Application of global sensitivity analysis to FDS simulations of large LNG fire plumes

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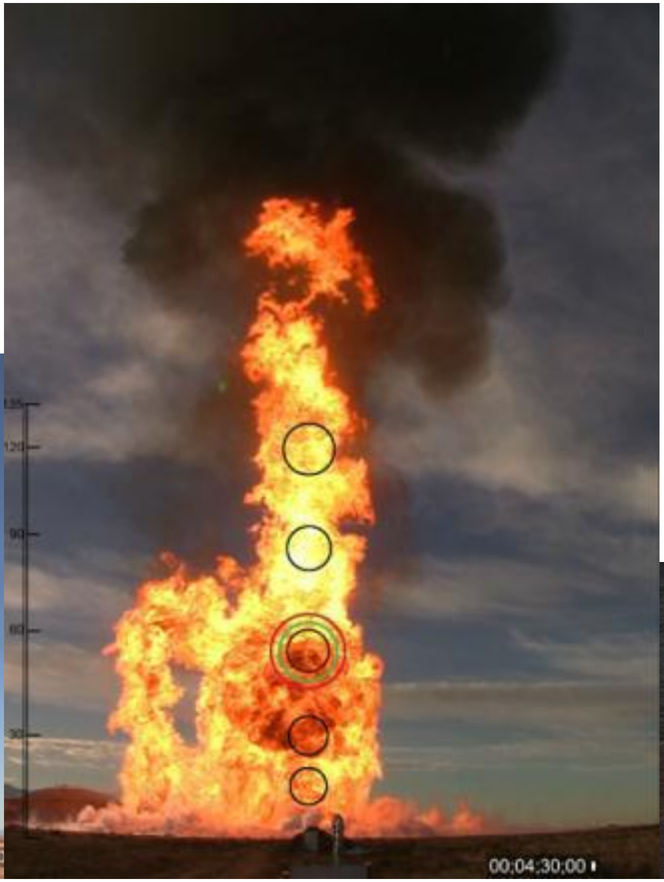
LNG pool fires

- Phoenix series tests, Sandia

21 m diameter

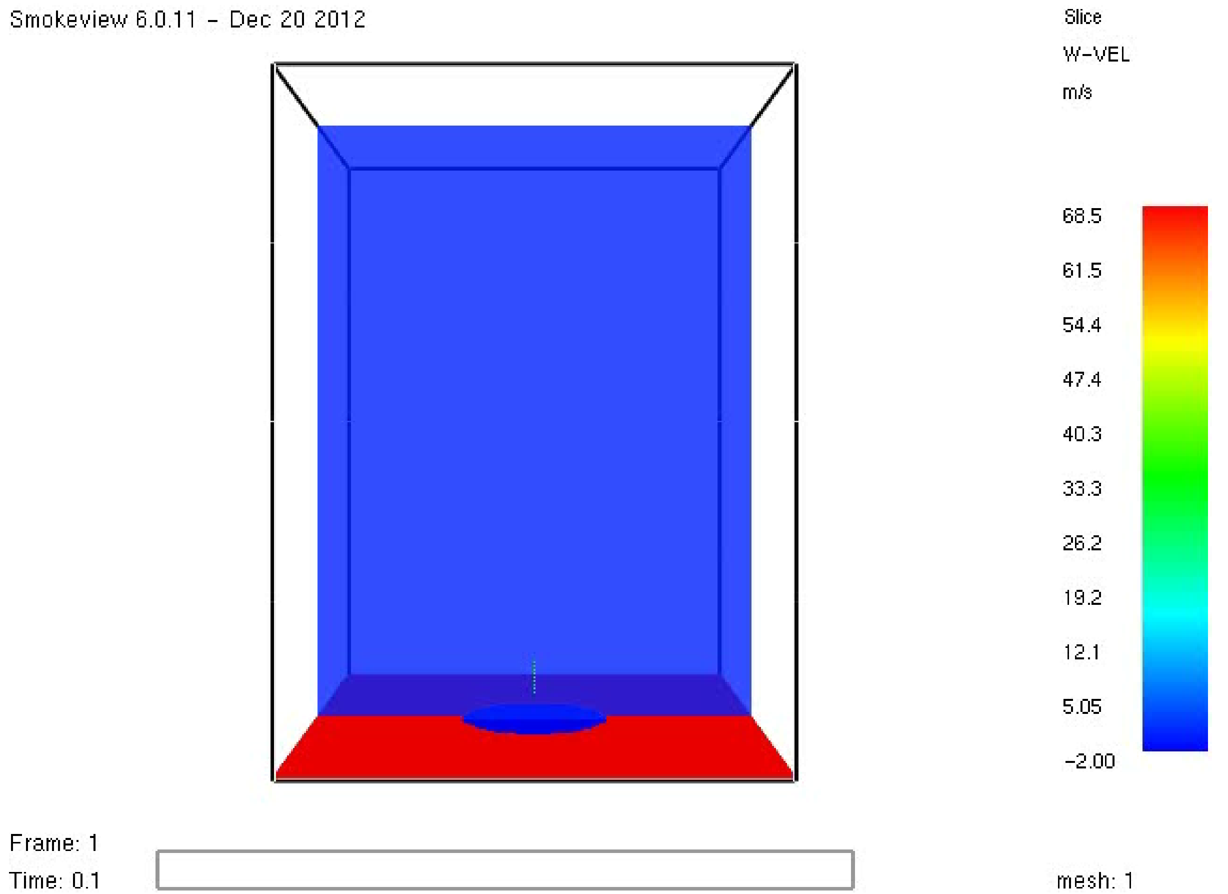


83 m diameter

- Blanchat et al. (2011), The Phoenix Series Large Scale LNG Pool Fire Experiments, http://prod.sandia.gov/techlib/access-control.cgi/2010/108676.pdf

Fire Dynamics Simulator (FDS)

- LES code for smoke and heat transport



- NIST, http://code.google.com/p/fds-smv/

Gaussian Emulation Machine (GEM)

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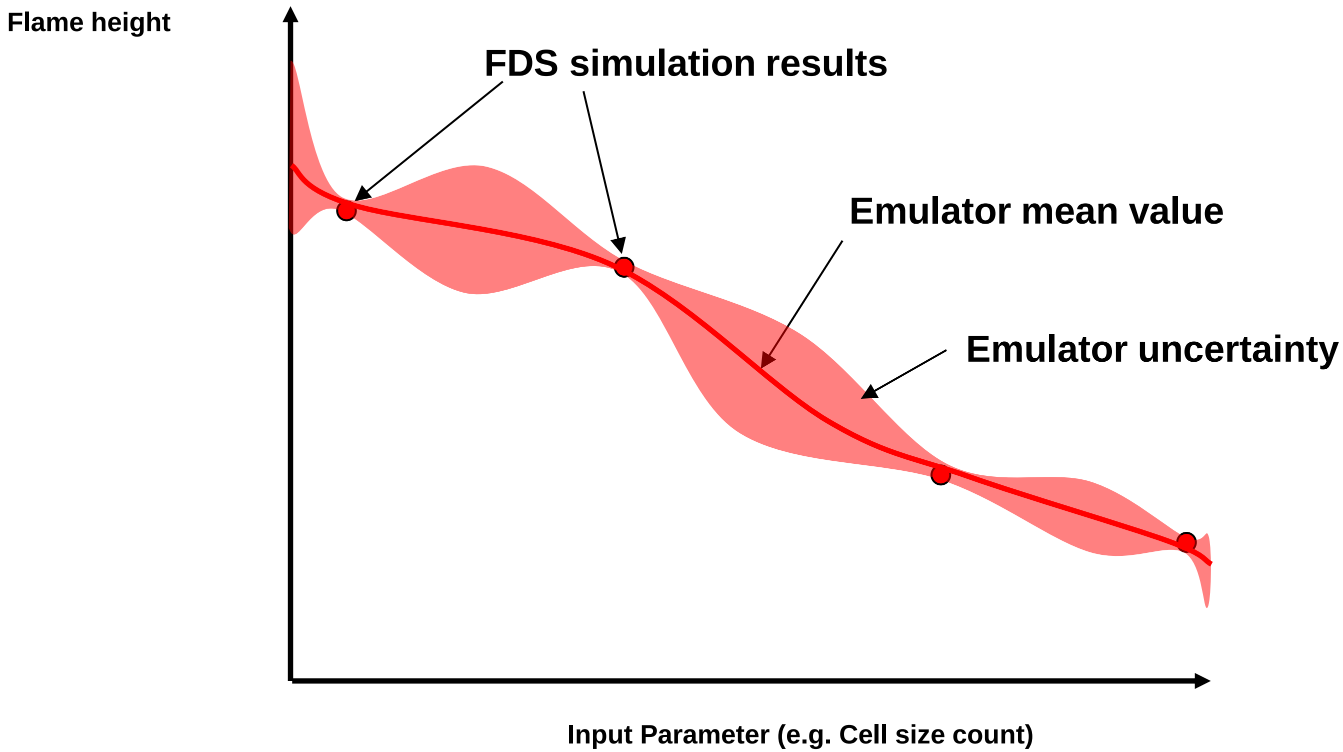

- Underlying assumption of emulator: output is a homogeneously smooth, continuous function of the input parameters
- Results will be similar if inputs only slightly perturbed – provides significant savings compared to “brute-force” Monte Carlo
- http://tonyohagan.co.uk/academic/GEM/

Model Input Ranges

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1. Mesh resolution $D^*/\Delta x$: 16 - 40

16 ← U.S. Nuclear Regulatory Commission validation study used $D^*/\Delta x$ from 4 to **16**

40 ← "good compromise … in terms of accuracy of the predictions and CPU time" W. Chung and C. B. Devaud (2008) Buoyancy-corrected *k-ε* models and large eddy simulation applied to a large axisymmetric helium plume, Int. J. Numer. Meth. Fluids 58, p57–89

2. Fire Diameter: 10 – 100 m (wide range!)

21 m ← Sandia LNG fire test 1

83 m ← Sandia LNG fire test 2

3. Burn Rate: 0.1 – 0.2 $kg/m^2/s$

0.11 $kg/m^2/s$ ← Raj USCG China Lake LNG on water in 2.2 m/s wind

0.2 $kg/m^2/s$ ← "Given the data from these past tests and the SNL test, the burn rate under calm conditions is probably bound by an upper limit of 0.2 $kg/m^2/s$ and is closer to 0.15 $kg/m^2/s$" Blanchat *et al*., 2011

4. Radiative fraction: 0.20 – 0.35

0.20 ← appropriate for clean-burning natural gas flames

0.35 ← FDS default for smoky hydrocarbon fires

5. Turbulence model: Smagorinsky/Deardorff

Smagorinsky, Cs = 0.20 ← Default with FDS versions 4 – 5

Deardorff ← Default with FDS version 6

Model Outputs

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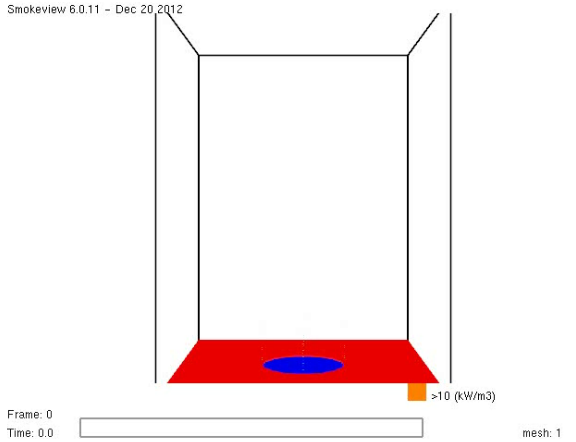
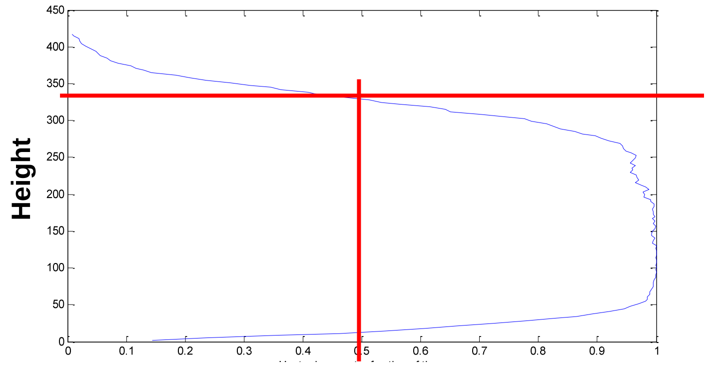
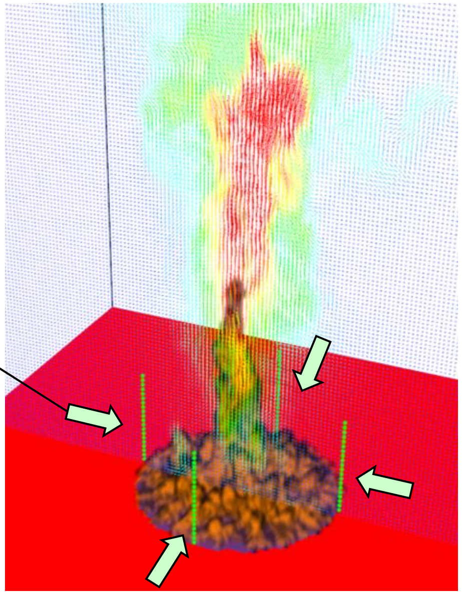
1. Flame height





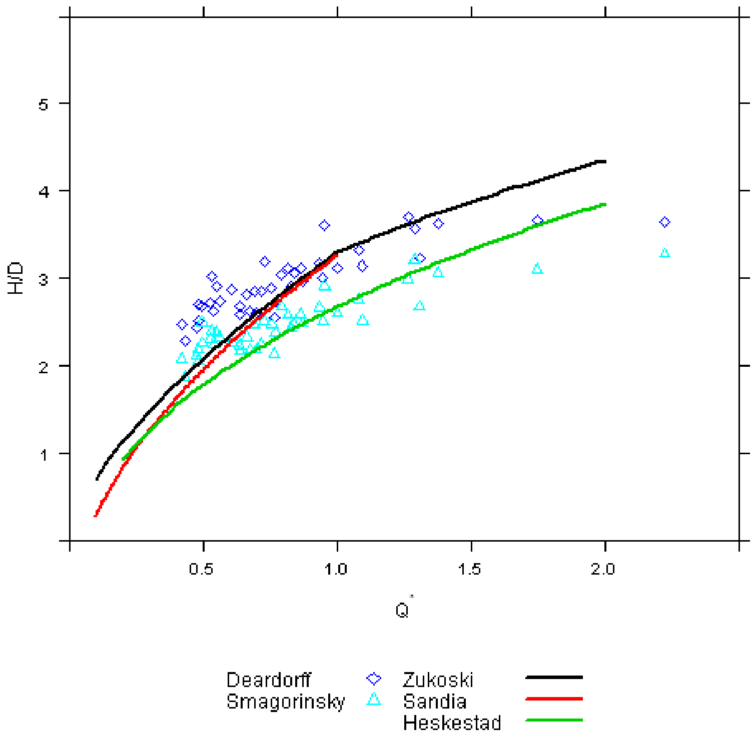
2. Entrainment velocity

Maximum mean radial velocity into the base of the fire plume

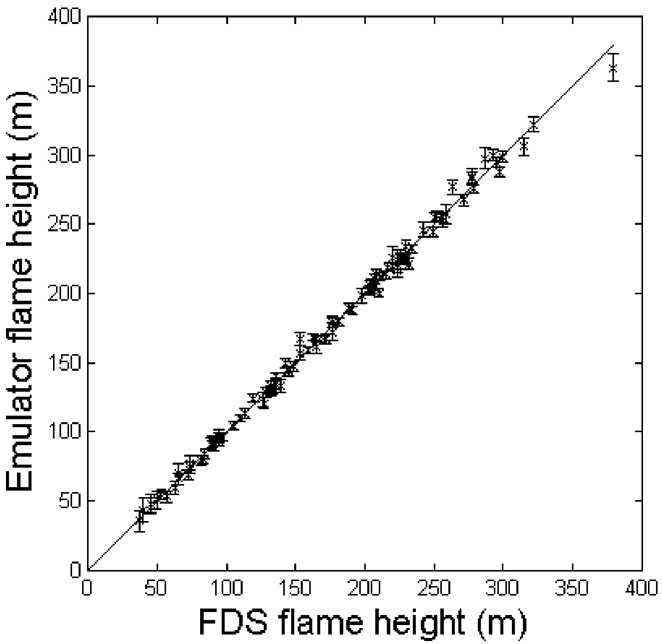


Checking

- FDS



- Emulator

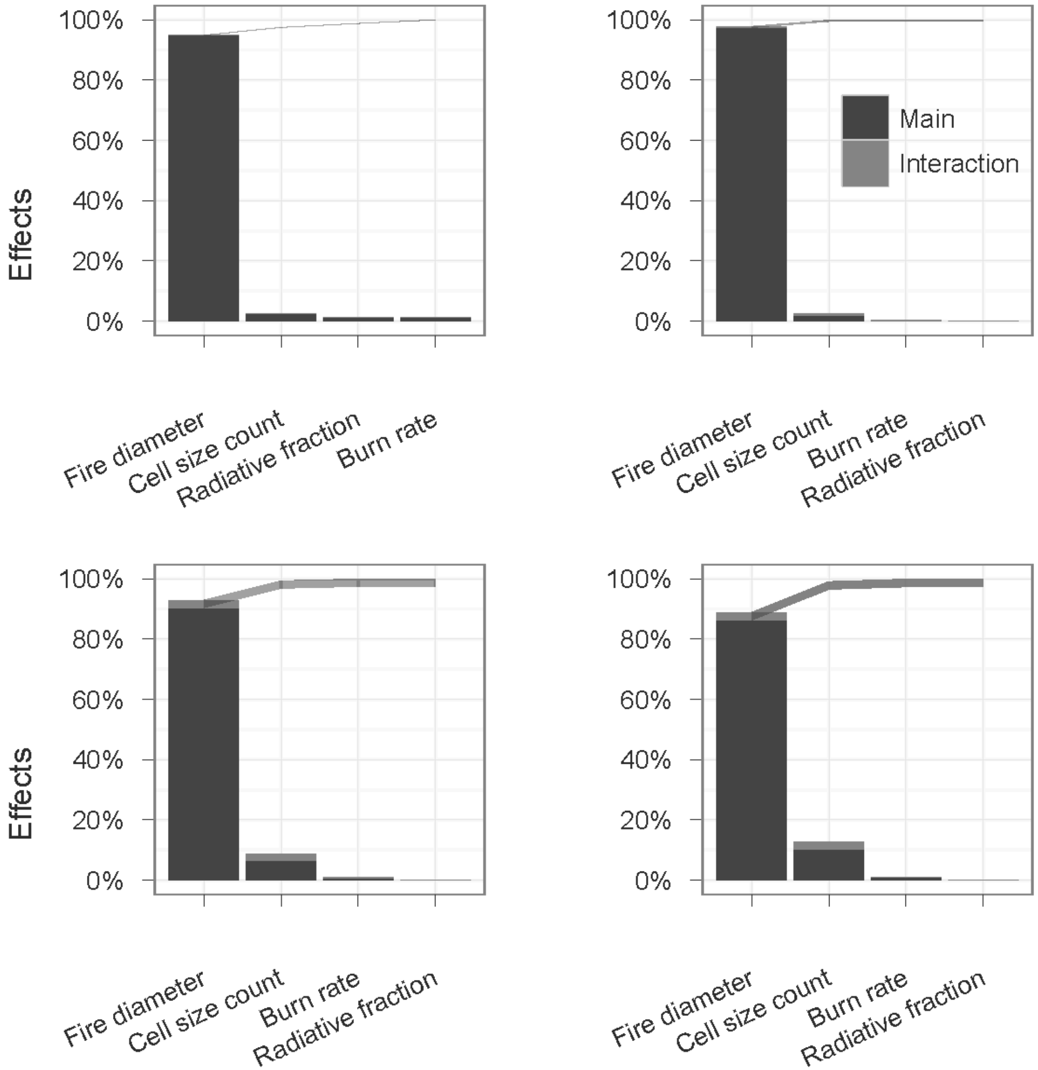


Main & Total Effects

Deardorff **Smagorinsky**

Entrainment

Flame height



Flame Height Analysis

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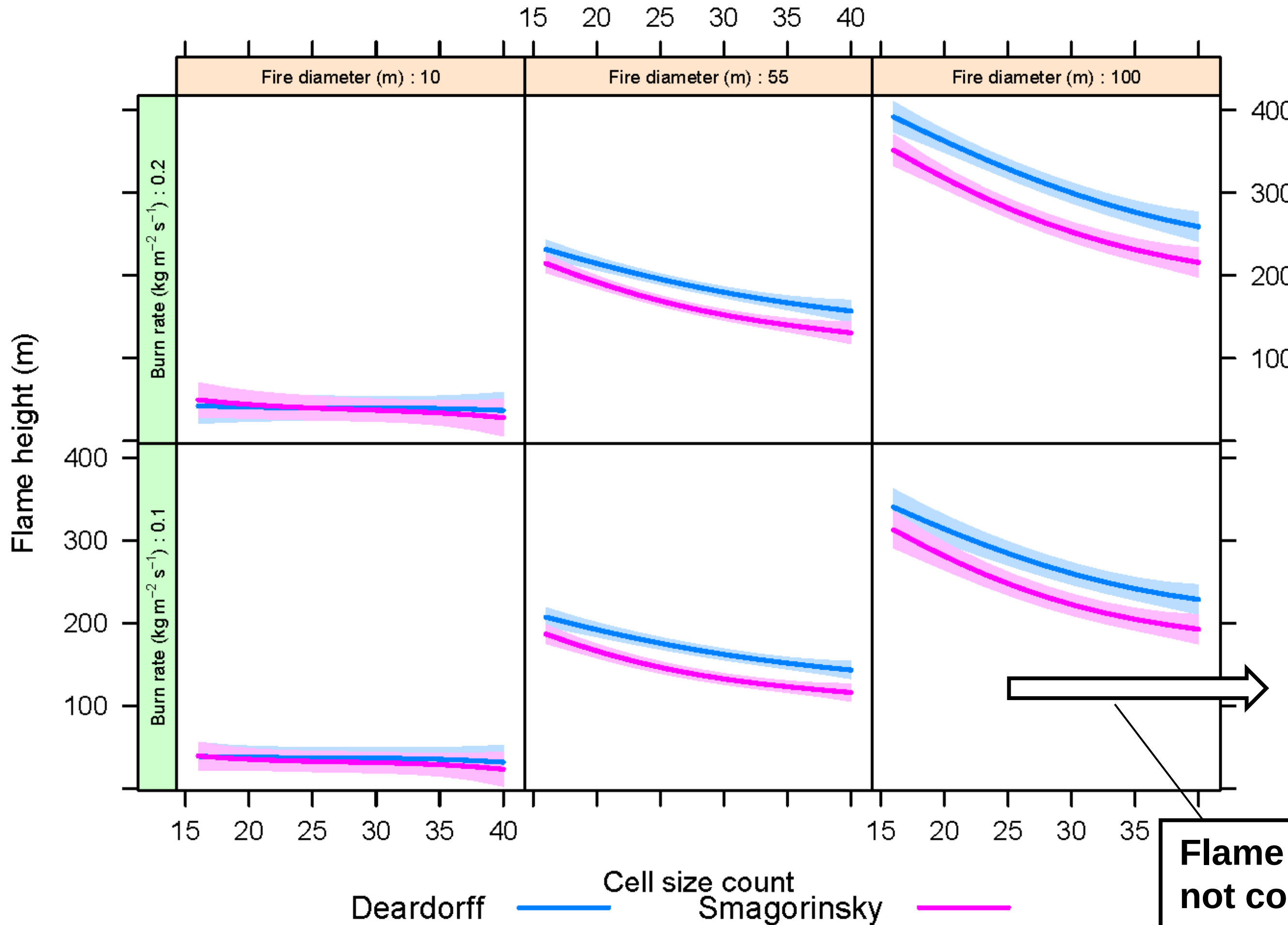
Flame height increases as fire diameter increases

Small increase in flame height as burn rate doubles



Flame height does not converge for large fires using finest grid

Conclusions

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- Global sensitivity analysis of FDS feasible on a fast desktop PC, using an emulator, but it takes a few weeks effort
- Entrainment rate
  - Mainly governed by fire diameter
  - Results depend on ranges of inputs (10 < D < 100m)
- Flame height
  - Governed by fire diameter, cell size, LES model
  - Increasing fire diameter or increasing cell size or using Deardorff model(?) gives larger flame heights

Learning Lessons

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- Useful to analyse influences on outputs using:
  - Variance based analysis (main and total effects)
  - Mean analysis: how outputs vary as a function of inputs
- Fire diameter range dominates analysis
  - Diameter varied by ×10, whereas other inputs ×2 or ×3
  - Use emulator to limit range of analysis without rerunning FDS
- Can we use these methods to transfer information from Model Validation to Risk Assessment?
  - **Model Validation** – compare model outputs to measurements
  - **Risk Assessment** – produce outputs we cannot usually measure

Future Work

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- Joint Industry Project or partnership on sensitivity/ uncertainty of process safety consequence models:
  - Short course on sensitivity/uncertainty analysis for process safety engineers
  - Develop sensitivity/uncertainty analysis toolbox and software interfaces for process safety consequence models (inc. CFD)
  - Apply different analysis methods to practical engineering test cases
  - Develop best practice guidance
- Possible questions to address:
  - What is the best way of incorporating input distributions, e.g. weather data, and on/off switches into sensitivity analysis?
  - Can we use experimental data, sensitivity analysis and Bayesian methods to quantify level of confidence in model outputs?
  - Can we estimate uncertainty in risk assessments?