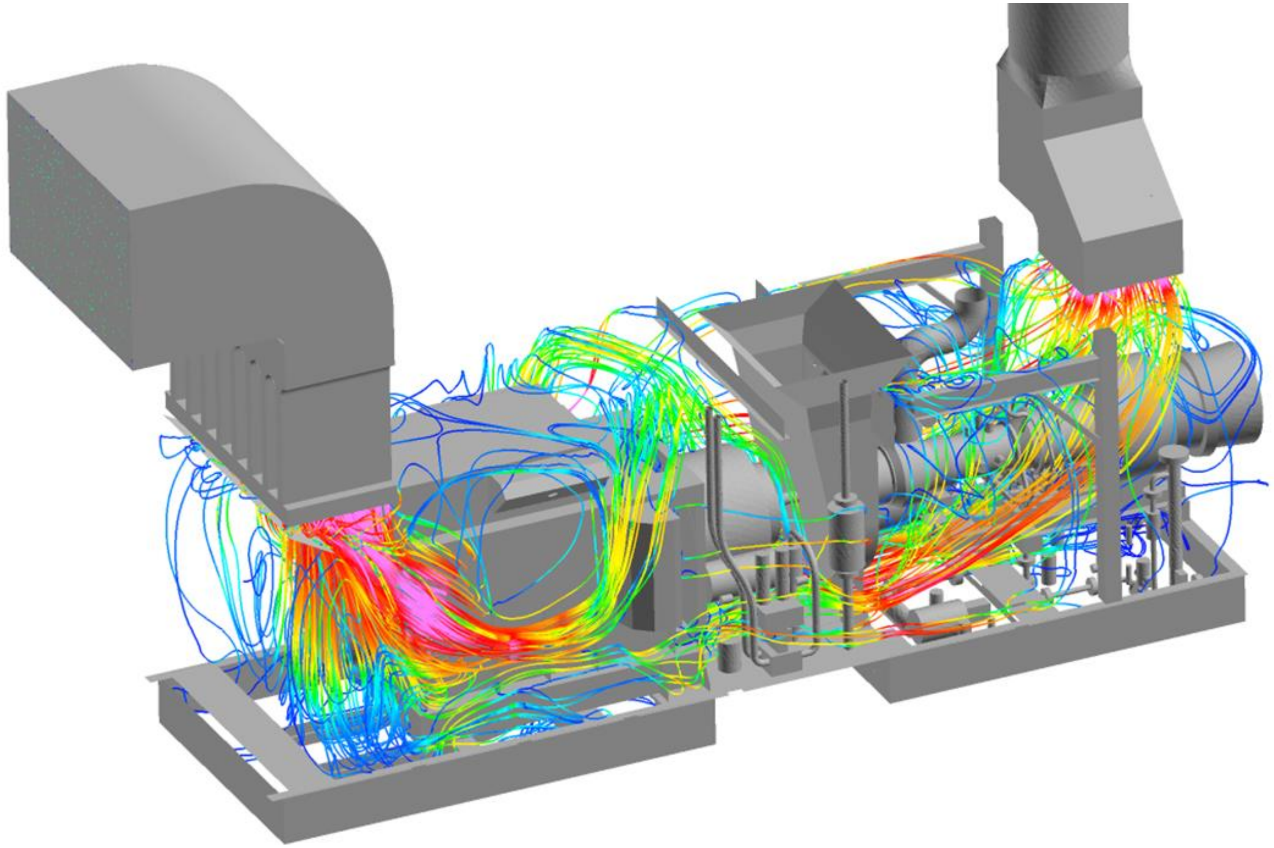

Hydrogen Usage in Gas Turbines – Impact on Enclosure Safety

Irfan Siddiqui – CFD Consultant

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SYSTEMS AND ENGINEERING TECHNOLOGY

FRAZER-NASH CONSULTANCY

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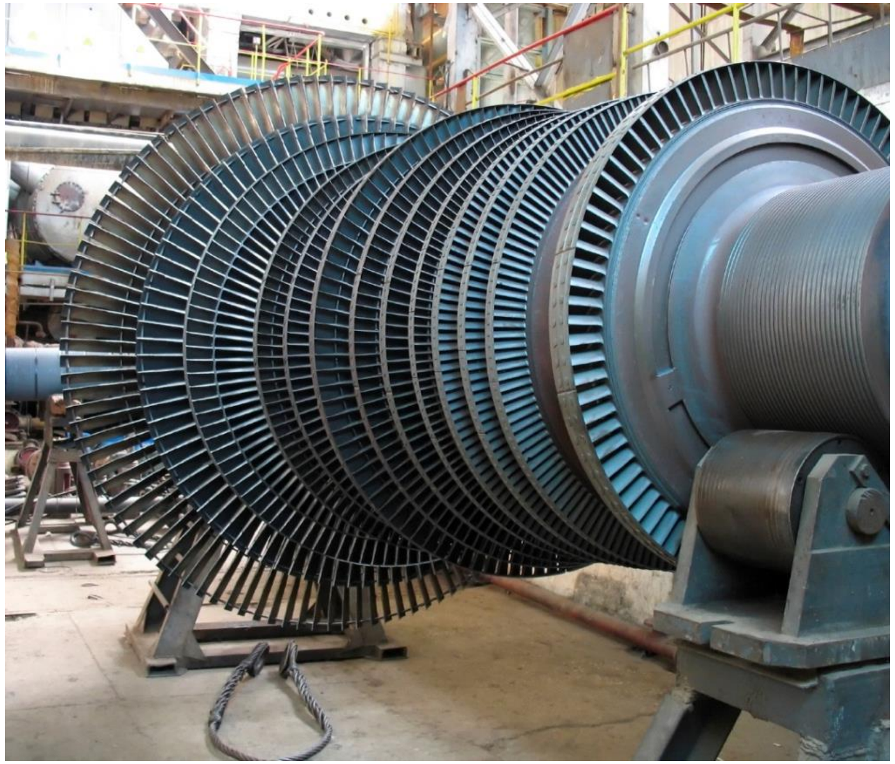
Frazer-Nash Introduction

Frazer-Nash - ATEX Compliance and Thermal Management

- Our Experience:
  - Frazer-Nash has been providing expertise in the design and analysis of gas turbine systems for **over 25 years**.
  - We have modelled **over 100 gas turbine enclosures** for a wide variety of clients.
  - We use our **extensive experience to** help our clients comply with operational regulations, and to develop enhancements that maximise the life and efficiency of their products and facilities.
  - Frazer-Nash was a member of the **Steering Group for the UK Health and Safety Executive led Joint Industry Project (JIP) in 2004** on gas leaks in gas turbine enclosures in order to satisfy the **European ATEX Directive**.
  - The guidelines and best practice generated from this project (HSL CM/04/09) are now part of the ISO 21789 standards.



Current Safety Approach – Hydrocarbon Fuels

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Gas Turbine Safety Requirements

BRITISH STANDARD

BS ISO 21789:2009

Gas turbine applications — Safety

ICS 27.040

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BSi British Standards

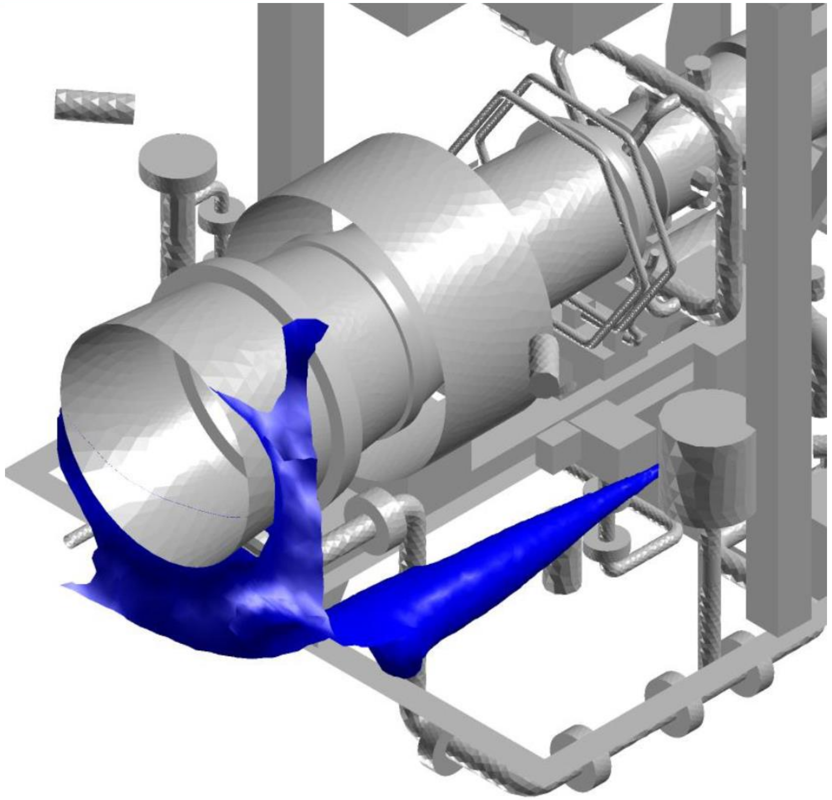
- Conventional ATEX approach cannot be used as ignition sources cannot be eliminated.

- The current basis of safety in the event of a gas leak is **dilution ventilation:**
  - Ventilation flow disperses leak flow and carries it to the outlet where it is detected by infra-red gas detectors.

- **ISO 21789:2009** (Gas turbine applications – Safety):
  - CFD modelling or other quantifiable techniques should be used to ensure adequate dilution of a gas leak is achieved.
  - Maximum undetected flammable gas cloud size criteria, based on methane explosion overpressure tests (0.1% enc vol).

Gas Turbine Safety Requirements

- CFD identifies stagnant regions in proximity to leak and ignition sources.
- A number of worst-case credible gas leak scenarios are modelled.
- Demonstrate that gas clouds, larger than 0.1% of the net enclosure volume are detected.
- In the event of ignition of an undetected gas cloud (less than 0.1% of the net enclosure volume), the overpressure created by the explosion will not exceed 10mbar.



- The enclosure must then demonstrated to withstand a 10mbar overpressure.

Challenges – Hydrogen Fuel Mixtures

Challenges – Hydrogen Fuel Mixtures

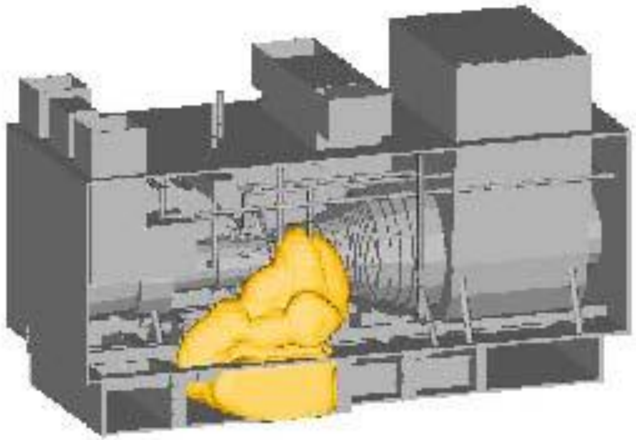
- Due to the differences in hydrogen properties, there are three key challenges that must be addressed:
  1. There are currently no standards which address hydrogen in gas turbine enclosures
  2. Practical issues with gas detectors
  3. The current CFD approach needs to be reassessed

Hydrogen Challenges - Standards

- The current ISO 21789 standard is not intended for use with hydrogen fuels. Upcoming revisions do not address hydrogen.

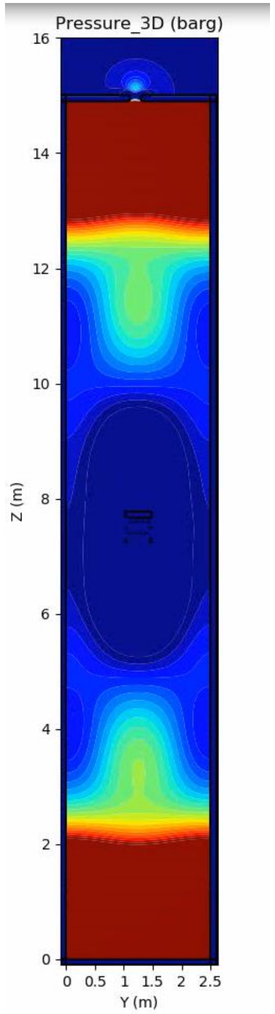
- The current safety criteria are not applicable for hydrogen fuels:
  - HSE tests are based on methane overpressures
  - 0.1% vol criteria is not valid for pure hydrogen or mixtures
  - Hydrogen explosion overpressures are significantly higher than for methane

- Deflagration to detonation transition:
  - Additional requirement to demonstrate no detonation potential



Hydrogen Challenges – Practical Issues

- Current infra-red gas detectors do not work for hydrogen
  - Increasing fuel hydrogen content reduces ability of infra-red gas detectors to detect leaks
  - Current thresholds need to be reassessed
- At higher hydrogen concentrations additional or alternative catalytic detectors will be needed:
  - Performance, detection speed, reliability in GT environment, maintenance requirements
- Higher explosion overpressures may require further reductions in gas detector thresholds
  - Operational issues with spurious trips
- Flame detectors may be ineffective at higher hydrogen concentrations due to clear flame
- Hydrogen leak propensity - Fuel system design or at least some components to be modified
- ATEX Zone 2, Gas Group IIC – requirement to replace some components

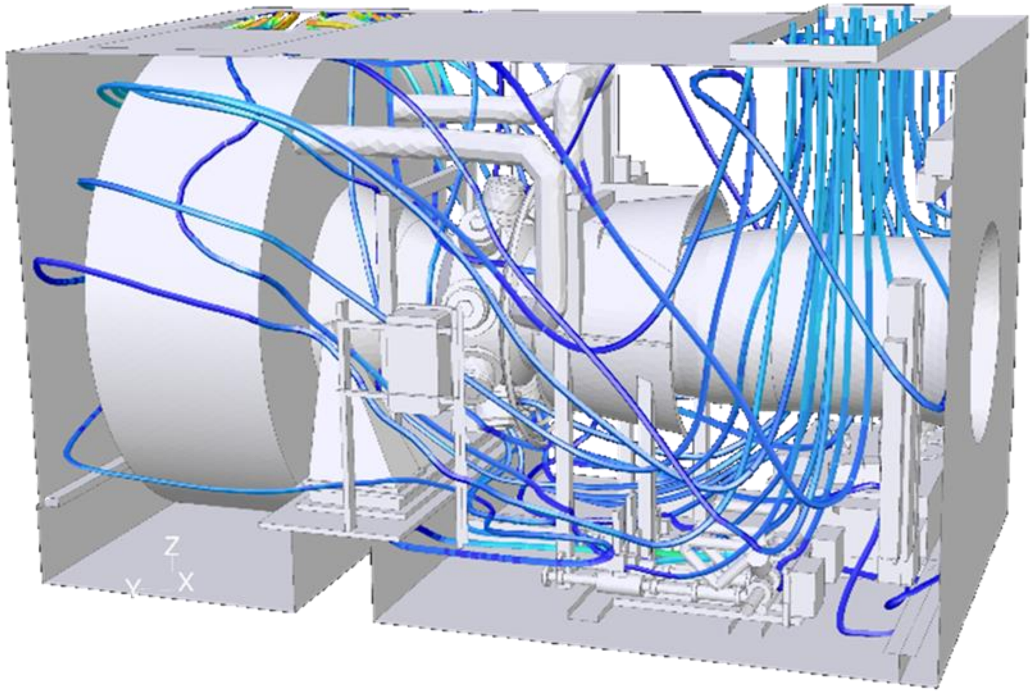


Hydrogen Challenges – Updated CFD Approach

- HSE tests are based on methane overpressures
  - 0.1% vol criteria is not valid for pure hydrogen or mixtures
  - Hydrogen explosion overpressures are significantly higher than for methane
    - Lower allowable gas cloud volume?
    - Outlet detectability demonstration more challenging
    - Mitigated to some extent by the lower air fuel ratio

- Hydrogen properties lead to:
  - Different leak flow rates and leak jet behaviour
  - Different gas cloud dispersion behaviour

- Hydrogen leak propensity:
  - Additional leak sources to be considered



SYSTEMS AND ENGINEERING TECHNOLOGY

HYFLEXPOWER

HYFLEXPOWER

- HYFLEXPOWER is the world's first power-to-hydrogen-to-power industrial scale technology demonstrator, part funded by the European Commission through the Horizon 2020 framework

- Frazer-Nash are currently completing a project for Centrax to:
  - Assess the suitability of the current methane safety criteria for a range of hydrogen fuel mixtures and define a new set of criteria if required
  - Assess the ventilation performance of the CX400 enclosure against the new criteria

- The results will be presented at the 2021 HySafe Conference

FRAZER-NASH CONSULTANCY

Irfan Siddiqui, CFD Consultant

Email: i.siddiqui@fnc.co.uk

www.fnc.co.uk