THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47th St., New York, N.Y. 10017

98-GT-321

REMEDIATION OF GAS EXPLOSION HAZARDS IN GAS TURBINE ENCLOSURES.

Yehuda L Sinai
CFX International,
AEA Technology, 8.19 Harwell,
Didcot OX11 0RA, UK

Jim Barrett
Hydro-Electric Production Services
Keadby Power Station, P.O. Box No. 3
Scunthorpe DN17 3BA, UK

ABSTRACT

Previous calculations exploiting Computational Fluid Dynamics techniques [1], and using the CFX-4 software, have indicated the presence of potential gas dispersion and explosion hazards in the acoustic enclosure and interconnect skid at Keadby power station. On the basis of those calculations, a different ventilation arrangement is proposed as a means of remediating the hazard. The proposed system is promising, indicating simultaneously a reduction in the size of the hazardous cloud and an increase in its detectability.

1. INTRODUCTION

The Health & Safety Executive (HSE) recently undertook a review [1] of the consequences of postulated gas leaks at Keadby Power Station. That review took the form of a collaborative effort by the HSE's Health & Safety Laboratory (HSL) and CFX International (previously known as CFDS) of AEA Technology plc, both on site measurements and theoretical predictions, taking account of the approach devised by Santon [2]. Santon has pointed out that with detection at the outlets, there is a unique relationship between the leak rate, the overall ventilation rate, and the concentrations at the outlets. There is therefore only a need to analyse one leak rate, namely the smallest leak to be detected. If the enclosure design copes with an explosion following such a leak, the enclosure safety level is considered to be adequate. A larger leak would be detected, and a smaller leak would lead to a weaker explosion. Santon has recommended that the volume of the cloud in which the concentration is greater than 50% LEL (viz. 50% of the lower explosion limit) should be no larger than 0.1% of the net enclosure volume.

Keadby power station features two CCGT units, each housed in its own acoustic enclosure and running on natural gas. The fuel supply mechanisms are housed in a relatively small compartment adjoining the enclosure, known as the 'interconnect skid'. The hazard is associated with possible leaks of the fuel either in the main enclosure or the skid. The existence of the enclosure and skid means that a gas leak could lead to the build-up of flammable or explosive mixtures, unless the ventilation system is designed to cope with such a scenario adequately.

Fire suppression and gas detection systems are in existence at the station. One detector is positioned in the skid, and additional detectors are situated in each of three outlets situated at the roof of the main enclosure.

The size of the explosive cloud, and its inventory, are not the only issues:- Detectability is another crucial matter. It is not uncommon for small leaks to be more dangerous than large ones because of their ability to generate clouds of considerable size whilst maintaining a lower detectability.

The CFD aspect of the review [1] included a number of calculations. The base case, named A2, considered a relatively small leak of methane from a supply pressure of 21 bar abs, through a breach of $42mm^2$, located to the side of, and close to the turbine casing, pointing approximately downwards. The other cases involved the same breach with different orientations, or different breach sizes, or different locations. An assessment was also made of the sensitivity of the results to mesh resolution (ideally, the solution should be mesh-independent).

Early results indicated that Case A2 would result in a substantial cloud which would not trigger the enclosure's gas detectors. In October 1996, Keadby Generation Limited commissioned AEA Technology to investigate possible means of remediating the hazard, using CFD. A few investigations of the background state, without leaks, were performed, in order to optimise the proposed design. All dispersion calculations were done under the same leak conditions as A2 explained above, apart from an additional run in which the source is beneath the turbine.

Presented at the International Gas Turbine & Aeroengine Congress & Exhibition
Stockholm, Sweden — June 2–June 5, 1998

The proposed new design relies on dilution ventilation, whereby the ventilation supply is concentrated in the environs of likely breaches, instead of being evenly distributed throughout the volume. The environment in the present enclosure is very congested, and it is for this reason that higher ventilation momentum has been introduced in the midst of that congestion. The proposed system is promising, indicating simultaneously a reduction in the size of the hazardous cloud and an increase in its detectability.

2. STATION MANAGEMENT APPROACH

From the initial production of management procedures and policies the philosophy of approach at Keadby Power Station was based upon the following principles:

- Minimisation of fuel gas leakage potential
- Maximisation of fuel gas leakage detection
- Rigorous policies, procedures and control measures

Prior to commercial handover of the plant in January 1996 relevant procedures had been developed and put in place. The initial investigations carried out by the Health and Safety Executive in early 1996 prompted a review of procedures and an enhancement of the already proactive approach philosophy.

Keadby approached the HSE and offered to carry out joint research using the Gas Turbines as a test case. Initial investigations commenced in June 1996 with measurement of the physical conditions within the enclosures such as air flow, velocities and temperature leading to a real set of input data for the subsequent modelling process.

CFD modelling using CFX-4 software [3] was then undertaken by AEA Technology on behalf of HSE. The results of the modelling showed that a potential existed within the turbine enclosure for a significant gas cloud to develop, due to a leak, and remain undetected with the current arrangement of ventilation and detection. As a result of these findings AEA Technology were commissioned to carry out additional work with the Keadby management team to attempt to model potential solutions to the situation, this commenced in October 1996.

Kvaerner Engineering Limited (KEL), the station turnkey contractor, also committed at this time to work with the team to develop a solution.

In parallel to these activities the station management team again reviewed all the procedures and policies in light of the findings. A root cause analysis was carried out to identify measures that could be put in place until an optimum solution was identified. The local HSE Inspector provided guidance and advice and was actively involved in discussing all the measures and controls developed and enacted at the site.

Risk assessments were again reviewed in light of the new insight and detailed changes to the procedures identified. These included:

- Enhanced quality control standards for the remaking of fuel gas pipe flanges and joints.
- Competency accreditation of personnel for the remaking of fuel gas joints.
- A reduction in protection alarm and trip settings for the gas detection system to take account of the disparity between actual potential gas levels in the enclosure and the detection capability of the existing systems.
- The utilisation of the fixed gas detection system diagnostics computer to monitor continually for any gas leakage to an accuracy of +/- 0.1% LEL.
- Revised access procedures.
- Revised operator actions upon receipt of gas leakage alarms.
- Revised procedures for potential leak checking on return to service after maintenance.

The physical checks supported by the modelling findings showed that stagnant areas existed within the enclosure where adequate dilution was not taking place. Various ventilation modification design changes proposed by AEA Technology were reviewed and modelling carried out to assess the impact these had on gas cloud formation and leakage detection probability.

An optimum design solution was developed, supported by modelling results, which resulted in reduction of gas cloud volume and methane inventory, coupled with a predicted increase in detection probability. Final design was completed in March 1997 and orders placed to fabricate the additional ventilation manifold and nozzles.

The design simply incorporated a new additional ventilation manifold located behind the combustion area providing additional air movement in the stagnant areas. The total air flow through the enclosure was actually reduced slightly and the existing air inlet louvers adjusted to retain the required air flow balance for cooling purposes. The design was approved by General Electric, the original gas turbine manufacturers.

The modifications were incorporated into one gas turbine in June 1997 with the other unit currently being installed. Initial tuning of the system is now completed and final verification of the modelling prediction is scheduled to take place in the near future.

Keadby continues to maintain a proactive stance and is now looking at other improvements that can be made in both the medium and long term to enhance the safety associated with the acoustic enclosures. These include the following:

- An interface connection between the gas detection diagnostic computer and the station DCS system to provide real time monitoring of the various detector readings, additional alarm point ability and trend monitoring.
- A reduction in flange type joints and a movement towards a fully welded fuel pipe system.
- Investigation into the potential of fitting isolation means in the fuel gas lines as close as possible to the machine to facilitate leak checking utilising inert gases.
- The development of acoustic monitoring systems to alarm in the event of detected noise frequency and level changes.

Scottish Hydro-Electric plc, the Keadby owner, has adopted this approach and philosophy, subsequently producing a Code of Procedure relating to the standards of management of these risks at all its CCGT and CHP plants along with detailed specification requirements for new plant.

3. MODELLING AND ASSUMPTIONS

Fortunately, it was possible to exploit the mesh already set up for the HSE project [1]. That mesh is relatively coarse (44,964 cells), in order to minimise running times and costs. As mentioned in the Introduction, mesh sensitivity was assessed, and the results indicated that theoretical accuracy has not been unduly sacrificed with this mesh.

3.1 Geometry

The mesh is multi-blocked, with Body-Fitted Co-ordinates able to follow the curved outline of the turbine casing. The casing was assumed to be axisymmetric, and features such as the combustion chambers were not modelled. The CFD model is illustrated in Figure 1, showing the surfaces and objects which are represented explicitly.

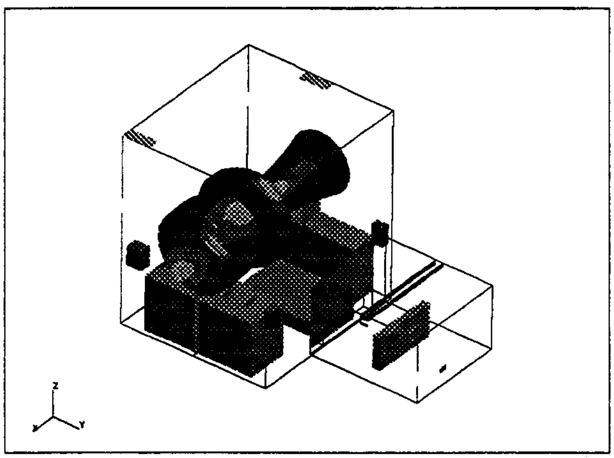

Figure 1: Geometrical model

Features which have been modelled explicitly include:

- The enclosure
- The skid
- The turbine casing and idealised supports
- A concrete support plinth at each end of the turbine
- A large horizontal plate in the enclosure, a little higher than the level of the skid floor, and idealised I-beams which support it
- A large vertical plate at the junction between the enclosure and the skid
- A solid blockage in the skid representing a particularly congested region
- Inlet protrusions in the enclosure
- The edges of a channel in the ceiling of the skid along which a jet of ventilation air flows

The co-ordinate system has its origin at the north-western corner of the enclosure floor. Here north refers to the cold (compressor) end, south to the hot (exhaust) end. Thus, the y axis points eastwards, viz. towards the skid. The z axis points vertically upwards (the right-hand-screw convention is used).

3.2 Fluid flow and heat transfer modelling

The flow has been assumed to be steady, buoyant, and fully turbulent. Immediately after the occurrence of a breach, the leaking gas will develop in a transient fashion, but it will not take long (probably tens of seconds or a few minutes) for conditions to reach equilibrium, and the asymptotic state is usually (but not always) the most onerous. Transient CFX simulations can and have been performed in some cases. The common buoyancy-modified k-ε turbulence model (with buoyancy terms in both equations), available as one of many options in CFX 4, was specified.

In addition to the above aspects, small-scale features, too small to be resolved by the mesh, have been modelled in terms of resistances and sources of heat within pre-defined 3-D regions.

The flow and heat transfer model employs standard correlations for equivalent tube banks [4], and assumes that the resistive medium is isotropic. The congestion modelling has been enhanced since the completion of this work and is being tested.

The leaking gas is methane, with a supply pressure of 21 bar abs and temperature of 300K. It has been modelled as a point source of mass, methane, enthalpy, and three components of momentum. Correlations for under-expanded jets have been used to deposit these sources at the cell which contains the sonic tip of the jet. The user specifies the breach location and its orientation.

3.3 Boundary conditions

Surface temperatures have been specified, sometimes as functions of position, on the basis of measurements made by the HSE [1]. For example, the enclosure's vertical walls have been assigned a linear variation of temperature (50C at the floor, 90C at the walkway). The floor, plinths, and roof temperatures have been fixed at 50C, 60C, and 130C respectively. All remaining explicit surfaces in the enclosure have been set to 60C. Surfaces in the skid are assumed to be adiabatic. The turbine casing's temperature has been idealised as 250C on the cold side of the combustion chambers, and 350C on the remainder.

It is acknowledged that most of the conditions adopted here are based on measurements in the existing plant, but their influences are believed to be weak in the coarse-meshed approach.

Ventilation air temperatures, for air entering through the conventional (present) inlets, have been set at the measured values (about 30C).

The most important aspect of the present work is the introduction of dilution ventilation as a means of improving mixing. This is achieved by concentrating the ventilation sources close to the regions in which the leaks are likely to occur. In the present project, this has been done by assuming one or more 'rings' of nozzles, concentrically arranged about the turbine's axis, and directing air approximately along the turbine and towards its cold end (in order to reduce the risk of ignition). Coding has been written so that the user may specify:

- the number of rings
- the number of nozzles in each ring
- the total flow through each ring
- the direction in which the nozzle points, as an angle relative to the turbine's axis (it is assumed that each nozzle axis and the turbine axis lie in the same plane)
- the nozzle area (or equivalently, the nozzle flow speed)

This design concept is shown in Figure 2. Resolving each nozzle's flow details is beyond the scope of this project, and each nozzle flow is represented in terms of point sources of mass, enthalpy, and the three components of momentum.

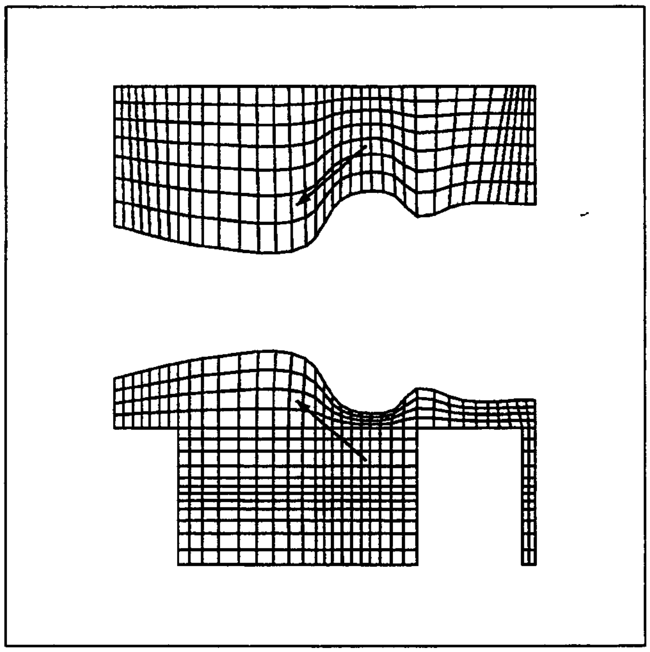

Figure 2: Definition of a ventilation 'ring'

Ventilation supply through the existing inlets may still be specified as before, in addition to the ring supply. Additional sources of air and momentum, positioned elsewhere may also be prescribed.

The ventilation air (and any leaking gas) leaves the computational domain via three pressure patches set in the enclosure's ceiling approximately at the positions of the actual outlets. They can be seen in Figure 1.

4. PRESENTATION AND DISCUSSION OF THE RESULTS

4.1 Preliminary Remarks

Several ventilation arrangements were explored, with various combinations of several rings and additional isolated sources. The optimisation process may perhaps have been taken further, given sufficient time, but in the circumstances a design involving one ring was chosen.

4.2 Results

A maps of the air speed in the background state of the chosen designs is shown in Figure 3, and the velocity vectors are depicted in Figure 4.

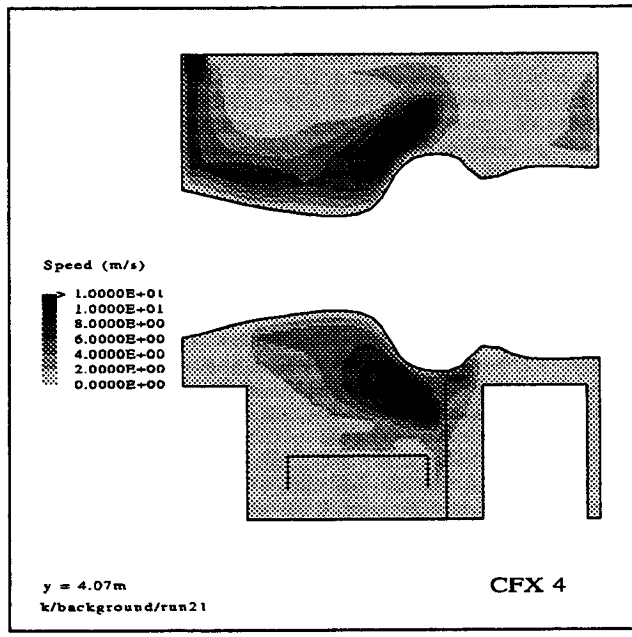

Figure 3: Map of air speed at y=4.07m

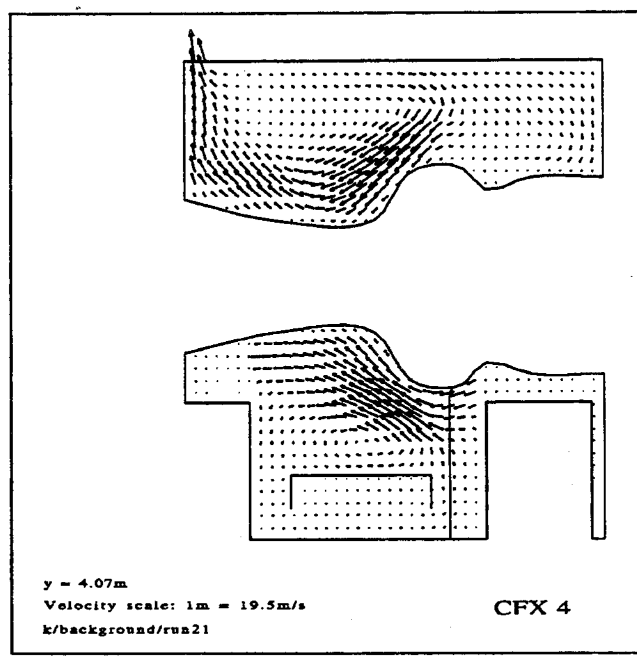

Figure 4: Velocity vectors at y=4.07m

These pictures lie in the vertical plane passing through the turbine's axis. It is emphasised that the ring nozzles are not being resolved in detail, and the speeds calculated by CFX in this case are therefore 'smeared' over the computational cells.

A picture of the 50% LEL cloud in the chosen design is provided in Figure 5.

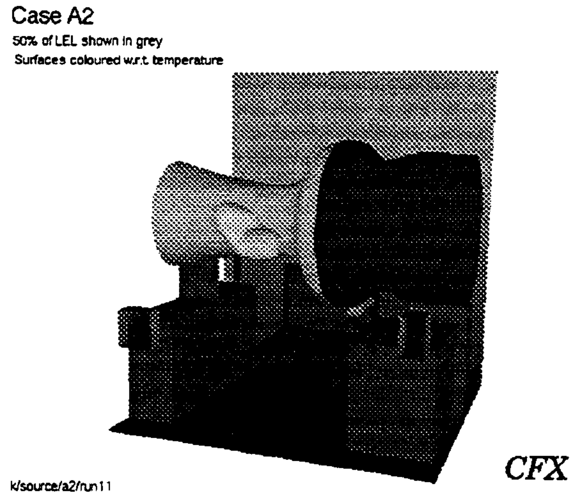

Figure 5: 50% LEL cloud

Information on the sizes of the methane clouds, methane inventories, and methane concentrations at the middle of the three outlets, is given in Tables 1 and 2 below. The total methane figure is the total inventory of methane in the whole computational domain. The cloud volume is defined here as the volume of the 50% LEL iso-surface, and the cloud methane mass is the mass of methane contained within that surface.

Table 1: Methane cloud characteristics

Case	Total methane (kg)	Cloud volume (m^3)	Cloud methane mass (kg)	Comments
A2 (Ref. 1)	2.07	6.47	0.122	Old design
A2	1.73	1.59	0.0365	New design

Table 2: Methane concentration (% LEL) at the centres of the enclosure outlets

Case	lowx	highx-lowy	highx-highy	Comments
A2 (Ref.1)	12.5	10.9	5.80	Old design
A2	14.6	26.0	6.04	New design

When interpreting these results, it should be remembered that the methane concentrations could be varying across the area of a given outlet. The outlet concentrations have increased because the total ventilation mass flow rate has been reduced. This is another advantage of the new design.

5 CONCLUSIONS

A modification to the ventilation arrangement in the enclosures and skids at Keadby Power Station have been investigated as a means of mitigating explosion hazards.

A system of rings of nozzles surrounding the turbine casing has been proposed. Several options were investigated. A small proportion of the enclosure's ventilation flow is still directed to the four existing inlets. The preferred design is promising, with the analysis indicating a reduction in the cloud size accompanied simultaneously by an increase in concentrations at the outlets. Thus, the hazard is reduced and detectability is increased.

A possible limitation of the model is the porous-medium approach for congested regions. This is counter-balanced by the savings in costs and run times which are accrued by such a technique.

ACKNOWLEDGEMENTS

The authors are grateful for the contributions and assistance provided by Rod Chistie (Keadby Power Station). The authors wish also to thank Libby Thick and Mark Owens of AEA Technology for their assistance in the preparation of this paper.

REFERENCES

1 Lea CJ, Hambleton RT, Hawksworth SJ, Sinai YL & Owens MP, "Assessment of Gas Dispersion in CCGT Enclosures: Measurement and CFD Modelling Using the CFX Software", presented at "Prevention and Control of Gas Explosions in CCGT and Steam Plants", 8 October 1997, London, IMechE.

2 Santon RC, "Explosion Hazards at Gas Turbine Driven Power Plants", Proc. IMechE Seminar on Prevention and Control of Gas Explosions in CCGT and Steam Plants, 8 October 1997, London. See also Proc. HAZARDS XIII, UMIST, 22-24 April 1997, IChemE.

3 CFX International, 1995, "CFX 4.1 Flow Solver User Guide", CFX International, AEA Technology, Harwell, Oxon, UK.

4 McAdams W H, *Heat Transmission*, McGraw-Hill, Third Edition, 1954.