Case Study Template

Please complete 3 short case studies (max. 2 pages each). These case studies can be updates of the ones that have already been submitted (if so please note this in the case study title) or new case studies that have been developed in the current reporting period.

1. Title of Case Study: Impact of fire and explosion research on industrial practices and public safety

2. Grant Reference Number: EP/R029369/

3. One sentence summary: Warwick FIRE research has contributed to cost savings and safety planning of its industrial sponsor and collaborator.

4. One paragraph summary:

(1) With an improved fire model helping insurance company FM Global to reduce the number of large-scale tests (approximately USD100,000 each) needed to devise fire protection strategies for their customers.

(2) Explosion models developed by Warwick FIRE has been used by industrial partner in safety studies of their facilities.

5. Key outputs in bullet points:

(1) Professor Wen's team has improved the treatment for thermal radiation in FireFOAM (2015 to 2019), the fire simulation solver within OpenFOAM with robust but relatively simple and faster grey gas models as well as more detailed models which considers band dependence of gas radiation properties. They also developed a new 'box' model to capture the spectral properties of gas radiation. It offers an effective and yet efficient solution to cater for the spectral radiative properties of combustion gases and mixtures of water droplets and gases in simulating fire suppression.

a) Xu, Baopeng, Wen, Jennifer X. 2020, The effect of convective motion within liquid fuel on the mass burning rates of pool fires - a numerical study. *Proc. of the Combustion Institute*.
b) Ivan Sikic, Siaka Dembele and Jennifer Wen, Non-grey radiative heat transfer modelling in LES-CFD simulated methanol pool fires, *J of Quantitative Spectroscopy and **Radiative Transfer**, Volume 234, September 2019, Pages 78-89.*

(2) HyFOAM, dedicated to hydrogen safety research has been developed within the frame of OpenFOAM. For explosion modelling, it uses the flame wrinkling combustion model with established formulations added to consider laminar flame speed variations with hydrogen concentration and non-unity Lewis number effects. The improved model has been used to numerically study the worst-case scenario involving pressurized hydrogen storage cylinders enveloped by an explosion using measurements from large-scale tests commissioned by Shell Global Solutions for validation.

c) Vendra, C. Madhav Rao, Wen, Jennifer X. 2019. Numerical modelling of vented lean hydrogen deflagrations in an ISO container. *Int. J of Hydrogen Energy, 44(17), April 2019, Pages 8767-8779.*
d) Vendra C. Madhav Rao, Pratap Sathiah and Jennifer X. Wen, Effects of congestion and confining walls on turbulent deflagrations in a hydrogen storage Facility-Part 2: Numerical Study, Int J of Hydrogen Energy,43(32): 15593-15621, June, 2018, https://doi.org/10.1016/j.ijhydene.2018.06.100.
e) Vendra C. Madhav Rao, Pratap Sathiah and Jennifer X. Wen, Numerical investigation of hydrogen-air deflagrations in a repeated pipe congestion, *Proc. 8th Int. Conf. on Hydrogen Safety, Yokohama, Adelaide, Australia, Sep.2019.*

6. Main body text

(1) A further beneficiary of collaboration with Warwick FIRE is Shell India Markets Private Ltd, as part of the Shell group. Through collaborative work between 2016 and 2019, Shell and Warwick FIRE developed HyFOAM. HyFOAM was designed specifically for the purpose of planning for a worst-case scenario where pressurized hydrogen storage cylinders are enveloped by an explosion, and with the code incorporating real world measurements from large-scale tests commissioned by Shell. By evaluating these ramifications of the considered worst-case scenarios in detail, HyFOAM will now see use in “design analysis and facility siting” for storage centers and refueling stations. Shell have also supplied Warwick FIRE with the in-house developed PDRFOAM, which will enable Professor Wen’s group to extend its modelling to deal with more complex geometries.
(2) The improved FireFOAM has been used by FM Global, an international insurance company, to reduce the number of large-scale fire tests (which typically costs USD100,000 per test) needed to devise fire protection strategy – constituting a key cost saving. Its use also enables the company to minimize the turn-over time for engineering problem solving. The code has also been released by FM Global at https://github.com/fireFoam-dev/fireFoam-dev for free downloading by worldwide industry and academia for fire protection analysis. Dr Yi Wang, added, “The model and numerical tool that Warwick’s research team contributed to develop has enabled our researchers and engineers to better understand the heat transfer and fire dynamics, and to conduct technically robust engineering evaluation and design in a cost-effective manner.

7. Names of key academics and any collaborators:

- Professor Jennifer X Wen, School of Engineering, University of Warwick.
- Dr Pratap Sathiah, Technical Safety Engineer, Shell Technology Centre Bangalore

  Shell India Markets Private Limited.
- Dr Yi Wang, Staff Vice President, Manager of the Fire Dynamics group in the Research Division of FM Global

8. Sources of significant sponsorship (if applicable):

1. Developing computationally efficient approaches for modelling radiative heat transfer of soot and evaporating water droplets in FireFOAM, funded by FM Global (PhD studentship, March 2014 – September 2018)
2. Improving Hydrogen Safety for Energy Applications (HySEA) through pre-normative research on vented deflagrations, EU Horizon 2020 (€450.4K within a €1.5M consortium, 1 Sep. 2015 to 31 Nov. 2018)

9. Who should we contact for more information?

Professor Jennifer X Wen, Jennifer.wen@warwick.ac.uk

10. Please indicate if you would like this case study to be included on the Consortium’s ARCHER web-page.

Yes