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HEALTH & SAFETY LABORATORY

HSL input into NAFEMS CFD Working Group: 2003-2005

HSL/2006/48

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Author(s): **N. Gobeau and M. Ivings**

Science Group: **Fire and Explosion Group**

CONTENTS

EXECUTIVE SUMMARY

Objective

To represent HSE at a Computational Fluid Dynamics (CFD) Working Group organised by the non-profit organisation the National Agency for Finite Element Methods and Standards (NAFEMS). The Working Group's principal aim is to promote the safe and reliable use of CFD in industry. An important part of its activity is the provision of training for CFD practitioners. It publishes a large number of books containing "how to" guidelines, benchmark studies, and background information on EA for the benefit of its members; these books are also made available for purchase by non-members. HSL contributed to this general aim and helped to raise the profile of health and safety applications.

Outcome

The objective was achieved by:

- Providing input at the regular meetings of the CFD Working Group to raise the profile of health and safety-related issues;
- Reviewing three papers for the NAFEMS publication "NAFEMS CFD Journal";
- Making a presentation at the NAFEMS-ERCOFTAC seminar on "Quality and Reliability of CFD simulations II"
- Making a technical presentation at the NAFEMS seminar on Fluid-Structure Interaction
- Finalising the educational booklet aimed at CFD practitioners on the use of CFD to predict the transport of smoke in complex enclosed spaces.

Recommendations

It is recommended that representation of HSE at the NAFEMS CFD Working Group should be continued. Participation in the regular meetings should be continued and where appropriate advantage taken of the various means of disseminating information offered by NAFEMS: a trade magazine; a scientific journal; technical seminars; a series of educational booklets.

1 INTRODUCTION

This project was agreed in December 2003 and supported by the OSD, FOD/RI and HID Divisions.

The project consists of HSL representing HSE at a Computational Fluid Dynamics (CFD) Working Group organised by the non-profit organisation the National Agency for Finite Element Methods and Standards (NAFEMS). The objective of the Working Group is to promote the safe and reliable use of CFD. HSL's involvement aims to raise the awareness of managers in industry on the potential of CFD to address health and safety issues, as well as to ensure CFD is used appropriately. HSL provides the technical expertise gained through projects sponsored by HSE, and NAFEMS organises the dissemination of the information taking advantage of its high profile in the industry.

This project is the continuation of HSL's participation which started a decade ago on behalf of the HSE Offshore Division. Over the years, HSL has applied CFD to fields of application other than major hazards, and so it has also expanded its representation of HSE on the NAFEMS Working Group. In particular, it has included the area of Occupational Hygiene (over the past four years) which has become increasingly important to HSE. HSL has also more recently promoted a relatively new technique, Fluid-Structure Interaction, which combines the two modelling tools CFD and Finite Element Analysis. This technique models the interaction between liquids and deforming solids.

This report presents the activities of the Working Group and more specifically the contributions from HSL, related to health and safety issues, for the period from December 2003 to November 2005. It provides first an overview of CFD, with a few examples of its application to health and safety-related issues, and some background information on the NAFEMS organisation and the CFD Working Group. It concludes with an evaluation of the extent to which this activity helps HSE to meet its objectives. Recommendations are made as to whether and how this activity should be pursued.

2 BACKGROUND

2.1 CFD OVERVIEW

CFD is a powerful computer-based mathematical modelling technique employed to calculate and analyse complex fluid flows in order to address a wide range of issues. Amongst these are health and safety-related applications.

For example, CFD has been used to predict the movement of smoke from possible fires in the Millennium Dome (Hiorns et al., 1999), to assess and mitigate explosion hazards in a gas turbine power plant (Lewis and Lea, 1999); to evaluate the risk to nearby population of an accidental release of chlorine into the atmosphere from a water treatment plant (Zhou and Lea, 1998); to estimate the occupational hazards following the application of pesticides (Gobeau and Lea, 1999); to assess the effectiveness of ventilation strategies in controlling the exposure of workers to airborne hazardous substances emitted during manufacturing processes (Andersson at al., 1993; Heinonen et al., 1996).

In addition, safety cases submitted to HSE increasingly involve the use of CFD predictions. CFD is, however, a complex method which can lead to misleading conclusions if it is not used and interpreted correctly.

2.2 THE NAFEMS ORGANISATION

The National Agency for Finite Element Methods and Standards (NAFEMS) was founded in 1983 with a specific objective, namely ‘to promote the safe and reliable use of finite element and related technology’. This was in response to the need for validating the proliferation of computer-based methods and codes that were increasingly used to solve practical engineering problems. Originally focused on the Finite Element method, which is widely used for stress analysis of structures, NAFEMS has widened its activities to include other computational techniques, such as CFD - which can be used to predict complex fluid flows.

Initially funded by the UK government, NAFEMS has been an independent non profit-making company since 1990. There are now over 700 corporate members from industry, academia, software houses and engineering consultancies. The majority are UK-based but there are also some non-UK based organisations.

2.3 THE CFD WORKING GROUP

The CFD Working Group was set up in 1995 to promote the safe and reliable use of CFD. This was a result of a joint IMechE/EPSRC meeting of experts, on ‘Uncertainty in CFD’ in 1994. This meeting highlighted the main sources of uncertainty and made key recommendations on the numerics, physics, validation and the role of the user. The NAFEMS Group, which consists of CFD experts from various organisations, is focusing on last two categories: the need for validation of CFD -through benchmarking- and the role of the user in CFD analysis - concentrating on appropriate training.

Currently the CFD Working Group is supported by representatives from the Industry (BNFL Engineering Group, Rolls-Royce, Pall Aerospace, Lotus Cars, HSL), CFD consultancies (Intelligent Fluid Solutions, Lea CFD Associates), CFD code vendors (Fluent Europe Ltd, ANSYS-CFX, CD-Adapco, Blue Ridge Numerics Ltd, Applied Computing and Engineering Ltd) and academia (University of Portsmouth, Heriot-Watt University).

The objectives of the Group are achieved by producing a range of educational material and associated activities:

- publication of leaflets advising new users of the benefits to be obtained from CFD and how to get started;
- publication of guidelines for best practice in CFD;
- publication of workbooks of examples in CFD for specific flows;
- compilation and publication of industrial case studies in CFD;
- summary and classification of benchmarks;
- organisation of seminars on specific topics;

All the materials published are sent free of charge to NAFEMS members; they can be readily purchased by non-members.

3 ACTIVITIES OF THE NAFEMS CFD WORKING GROUP

3.1 MEETINGS

Eight quarterly meetings were held during the period December 2003 – November 2005.

At the meetings the different activities, presented in more detail below, were discussed and agreed.

3.2 COLLABORATION WITH ERCOFTAC

Two seminars titled 'Quality and Reliability of CFD simulations' have been organised jointly with the European Research Community On Flow, Turbulence And Combustion (ERCOFTAC). ERCOFTAC has, as its name implies, a focus on research. However, one of its aims has always been to encourage communication between academics and industry, to ensure that research findings are made available to industry. Recently, ERCOFTAC's work with industry has concentrated on quality and trust in CFD, hence the collaboration with NAFEMS. The seminars held on 9 March 2004 and 13 September 2005 were both hosted by Nottingham University. The seminars attracted a wide range of attendees from industry and much positive feedback was received.

Note that HSE is also represented by HSL on ERCOFTAC initiatives.

3.3 SEMINARS

In addition to the above seminars on quality and reliability of CFD, a seminar was also organised by NAFEMS on 'CAD/CFD Integration' on 24 November 2004 in London. There were 43 attendees.

3.4 EDUCATIVE MATERIALS

The booklet 'How to Understand CFD Jargon' by A. de Souza has been made available online on the NAFEMS website: www.nafems.org. This document provides clear definitions of CFD-specific technical terms and is thus very useful for non-CFD specialists. In particular, it is relevant to HSE Inspectors who may receive safety cases based on CFD predictions or who may use CFD to identify health and safety issues related to the transport of fluids.

Three booklets are in preparation:

- 'How to Undertake a Smoke Movement Analysis in Complex Enclosed Spaces' by C.Lea, N.Gobeau, S.Ledin. Publication scheduled in 2006

  This is aimed at CFD specialists who have little or no experience of applying CFD to the specific application of modelling smoke movement. It is being written by HSL – see Section 4 for more detail

- 'How to Validate Industrial CFD' by C. Lea. Publication scheduled in 2006

  Its objective is to provide tools and techniques to quantify and reduce uncertainty in CFD, thereby increasing its reliability, usefulness and value.

- 'How to Make a CFD Project fit for purpose' by C. Lea. Publication scheduled in 2006

> The objective of this leaflet is to provide tools and techniques to help provide simulation results which fully meet project requirements and constraints – in particular when faced with applications with considerable model complexity.

A survey to identify which booklets would be most welcome by the Industry and Academia was undertaken this year. The results of this survey will decide the content and format of future publications and events organised by NAFEMS

3.5 COURSES

The organisation of basic CFD courses is currently under discussion. This was initiated by a few requests coming from the Industry. NAFEMS would organise these courses based on its experience in courses on Structural Analysis. They would be aimed at industrial users and would complement the existing specialised CFD courses organised by the universities and the training courses undertaken by the CFD code vendors on their products.

3.6 WEBSITE

The NAFEMS website has been re-designed and updated. In particular, the convergence guidelines available online have been revisited. The new version will be available on the NAFEMS website soon.

More information is now provided on the web: details of the events organised by the CFD Working Group and in the future the minutes of the meetings will also be added.

3.7 CFD JOURNAL

The CFD Working Group is publishing a Journal with test cases of CFD simulations.

After a period of interruption in the publication of the Journal, due to the editor leaving the UK, one issue of the Journal was published in 2004 and one is in preparation for 2006. The intention is to issue one Journal per year in the near future, and increasing to several issues per year if there are a large enough number of papers received.

3.8 COLLABORATION WITH OTHER NAFEMS WORKING GROUPS

The Group has increasingly collaborated with other NAFEMS Working Groups and in particular with the following groups: CAD/CFD Integration to consider the needs of CFD analysis when creating CAD geometries; Education and Training, helping with the publication of the 'Why do multiphysics' booklet; the UK Steering Group, for the organisation of a training course for design engineers and CAD users.

3.9 TRENDS OF THE CFD WORKING GROUP

The CFD Working Group is increasing its collaboration with other NAFEMS Working Groups, thus raising the profile of CFD to a wider technical audience.

It is also trying to develop contacts with CFD specialists in other countries. Many papers in the 2006 issue of the CFD Journal will come from the NAFEMS German Steering Group. The CFD

Working Group, the members of which are all UK based, is willing to liaise with and include corresponding members. This reflects the ambition of NAFEMS, originally a National Agency, to become international.

4 HSL CONTRIBUTIONS

4.1 MEETINGS

Nathalie Gobeau, HSL, has attended six of the eight meetings over the period December 2003 – November 2005. The meeting in June 2005 was hosted by HSL in Buxton.

4.2 EDUCATIVE MATERIALS

HSL has commented on all of the relevant documents published and has contributed to defining the aims and target audiences of the booklets in preparation. It has also helped the design of the survey making sure that the profile of health and safety issues were raised and that this will be reflected in the future publications of NAFEMS.

HSL has also finalised the booklet on the use of CFD for the prediction of smoke movement in complex enclosed spaces. The booklet is based principally on the findings of the research project JR04080 which was funded by RI, HID and OD. It is aimed at people who have some experience of CFD, even if limited, but little or no experience of applying it to smoke movement in complex enclosed spaces. The draft has been peer-reviewed by three referees and the comments are now being implemented. It is expected that the booklet will be published early in 2006. It will be distributed to NAFEMS members. Non-member will be able to purchase it for a small fee covering the cost of publication.

4.3 PRESENTATIONS AT SEMINARS

Two presentations have been made by HSL staff:

- ‘Benefits of Simulation’ seminar in Salford University in July 2005: This seminar, organised by the UK Steering Group, presented a few practical examples where numerical techniques have been used to address an issue. The aim was to raise the awareness of managers of how these relatively new techniques can complement more traditional methods. James Hobbs presented a simulation technique based on a combination of CFD and FEA methods and showed how it could be employed to investigate an incident.

- ‘Quality and reliability of CFD simulations II’ in Nottingham on 13th September 2005: This seminar followed on from the successful running of the similarly titled event the previous year. Mat Ivings made a presentation on the development of some best practice guidelines for the application of CFD to gas turbine safety. A range of other presentations were made including applications of industrial CFD and how practitioners deal with uncertainty.

The slides from these presentations are included in the appendix.

4.4 PEER-REVIEW OF PAPERS FOR THE CFD JOURNAL

HSL is part of the Editorial Committee of the NAFEMS CFD Journal and as such has reviewed four papers for publication in the 2004 and 2006 issues of the CFD Journal.

5 RELEVANCE TO HSE OBJECTIVES

This project contributes to the HSE aim of promoting risk assessment and technological understanding by:

- publicising the appropriate use of CFD, a complex mathematical tool, to assess the risks to the health and safety of workers and members of the public.

- providing advice on CFD for health and safety applications, to avoid misuse of the technique.

The presentations at seminars raised the profile of health and safety issues to a large audience. A few practical examples of how CFD could be used to tackle health and safety problems were presented to the Industry who were interested in CFD but may not have been aware it could be applied to health and safety in addition to product design etc..

Also, the presentation by HSL at the NAFEMS Quality and Reliability seminar presented the best practice guidelines on the application of CFD for assessing the effectiveness of ventilation in gas turbine enclosures for mitigating the risk posed by potential gas leaks. Effectively, as for any complex risk assessment tool, the quality and reliability of the predictions obtained by CFD depends on how well the technique is understood and applied by the CFD practitioner.

The educational booklet being prepared by HSL on 'How to Undertake a Smoke Movement Analysis in Complex Enclosed Spaces by CFD' has the aim of promoting the use of CFD for the assessment of risk related to fires and also providing guidance to CFD practitioners for this specific application. It is expected it will improve the quality of the CFD results presented to HSE Inspectors in safety cases and ultimately the measures taken to protect workers and members of the public from the risks of exposure to smoke. This can help to achieve the above targets of HSE of reducing work-related ill-health.

6 RECOMMENDATIONS

It is recommended that HSL should continue to represent HSE's interests at the NAFEMS CFD Working Group.

As a minimum, HSE should be represented at the quarterly meetings of the CFD Working Group in order to be able to influence the activities of the Group and thus make sure that the health and safety-related issues maintain a high profile.

In addition, opportunities for promoting CFD and providing advice to specific health and safety applications through the Group should be taken. These could include: writing articles in the monthly 'Benchmark' magazine; making presentations at the CFD seminars; producing educative booklets and writing papers in the CFD Journal. Other possibilities, such as organising a seminar on a health and safety issue, could also be envisaged although they may require more input from HSL.

7 REFERENCES

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'CFD modelling of chlorine dispersion at Tai Po Tau water treatment works.'
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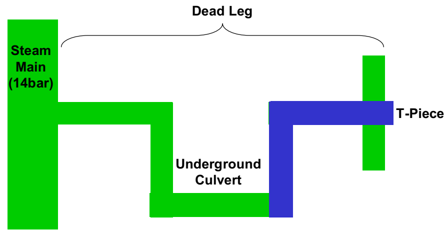
APPENDIX A

HSL presentation at the Business Benefits of Simulation, University of Salford, July 2005

Experimental and FSI Modelling of Water Hammer

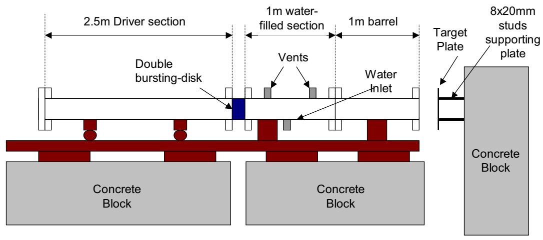
JAMES HOBBS - HEALTH & SAFETY LABORATORY

The Incident

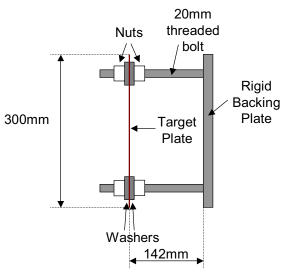


The Incident: Result

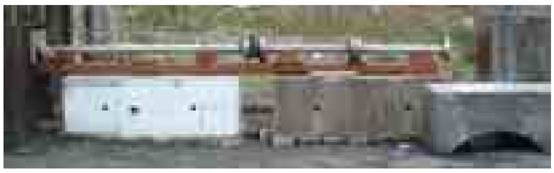
Experimental Work



Experimental Work



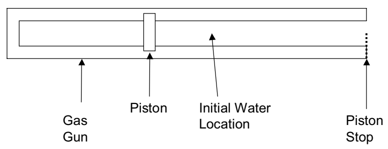
Experimental Work



Numerical Modelling

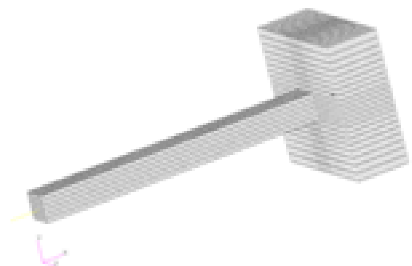
- Fluid-Structure Interaction analysis using MSC.Dytran
- Lagrangian Shell elements for tube, piston and target plate
- Eulerian mesh for water
- Beam elements for bolts

Schematic of Gas Gun



Target Plate

Eulerian Mesh

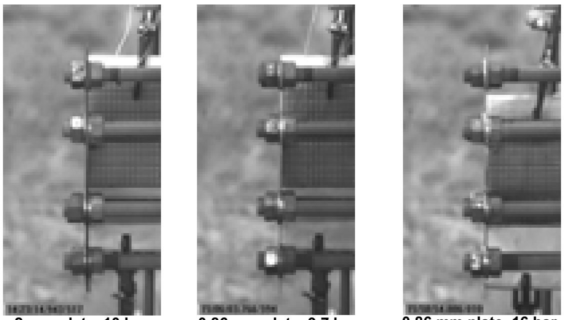


Experimental Tests

Test	***Target plate thickness (mm)***	***Driving pressure (bar gauge)***	***Peak deformation (mm)***	***Permanent plastic deformation (mm)***
1	0.86	9.7	39	27
2	2.05	10.0	-	2
3	3.00	≃ 9.0	-	1
4	0.86	16.3	45	37

Experimental Tests

Experiments



2 mm plate, 10 bar | 0.86 mm plate, 9.7 bar | 0.86 mm plate, 16 bar

Plate Deformation

Numerical Results

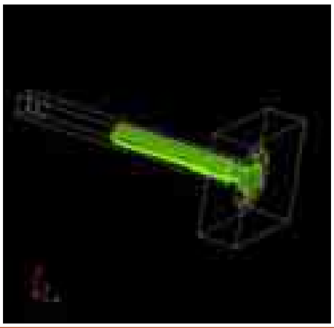
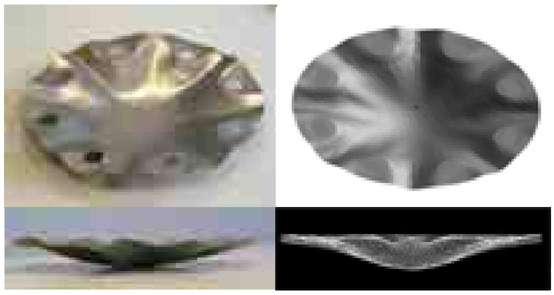
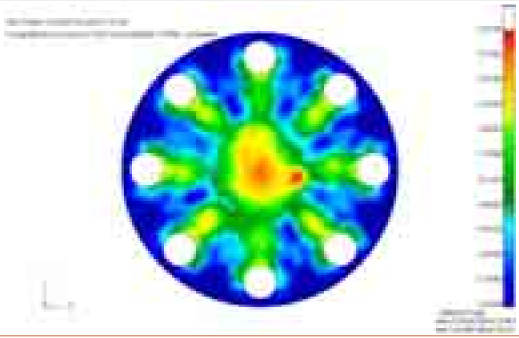
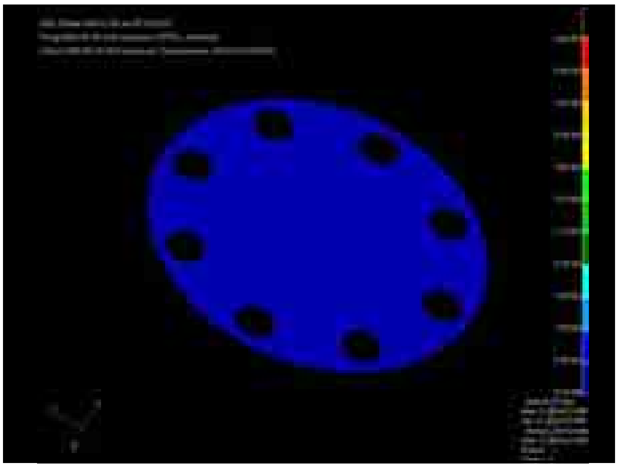


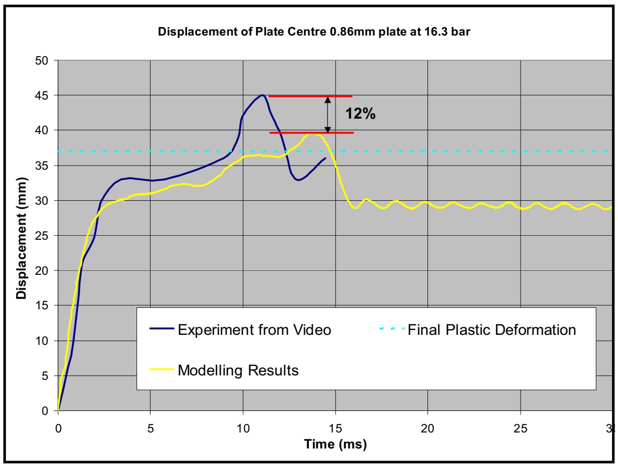
Plate Deformation

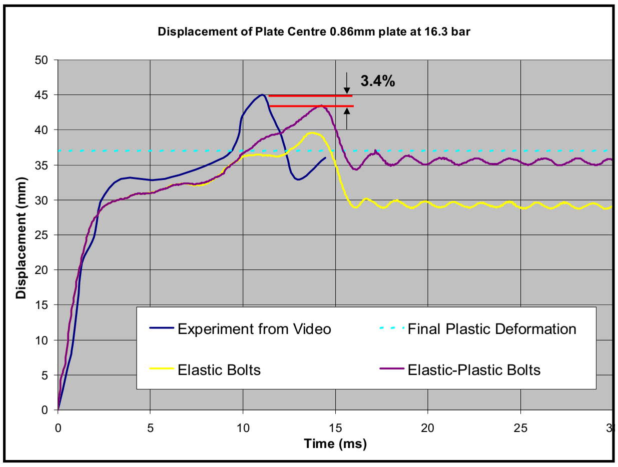


Plastic Deformations









Conclusions

- Experimental and Computational modelling performed
- Potential damage from water hammer shown
- Results agree very well…
  – provided you get the boundary conditions and material properties right

APPENDIX B

HSL presentation at the Quality and Reliability Seminar, University of Nottingham, 13 September 2005

Development of Best Practice Guidelines for the application of CFD to gas turbine safety

Dr Mat Ivings
Section Head
Computational Modelling Section

ERCOFTAC-NAFEMS Seminar
Quality and Reliability of CFD

HEALTH & SAFETY LABORATORY

Contents

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Background

- A leak of flammable gas within a gas turbine enclosure poses a hazard to the integrity of the enclosure and to personnel
- This risk is mitigated by an effective gas detection strategy and ventilation
- HSE Guidance specifies that leaks that are too small to be detected should be sufficiently small not to pose a hazard

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Background

- Role of CFD:
  - Assessment of ventilation against quantitative HSE criterion
- CFD fairly well suited to this application
- CFD used to consider 'worst case scenarios'

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Gas Turbine Joint Industry Project

- HSL recently carried out a large 'joint industry project' (JIP) to provide a more soundly based criterion on which to assess the explosion risk in a gas turbine enclosure
- The project was sponsored by 28 industrial sponsors and HSE

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Outstanding safety questions on the use of gas turbines for power generation: List of Sponsors

- 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

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Gas Turbine Safety JIP

Project aims:

- To establish the degree of conservatism in the current HSE guidance on the ventilation of gas turbine enclosures and possibly define a new less stringent criterion
- To provide a well substantiated means to comply with the European ATEX directives
- Use the outcome of the research to inform a harmonised European standard

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Research programme

- The Experimental programme included
  - explosion tests and
  - simulated gas releases
- The CFD modelling programme included
  - sensitivity studies and
  - development of best practice guidelines
- The results of both programmes fed into the definition of a new safety criterion

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Key experimental objectives

- To establish the effect of congestion on over-pressure generated from ignition of flammable cloud sizes which fill between 0.1% & 1.0% of an enclosure volume
- To establish the effect of absolute cloud size, as well as its percentage fill of an enclosure, on over-pressure generation.

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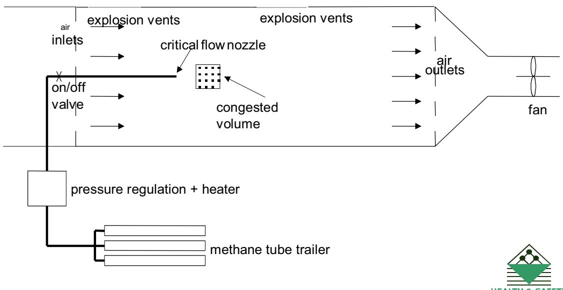
Experimental rig



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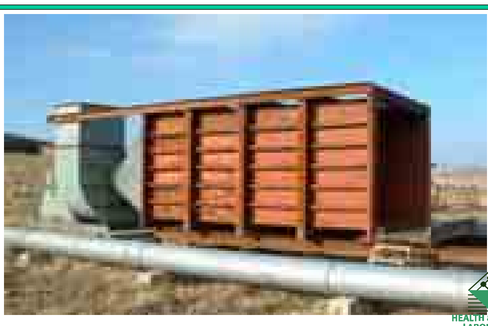
Experimental test enclosure



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Experiments

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CFD modelling

Objectives:
- Provide data to help define new safety criterion
- Investigate key issues on application of CFD to model ventilation in GT enclosures

- Validated CFD through comparison with experiments and empirical model data

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CFD modelling

Key issues
- Methods for modelling the source
- Porosity model to account for congestion
- Also looked at:
  - Mesh sensitivity
  - Buoyancy
  - etc.

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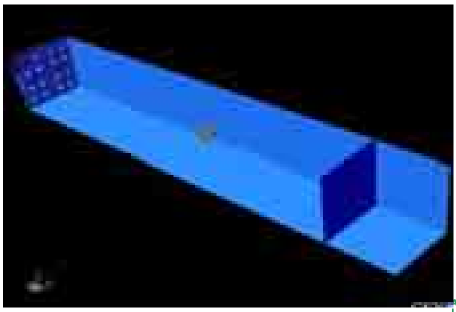
CFD Domain



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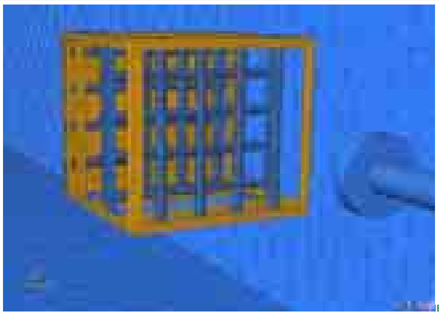
Computational Grid



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Experiments

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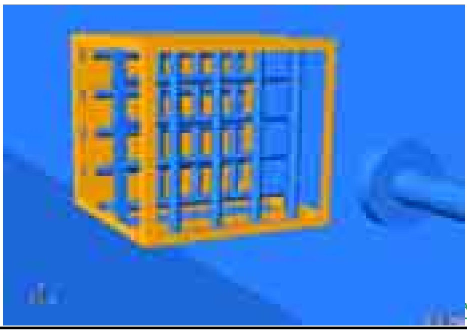
Gas Cloud



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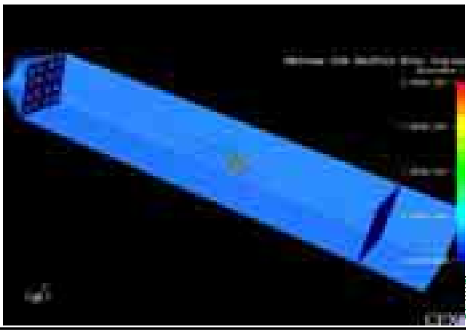
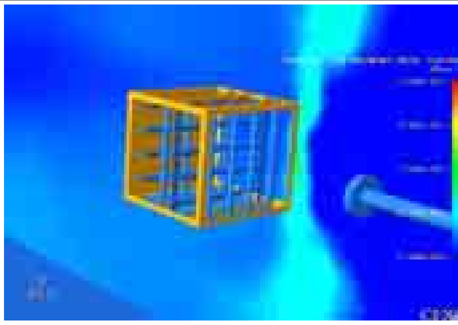
Flow Visualization



Flow Visualization



Best Practice Guidelines

Objectives:

- Formulate guidelines to be used by industry for application of CFD for assessing effectiveness of ventilation in GT enclosures
- Formulate guidelines to be used by industry for making in-situ measurements in GT enclosures for assessing effectiveness of ventilation and CFD model validation

Best Practice Guidelines

- Best practice guidelines are available to the public:

- CFD CM/03/12
- In-situ testing ECO/03/06

www.hse.gov.uk/research/hsl/fire.htm

CFD Best Practice Guidelines

Method:

- Survey members of the JIP for methods used for application of CFD
- Carry out sensitivity studies and draw on conclusions from CFD programme of work
- Consider issues specific to this application of CFD

CFD Best Practice Guidelines

- 1 Introduction - Aims and scope of the guidance
- 2 Overview of CFD methodology
- 3 Aims, benefits and limitations of a CFD approach
- 4 Overall approach
- 5 Geometry and grid
- 5.1 Geometrical resolution
- 5.2 Computational grid
- 6 Physical sub-models
- 6.1 Turbulence
- 6.2 Compressibility
- 6.3 Buoyancy
- 6.4 Heat transfer
- 6.5 Physical properties
- 6.6 Porosity
- 6.7 Time dependency

CFD Best Practice Guidelines

- 7 Boundary conditions
- 7.1 Ventilation inlets and outlets
- 7.2 Walls
- 7.3 Gas leak
- 8 Numerics
- 8.1 Discretisation
- 8.2 Convergence
- 9 User
- 10 Validation and sensitivity analyses
- 11 Documentation
- 12 Checklist

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Best Practice Guidelines observations / key issues

- Varying approaches to the same problem
- Source modelling
- Porosity modelling
- Validation and user
- Post processing

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Project Outcomes

- New safety criterion governing the use of gas turbines in enclosure
- Production of best practice guidelines on CFD modelling and in-situ testing
- New European standard will be influenced by this research

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Conclusions

- CFD is used widely as a means for demonstrating the effectiveness of GT ventilation
- Relatively mature application
- However, there are various pitfalls / sensitivities to be aware of
- Best practice guidelines have been developed to improve standards

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