine Enclosures

Objective

- To develop new safety criterion governing the use of gas turbines in ventilated enclosures

Gas Turbine Enclosures

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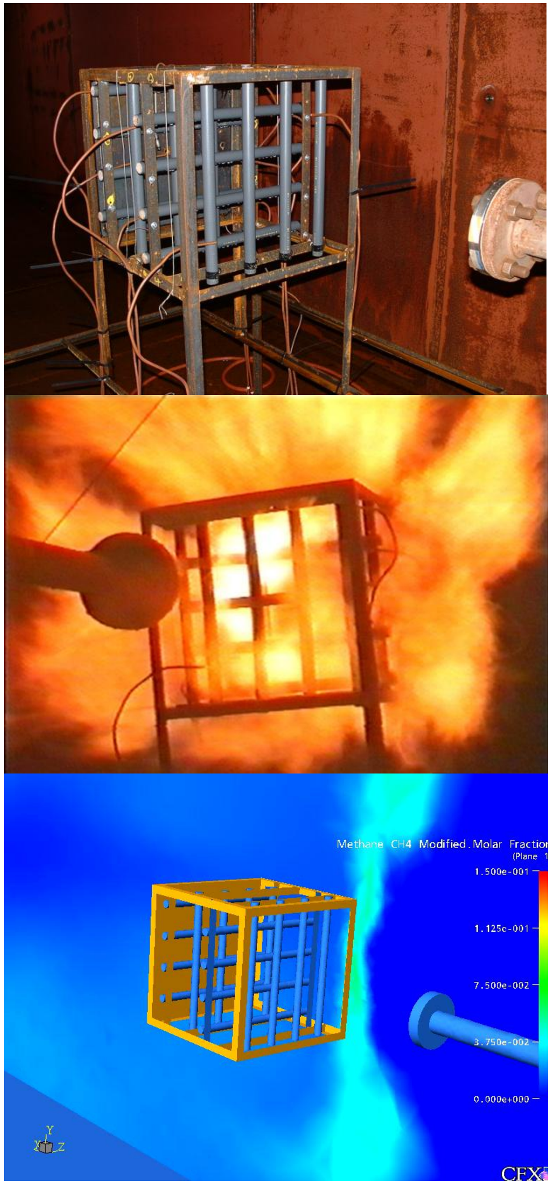
- Establish effect of:
  - congestion
  - cloud size
  - percentage fill of an enclosure

  on explosion overpressure
- Review effects of overpressure on people and gas turbine enclosures
- Define limits for the potential minimum and maximum leak sizes to be considered in a risk assessment
- Establish the accuracy bounds of CFD predictions of gas cloud size for high pressure releases into congested regions



Gas Turbine Enclosures

- AEA Technology Engineering Software
- Alstom Power Generation Ltd
- Cullum Detuners
- Darchem Flare
- Derwent Cogeneration Ltd
- Deeside Power
- Dresser Rand (UK) Ltd
- Flowsolve Ltd
- Fluent Europe Ltd
- Frazer Nash Consultancy
- GE Power Systems
- GHH Borsig
- Groveley Detection Ltd
- HSE
- Information Search & Analysis Consultants
- Innogy Operations and Engineering
- Killingholme Power Ltd
- Mitsubishi Heavy Industries Europe Ltd
- Mobius Dynamics Ltd
- Powergen CHP Ltd
- Rolls Royce Plc
- Scottish Power
- Thames Power Services Ltd
- Transco National Transmission System
- WS Atkins

Gas Turbine Enclosures

Conclusions

- New safety criterion governing the use of gas turbines in ventilated enclosures:
  - 100% LEL equivalent stoichiometric volume < 0.1% of the net enclosure volume or $1 m^3$

- Santon, Ivings & Pritchard “A new gas turbine enclosure ventilation design criteria” ASME Turbo Expo 2005, 6-9 June 2005
- HSE guidance note PM84[(1)], "Control of safety risks for gas turbines used for power generation"
- Best practice guidelines on CFD modelling and in-situ testing
- Influenced Standard ISO 21789 “Gas turbine applications – safety”

Area Classification

Background

- ATEX Workplace Directive (1999/92/EC) requires area classification of all non-domestic natural gas installations
- Guidance developed for high pressure gas supply applied to low pressures (<10 bar)
- BS EN 60079-10 guidance on area classification
  - Based on "Vz": volume of cloud with average concentration 50% LEL
  - Method for calculating Vz leads to significant over-conservatism

Joint-Industry Project Aims

- To develop a new (more realistic) calculation of Vz and improve approach to area classification of low pressure gas systems

Area Classification

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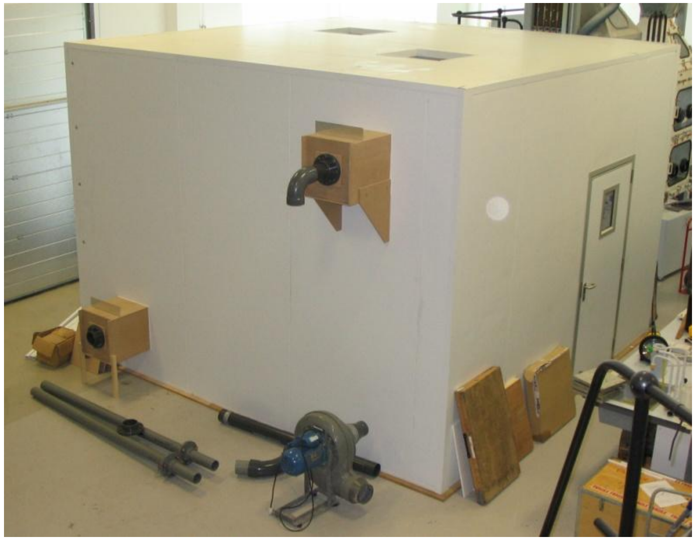
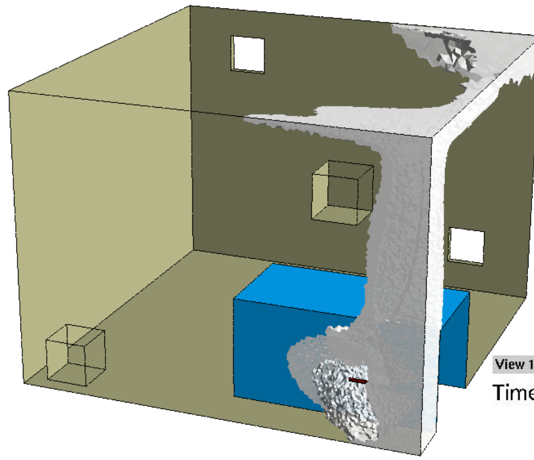
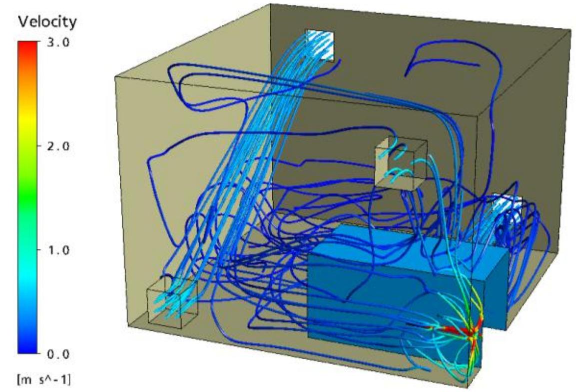
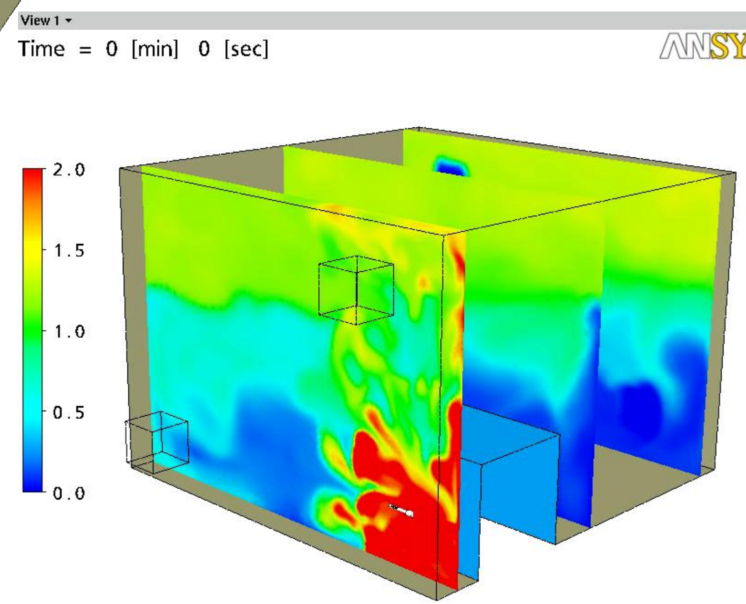


Methane gas releases in a ventilated room







Area Classification

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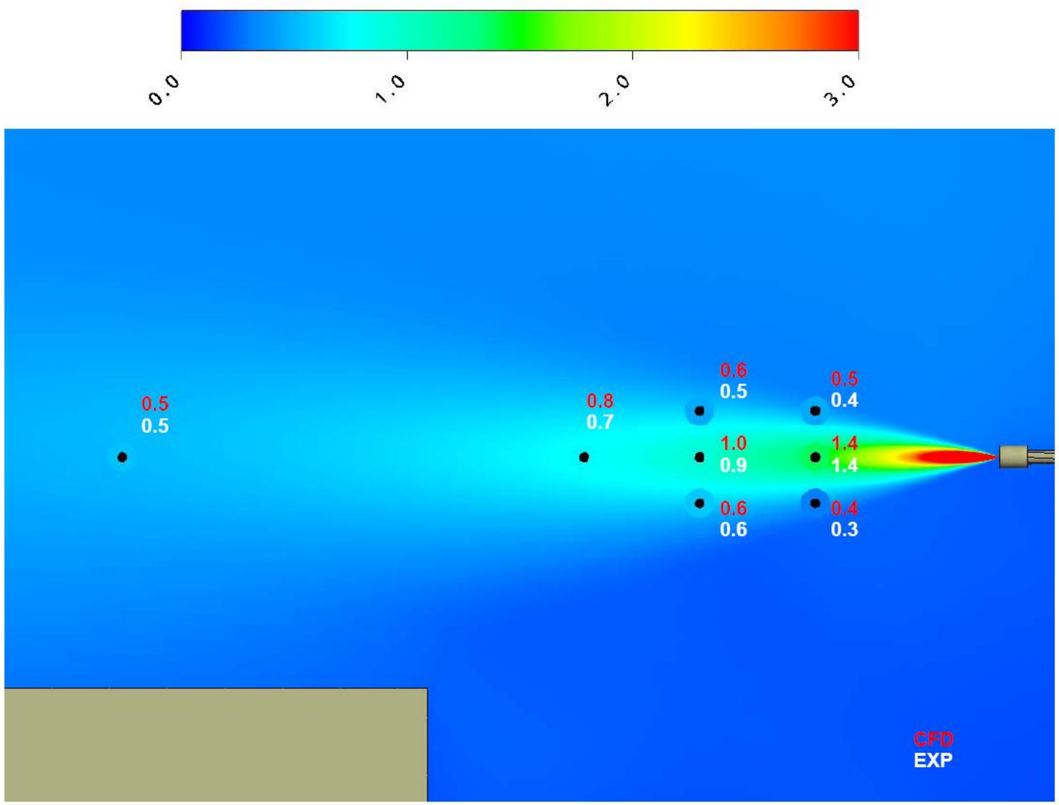
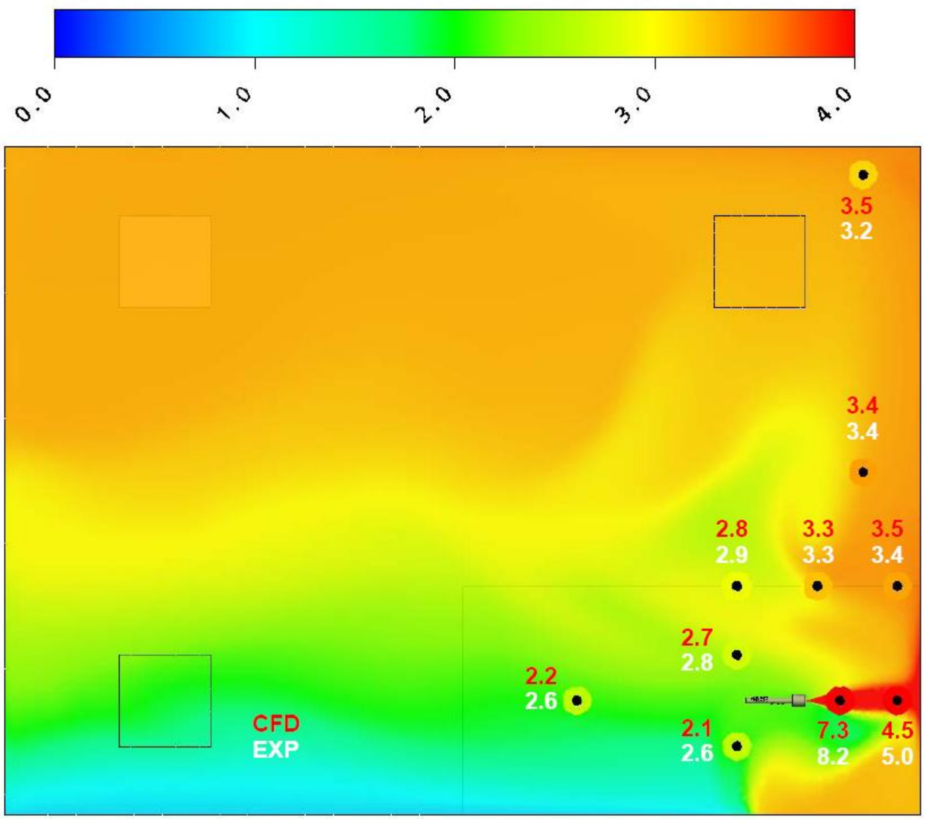
Model validation: free jets, wall jets, confined jets





CFD (background contours) and measurements (coloured circles)

Area Classification

Conclusions

- Alternative approach to assess ventilation effectiveness to BS EN 60079:10, based on the average gas concentration at the ventilation outlets, c_{out}
- New calculation uses ventilation rate rather than ACH
- Provided c_{out} < 10% LEL and the source unconfined (no re-entrainment) : Zone 2 NE applies
- Upper bound of 1 g/s in enclosures and 2 g/s outdoors for Zone 2 NE
- Developed integral model for predicting Vz in ventilated enclosures and outdoors: Quadvent software

Area Classification

- HSE (2008) “Area classification for secondary releases from low pressure natural gas systems”, Research Report RR630, http://www.hse.gov.uk/research/rrhtm/rr630.htm
- Webber, Ivings & Santon “Ventilation theory and dispersion modelling applied to hazardous area classification”, J. Loss Prev. Proc. Ind., 24, p612-621, 2011
- Santon, Ivings, Webber & Kelsey “New methods for hazardous area classification for explosive gas atmospheres”, IChemE Hazards XXIII Conference, Southport, UK, 12-15 November 2012
- Ivings “Technical input on ventilation effectiveness for area classification guidance EI15”, HSL Report MSU/2012/10, 2012
- Quadvent software: http://www.hsl.gov.uk/products/quadvent.aspx

Gas Sensor Networks

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Objectives

- Investigate the performance of flammable gas detectors over the long term (approximately 12 months)
  - noise, drift and accuracy
  - response to environment e.g. temperature, humidity, rain, fog
- Investigate means of improving detectability from grid of detectors
  - more effective location of detectors
  - combination of detector type (point, line, acoustic)
  - more effective use of data
  - identification of location and strength of source

Gas Sensor Networks

HEALTH & SAFETY LABORATORY

Objectives (cont.)

- Investigate effect of fluctuating gas concentrations on flammable gas detector response
- Investigate reliability of models used to assess flammable cloud sizes in risk assessments
- Methodology: lab/field-scale measurements and CFD
- HSE-funded project: 2013 –

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Flammability of Gas Mixtures

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- **Objective**: to investigate hazards posed by gas releases of mixtures containing hydrocarbons and CO_2 gas

- **Applications**:
  - Venting of inerted hydrocarbon storage tanks
  - Decommissioning of aging facilities
  - Carbon capture and storage

- **Methodology**: experimental and modelling study
  - confined explosions
  - jet ignition tests

Flammability of Gas Mixtures

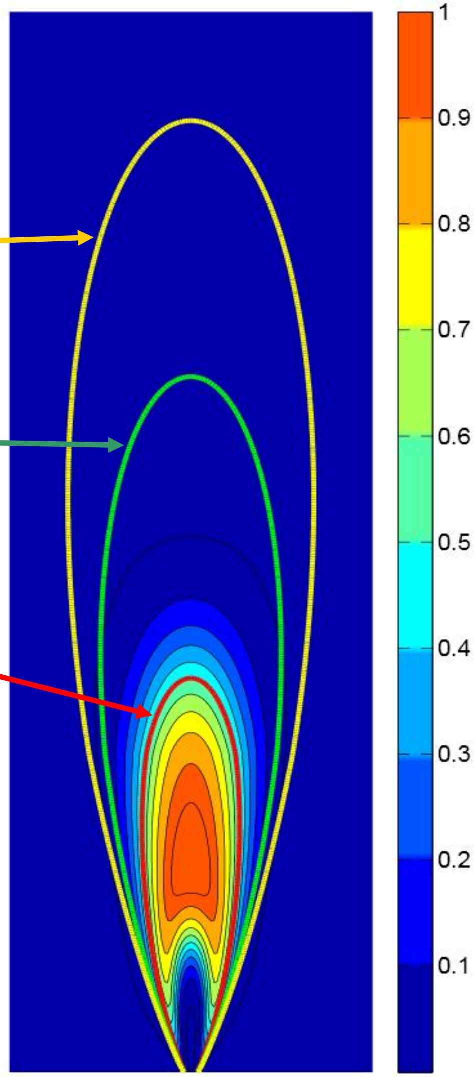
Many definitions for flammable cloud extent:

Vz (average conc. 50% LEL)

50% LEL contour

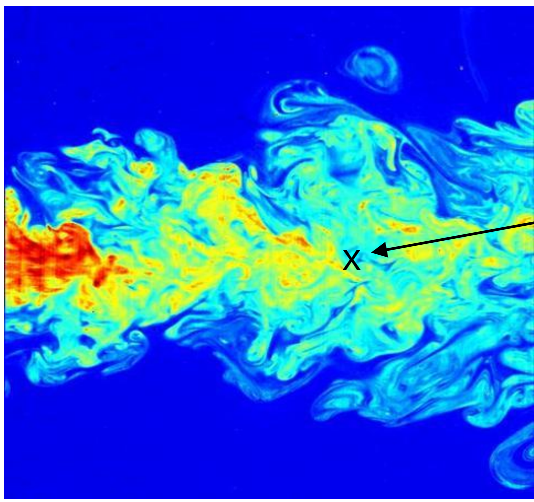
100% LEL contour

Flammability Factor (FF)

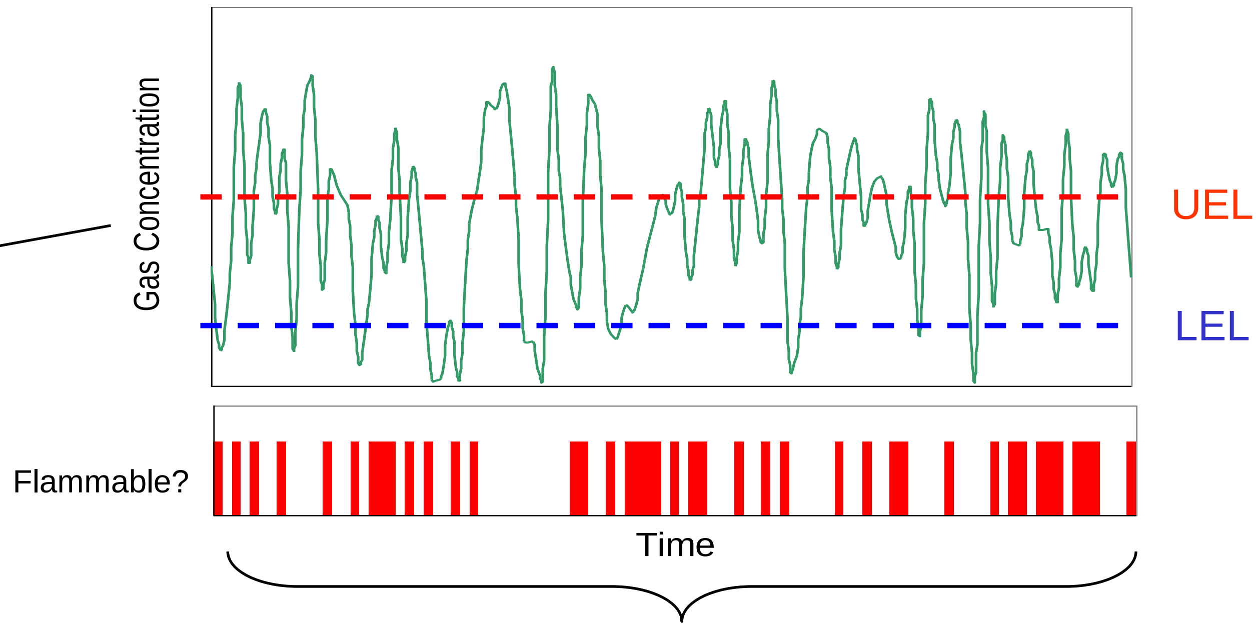


Flammability of Gas Mixtures

- Flammability Factor definition: proportion of time that the gas concentration is within the flammable range



© C. Fukushima, J. Westerweel, TU Delft



Flammable at this position for 40% of the time

(Flammability Factor = 0.4)

Flammability of Gas Mixtures

- Flammability factor model:

Centreline Mean Concentration:

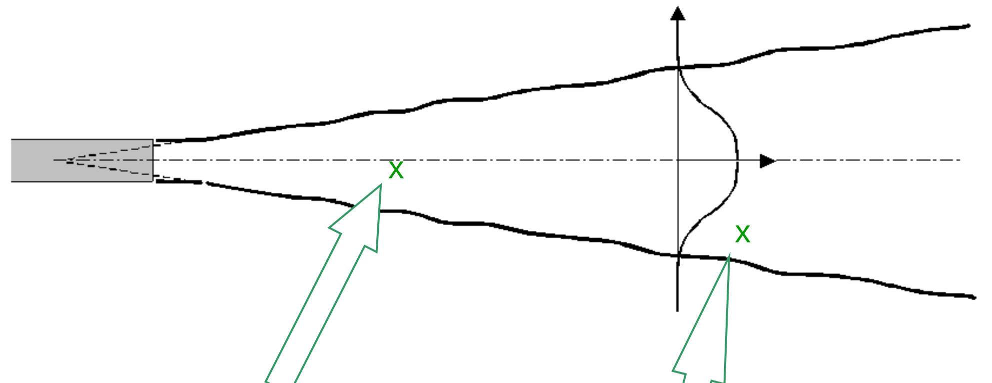
$$C_{cl} = 5C_0\left(\frac{\rho_0}{\rho_a}\right)^{-1/2}\left(\frac{x'}{D}\right)^{-1} \qquad C_{cl} = a_C C_0 Fr^{1/8}\left(\frac{\rho_0}{\rho_a}\right)^{-7/16}\left(\frac{x'}{D}\right)^{-5/4}$$

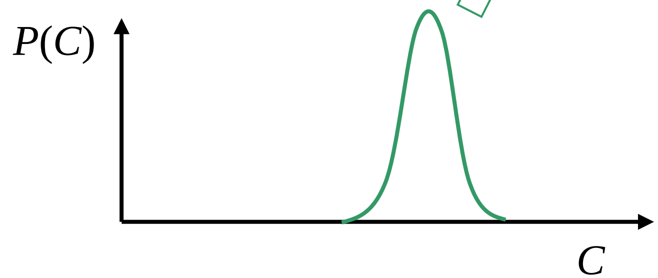
Radial Mean Concentration:

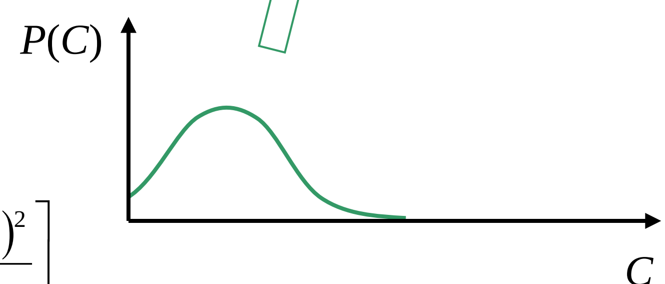
$$\frac{C}{C_{cl}} = \exp\left[-K_C\left(\frac{r}{x'}\right)^2\right]$$

RMS Concentration:

$$\overline{c^2} = \beta C\left(\alpha C_{cl} - C\right)$$







Turbulent Intermittency:

$$I = \frac{K+1}{\left[\left(\frac{\overline{c^2}}{C^2}\right)+1\right]}$$

Concentration PDF:

$$P(\tilde{c}) = (1-I)\delta(\tilde{c}) + \frac{IA}{\sqrt{2\pi\overline{c_c^2}}}\exp\left[-\frac{(\tilde{c}-C_c)^2}{2\overline{c_c^2}}\right]$$

Flammability of Gas Mixtures

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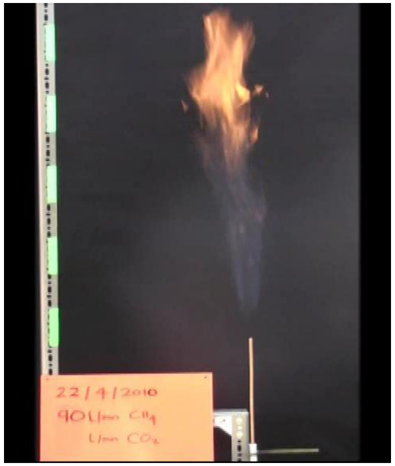

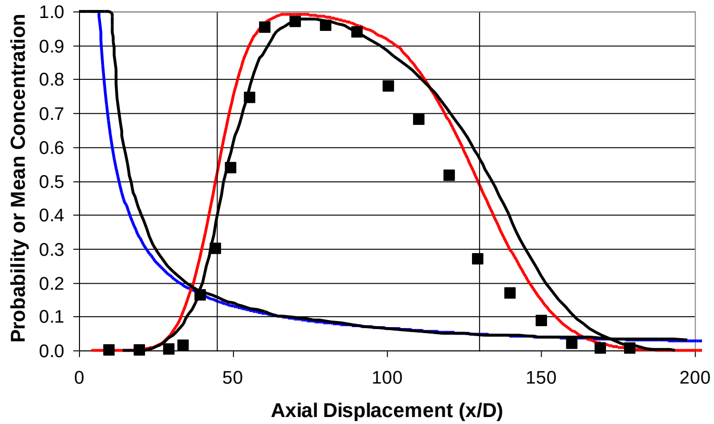

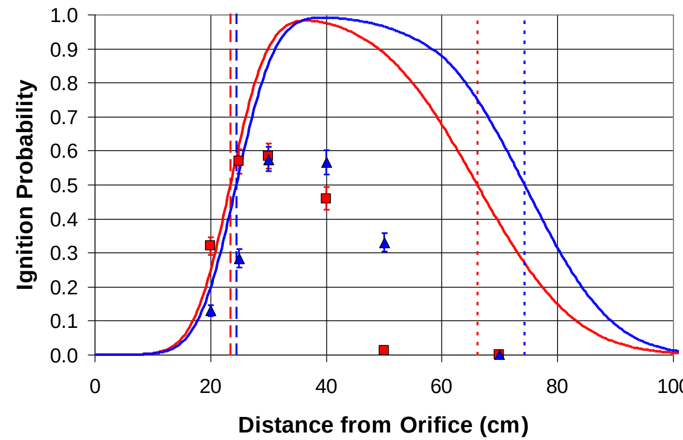

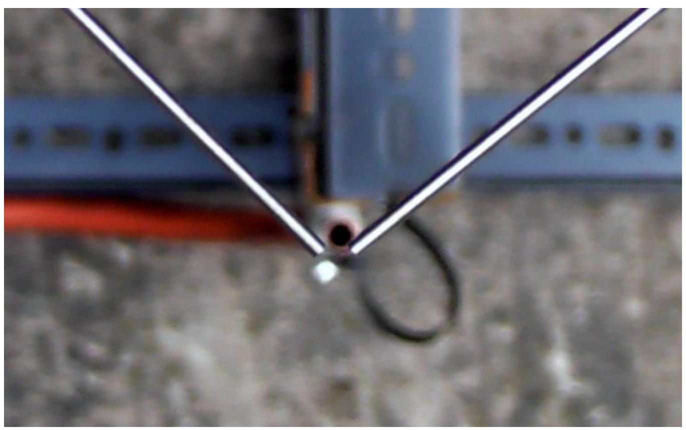

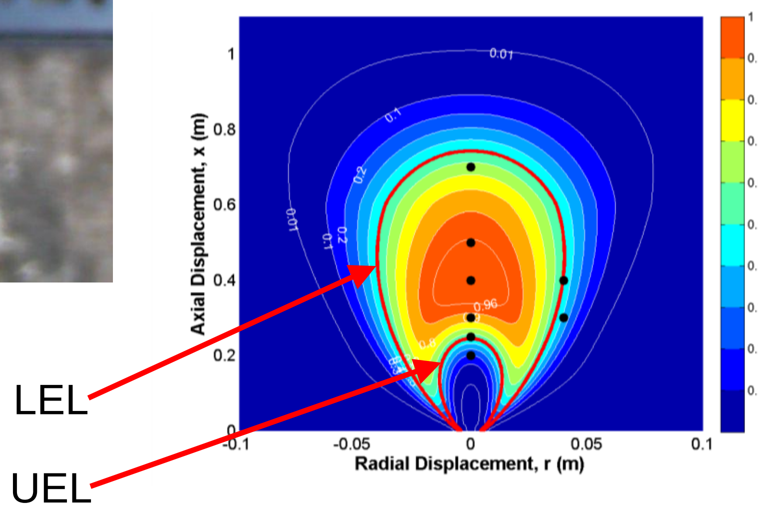

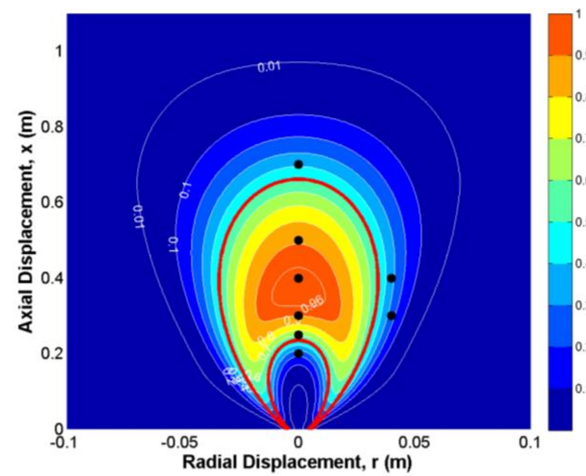

Flammability of Gas Mixtures

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Conclusions

- Explosion tests investigated reduction of overpressures in methane/CO_2 mixtures
- Effect of 20% CO_2 on flammable jets extent demonstrated
- Flammability Factor model validated for free jets
- Experiments showed that FF is sensitive to ambient wind
- Reviewed CFD models for flammability factor

- Gant, Lea, Pursell, Fletcher, Rattigan & Thyer "Flammability of Hydrocarbon and Carbon Dioxide Gas Mixtures: Measurements and Modelling" HSL Report MSU/2010/21, 2011
- Gant, Pursell, Lea, Fletcher, Rattigan, Thyer and Connolly "Flammability of hydrocarbon and carbon dioxide mixtures" Process Safety and Environmental Protection, 89 (6), p472-481, 2011
- Pursell et al. and Gant et al. "Flammability of hydrocarbon/CO_2 mixtures", IChemE Hazards XXII Conference, Liverpool, UK, 11-14 April 2011

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Oil Mist Explosions

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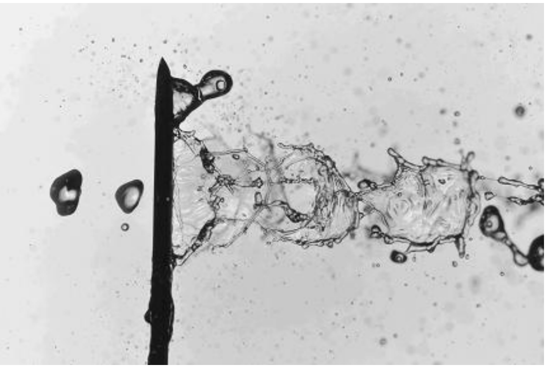
Background

- Mists of flammable liquids at temperatures below their flash point can ignite and explode
- Santon (2009) review: 20 mist explosion incidents, 29 fatalities
- Guidance for flammable mists from high-flashpoint fluids:
  - BS EN 60079-10-1 Annex D: limited guidance (only qualitative)
  - IP15: “there is little knowledge on the formation of flammable mists and the appropriate extents of associated hazardous areas … Further research is needed”
- No specific standards on protective equipment for use in flammable mist atmospheres

Oil Mist Explosions

Objectives



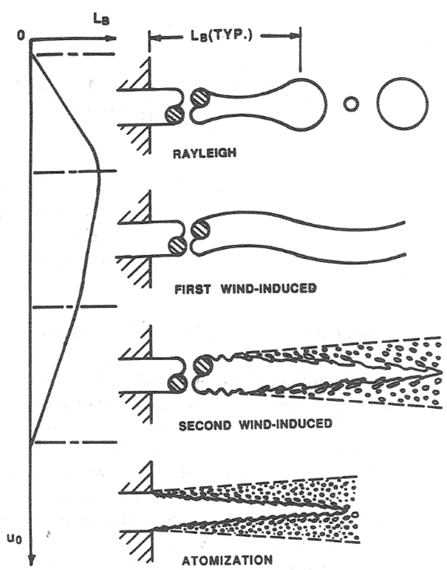
- To develop practical guidance on:
  - Formation of flammable mists
  - Area classification zone and extent
  - Mitigation measures
  - Protected equipment concepts, and equipment selection

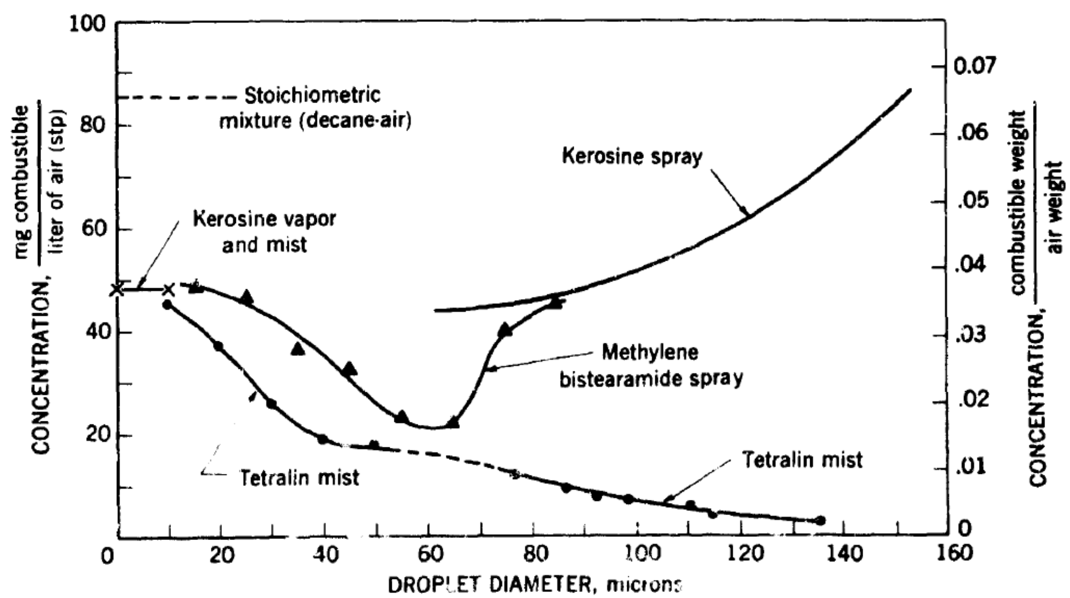
- Joint Industry Project: Jan 2011 –
- Experiments in progress at Cardiff University

Oil Mist Explosions

Literature Review

- Gant "Generation of flammable mists from high flashpoint fluids: Literature Review", HSE Research Report – in press, 2013
- Gant, Bettis, Santon, Buckland, Bowen and Kay "Generation of flammable mists from high flashpoint fluids: Literature Review" IChemE Hazards XXIII Conference, Southport, UK, 12-15 November 2012





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Fire & Explosion Model Reviews

- Lea & Ledin "A review of the state-of-the-art in **gas explosion modelling**", HSL Report HSL/2002/02, 2002
- Deevy & Ledin "Assessment of **FLACS-DESC**", HSL Report CM/04/16, 2004
- Ledin "Review of **COMEX** and **NVBANG** explosion models", HSL Report HSL/2005/05, 2004
- Ledin "Review of **CEBAM** explosion model", HSL Report HSL/2006/12, 2006
- "Evaluating **fire and explosion models** for offshore design", HSE DVD, 2007
- Gant & Hoyes "Review of **FLACS version 9.0: Dispersion modelling** capabilities", HSE Research Report RR779, 2010
- Lea & Ledin, "**Fire and explosion model Wiki**" HSE draft version due April 2013

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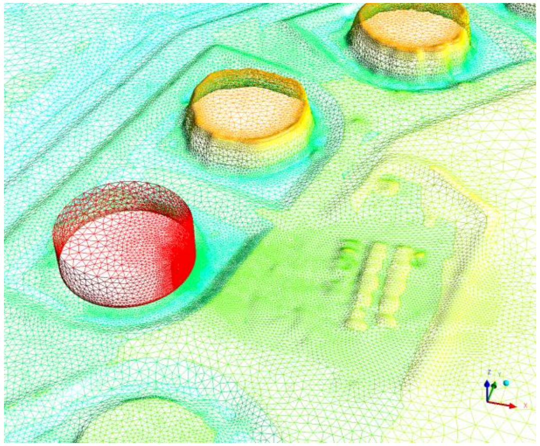
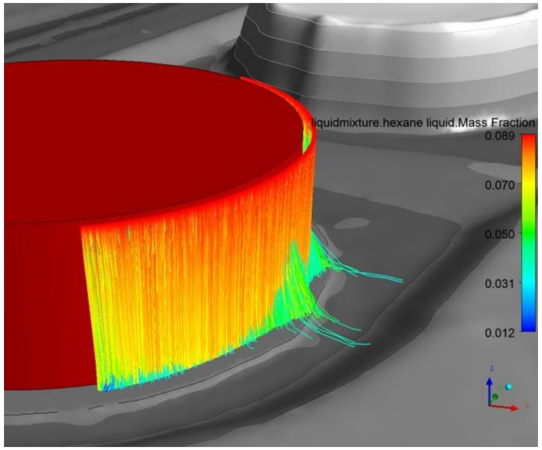
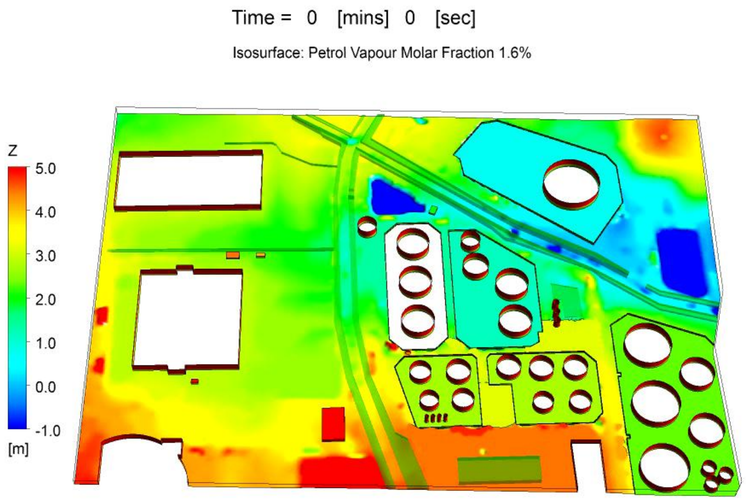
Ongoing Work…

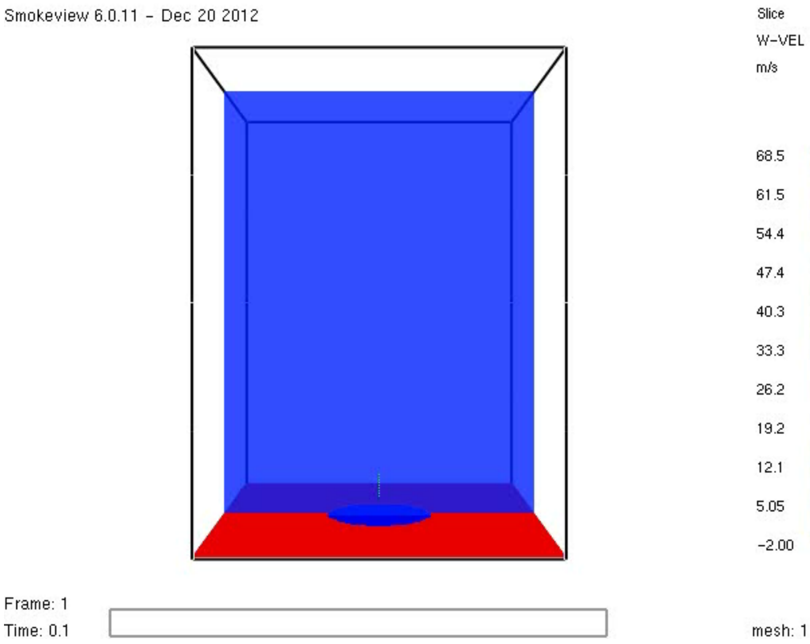
Vapour cloud generation from tank overfilling







LNG pool fires



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