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Experiments of ignited gas jets : work on overpressure

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Research and Innovation Center in Gas and New Energies

RESEARCH & INNOVATION DIVISION

Background

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Existing knowledge on ignited natural gas releases

1. Experiments (full scale) of punctures and ruptures of HP gas pipelines

-> release, dispersion and fire in uncongested areas.

No explosion

2. Experiments for explosion scenarios on medium to high congestion modules.

-> BUT with quiescent gas cloud or with low release rates (BFETS, MERGE, Baker Risk…)

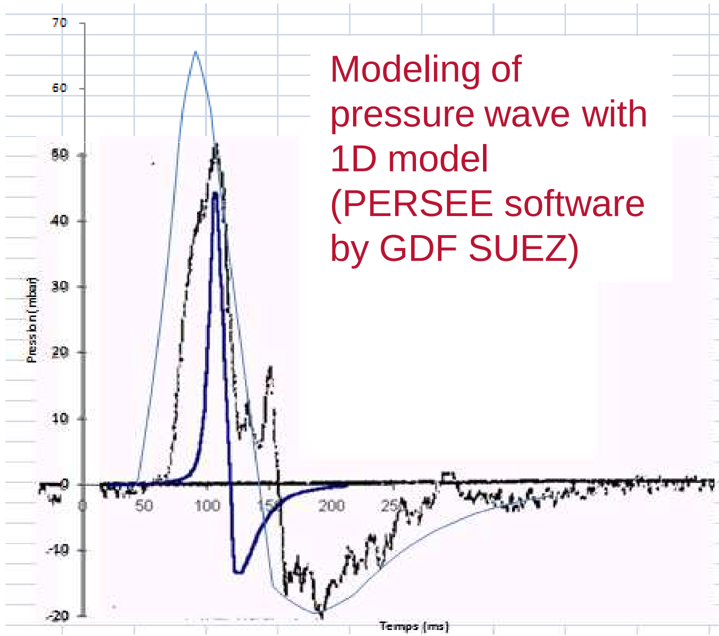
Ex : Baker Risk, ethylene, < 1kg/s

Existing knowledge

3. Experiments of gas jet explosions (MERGE, INERIS)

-> but with low flowrates + lack of datas on turbulence and flame behaviour

INERIS MERGE, methane 10-15 kg/s
Max P = 84 mbar



Need for gas ignition experiments with real pressurized releases

- **Why ?**

1/Lack of data on gas dispersion with real pressurized releases in congested areas

2/Lack of data on gas explosions with real pressurized releases in congested areas. Explosions can be enhanced by the turbulence of jets coupled to congestion : possible underestimation of explosion consequences.

Bonus data : flame dimensions and heat fluxes for risk assessment of above-ground pipelines failures

Gas explosions in QRAs are modeled with quiescent gas at stoechiometry

- **Is it always conservative compared to real pressurized jets ?**
- **Are CFD Models like FLACS validated for real pressurized jets ?**

Need for gas ignition experiments with real pressurized releases

- How ?

  - **Step 1 : organize small-scale jets experiments with accurate turbulence measurements and flame behaviour analysis.**

  - **Step2 : organize large scale experiments of ignited gas jets, with measurements of gas concentrations (dispersion), overpressures, flame speed and dimensions, and heat flux.**

  - At each step, two types of explosion tests :
    - In open field: to understand effect of initial turbulence and flame propagation in a jet
    - In different congested areas: to understand interaction between initial turbulence and obstacles

Small-scale experiments on ignited gas jets:
INERIS / GDF SUEZ

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Ongoing work by GDF SUEZ and INERIS

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- **Small-scale experiments at INERIS tests site on gas jets explosions**

Horizontal release of methane : 0,8 kg/s

1/ Unignited jets -> *concentrations, velocities, turbulence measurements*
2/ Ignition near UFL -> *overpressures, flame speed*
3/ Ignition near LFL
Unconfined releases.

1. **Free jets** : tests carried out in 2012.

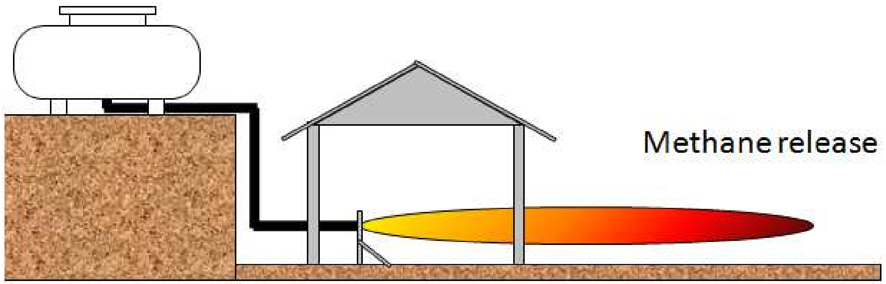
2. **Grounded and impinging jets** : tests planned for the end of 2013 (obstacles = series of pipes with several pitches and volume blokage ratios).

- **Objectives :**

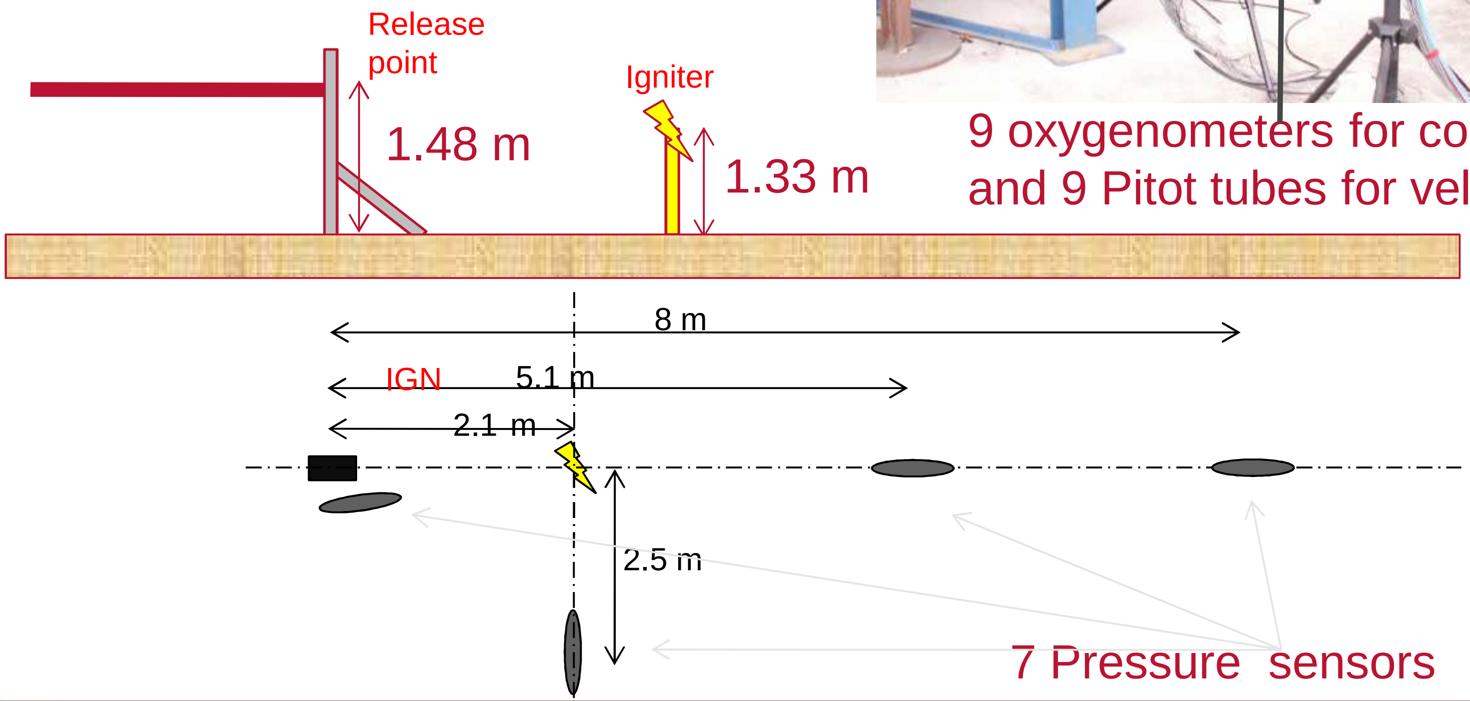
Understanding the physics by varying the ignition point within the flamable jet (5%vol -> 13%vol) and the level of congestion.

Small-scale experiments, INERIS / GDF SUEZ

Experimental device :

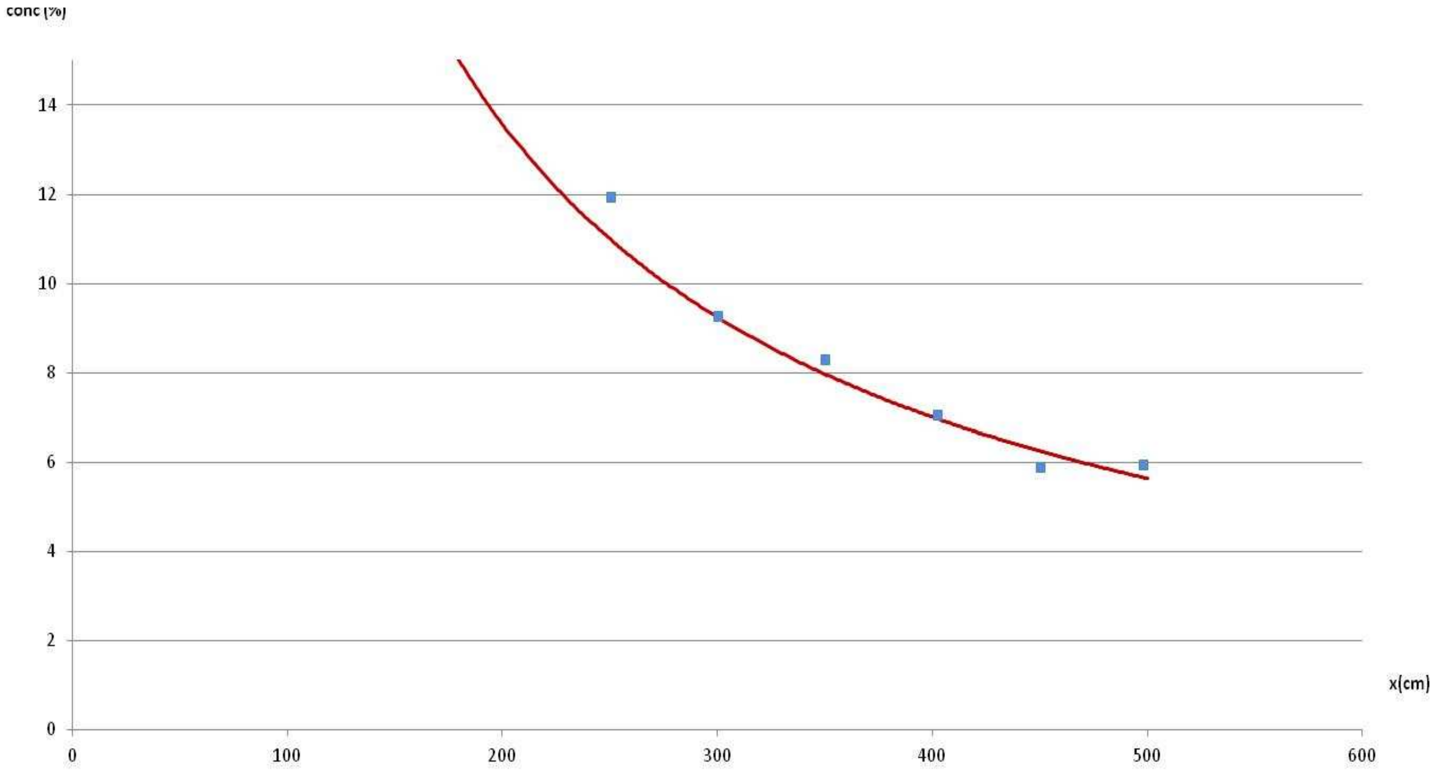


9 oxygenometers for concentration and 9 Pitot tubes for velocity



Measurements of mean CH4 fraction agree well with literature

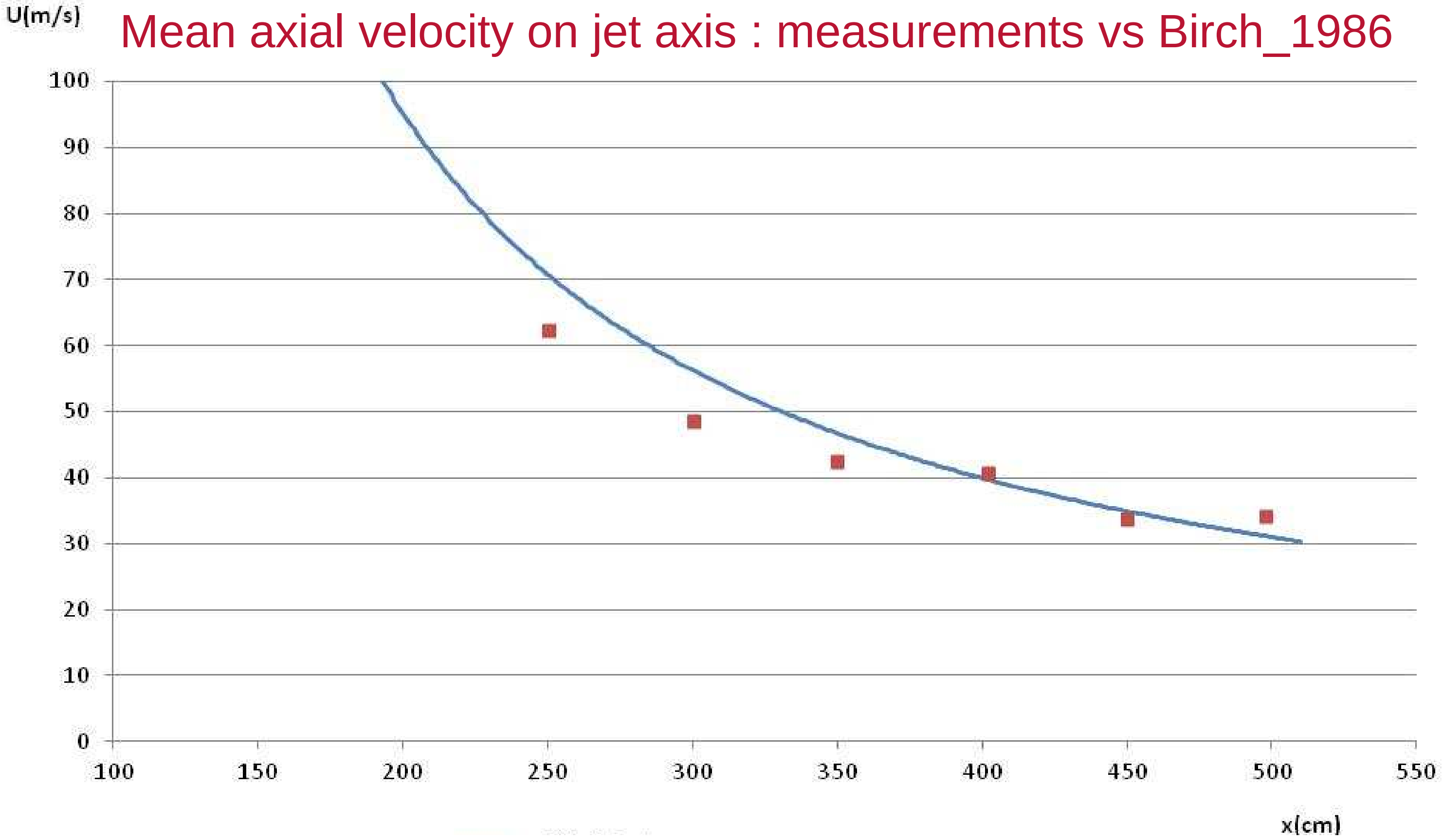
CH4 fraction (vol) on jet axis : measurements vs Birch_1984



Measurements (oxygenometers) agree well with experimental correlation by Birch (1984).

Mean CH4 fraction transverse profiles agree with correlations for subsonic jets (Hinze, 1972) : -10% / +25%.

Measurements of mean velocity agree well with literature

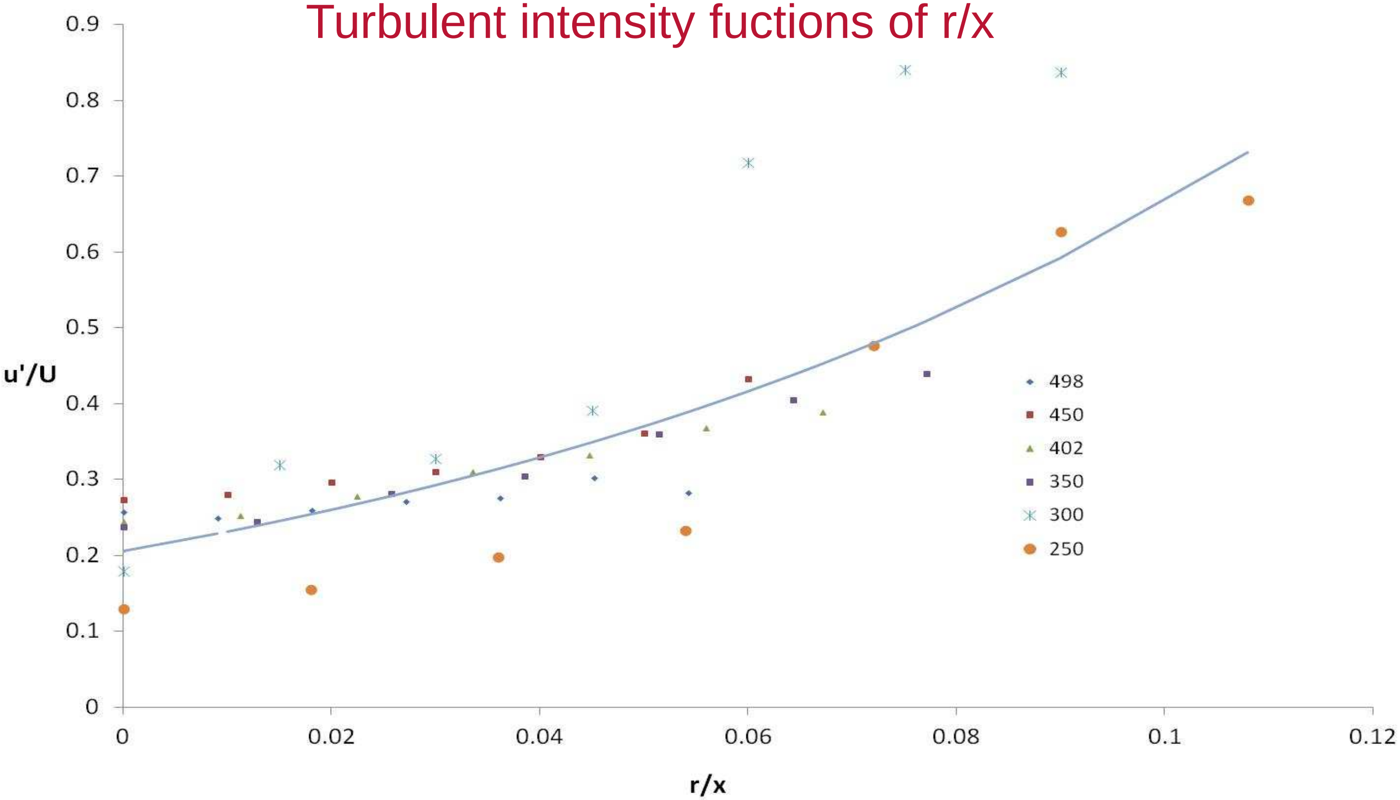


Mean axial velocities on jet axis agree with experimental correlations by Birch (1986) for supersonic air jets.

Transverse profiles of mean axial velocities agree with data for subsonic jets: Hinze (1972).

Measurements of turbulent intensity

Turbulent intensity fuctions of r/x



•Measurements between 5%vol and 8% vol of CH_4 on jet axis : agree with literature for subsonic jets

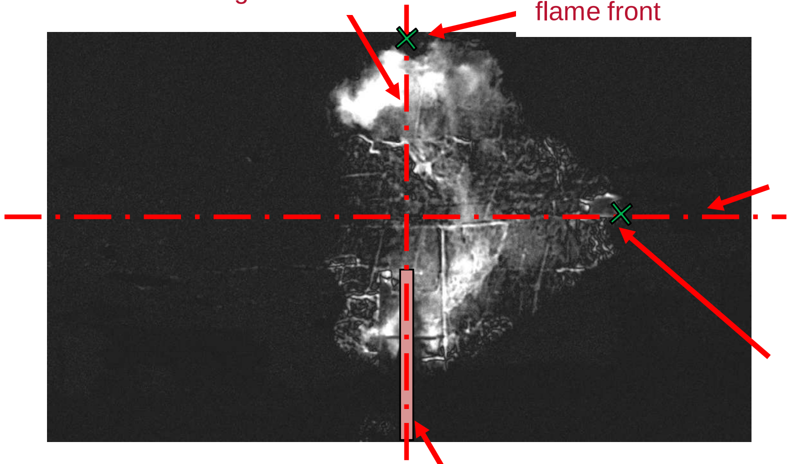
•Uncertainties closer to the jet orifice (higher frequency of turbulence).

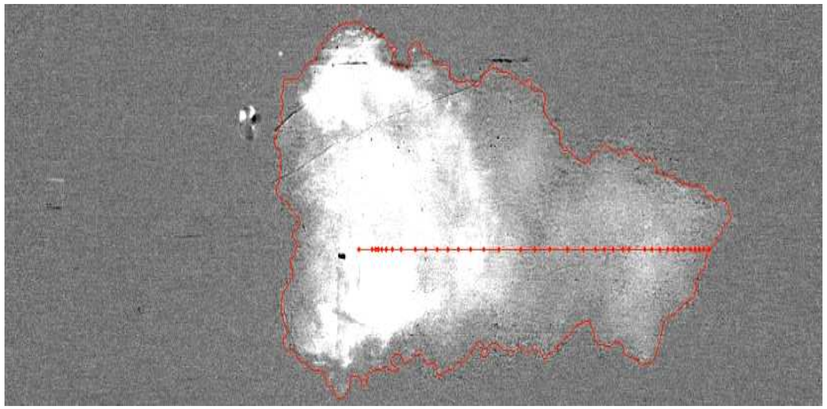
Integral length scale of turbulence Lt : lack of literature

But orders of magnitude OK compared to literature

Ignition tests

High speed camera : estimate of the flame front velocity : max velocity around 120 m/s





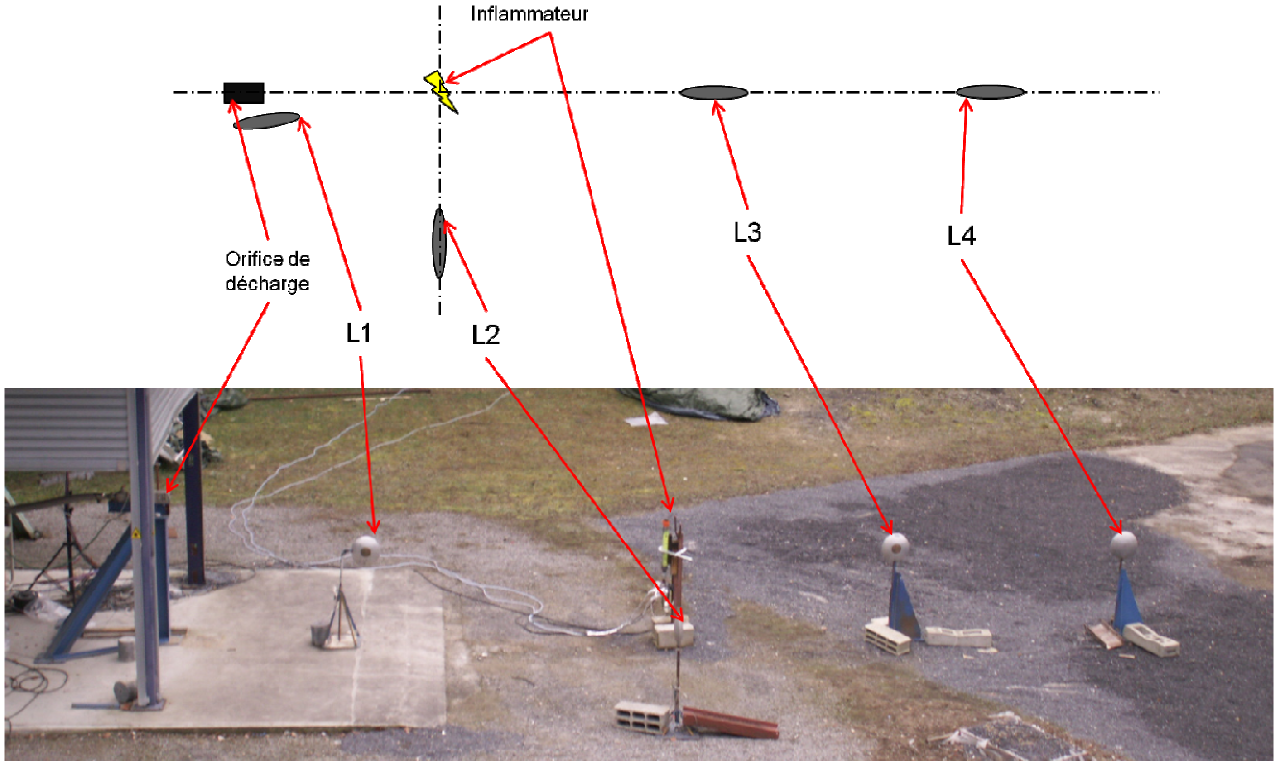
Flame vizualisation with images post-processing

Ignition tests

- **Overpressures measured around the jet : 0-15 mbars**

- **No pressure when ignition at 5%vol**

- **Higher overpressures when ignition at 10-13% vol**



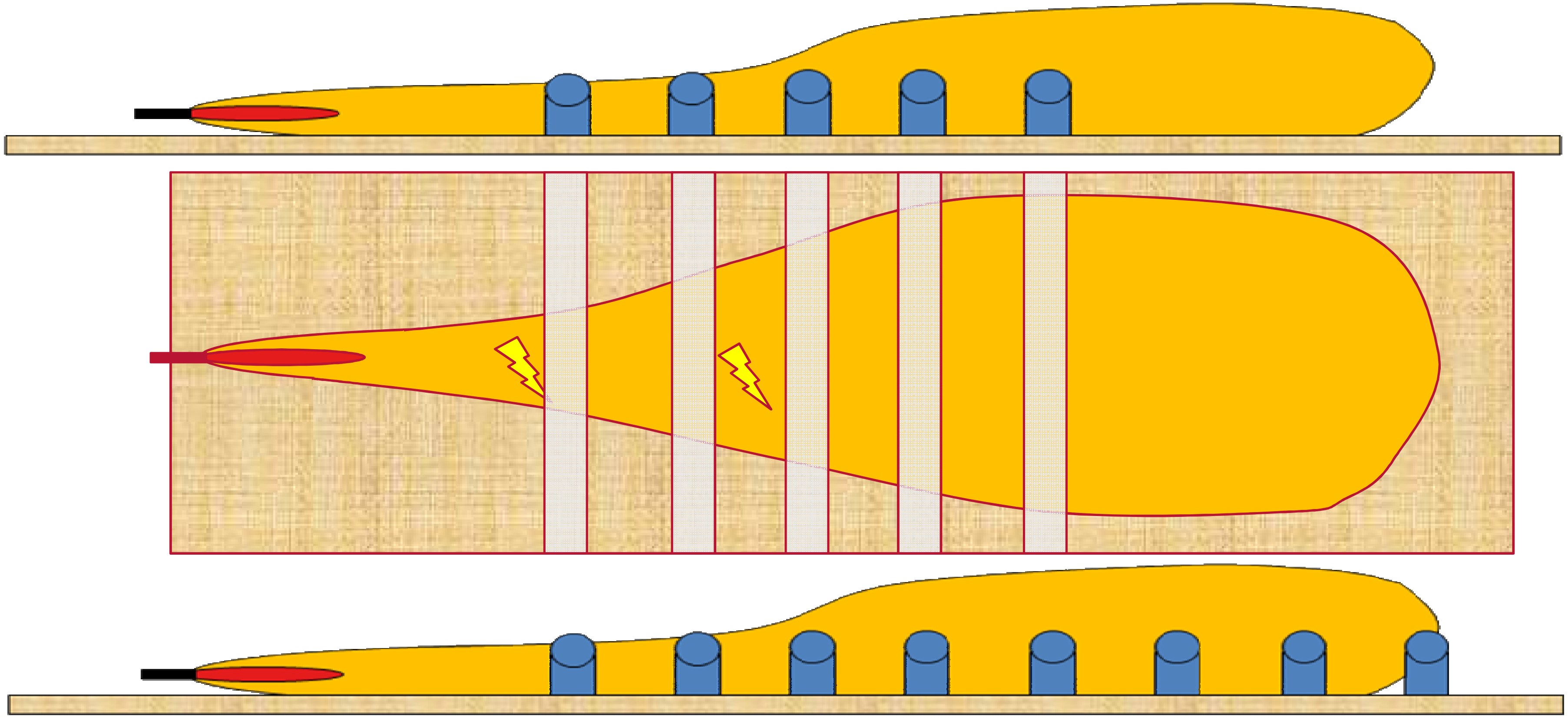
Test of the 1D model of PERSEE software developed by GDF SUEZ (integral model for dispersion + Deshaies and Leyer model for overpressure).

-> 0 / +100% for most experiments

Future tests (oct-nov 2013) : grounded jets with obstacles

Partial scaling from low congestion onshore sites:

- **Same pitch**
- **Same area blokage ratio**
- **Lower release rate and smaller flamable jet**



Uncertainties on numerical simulations of explosions with real releases

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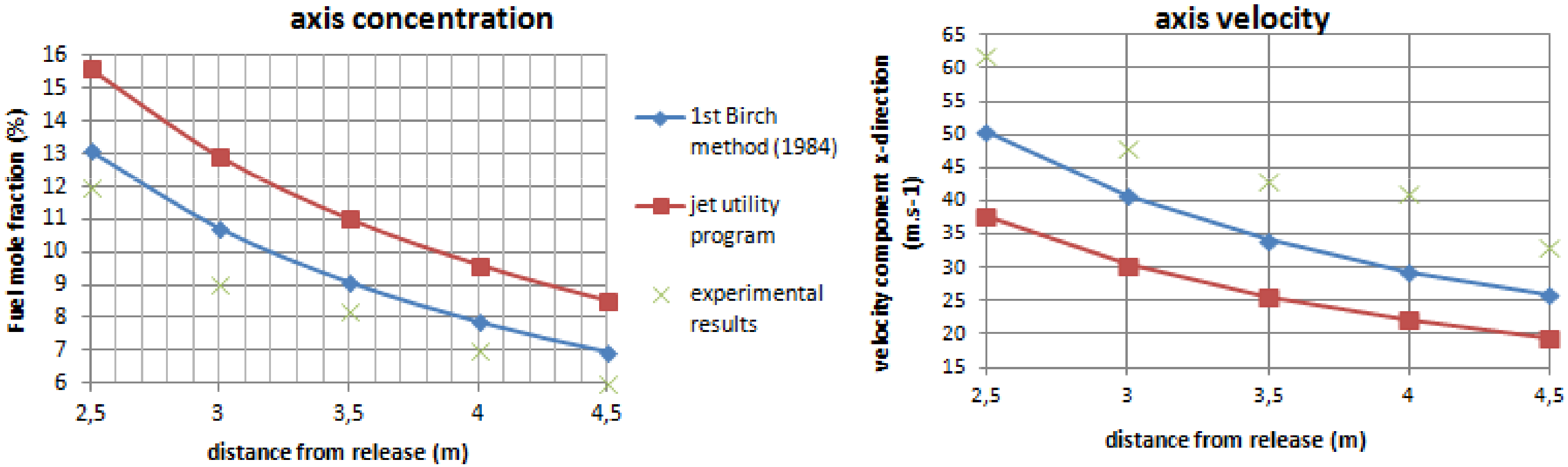
Numerical simulations of small-scale tests in open field (FLACS)

Uncertainties on the modeling of the jet dispersion and methods for calculation of the source term

Simulation with FLACS of a free jet of HP Natural gas. Release rate : 0.8 kg/s.
Two ≠ methods for source-term.

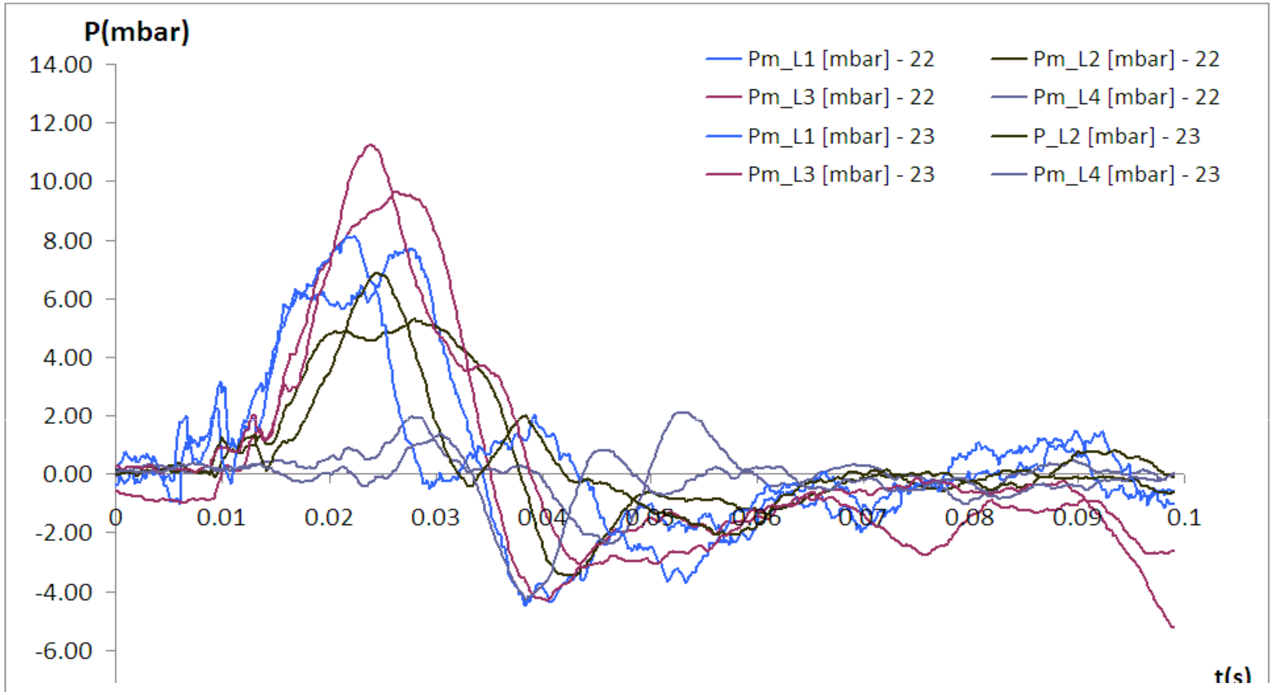


Deviation: experimental results - FLACS	Fuel mole Fraction	velocity
1st Birch method (1984)	+12%	-23%
jet utility program	+35%	-42%

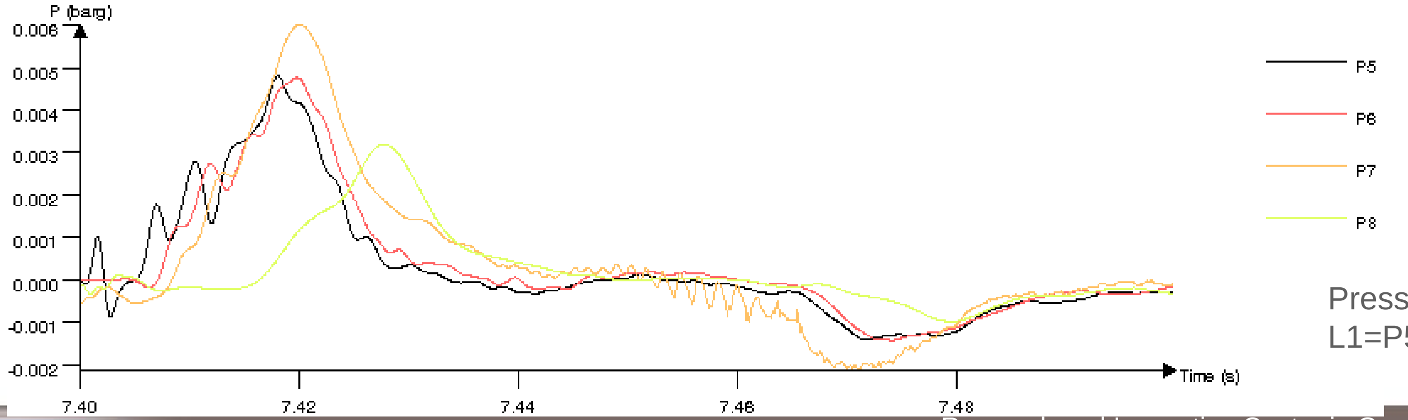
Numerical simulations of small-scale tests in open field (FLACS)

Simulation with FLACS of the ignition of a free jet of HP Natural gas. Release rate : 0.8 kg/s.

Underestimation of overpressure by FLACS



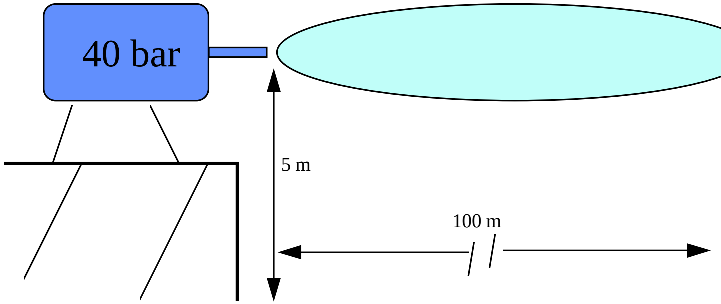
FLACS (with volume ignition) represents well the pressure signals, but pressure peaks are underestimated (0 / -50%)



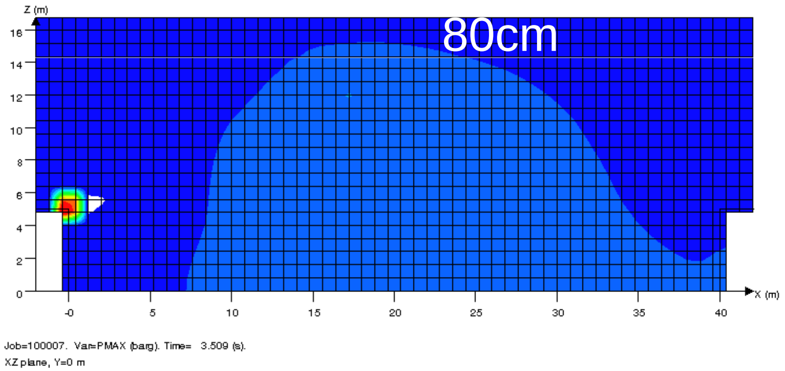
Pressure Sensors :
L1=P5, L2=P6, L3=P7, L4=P8.

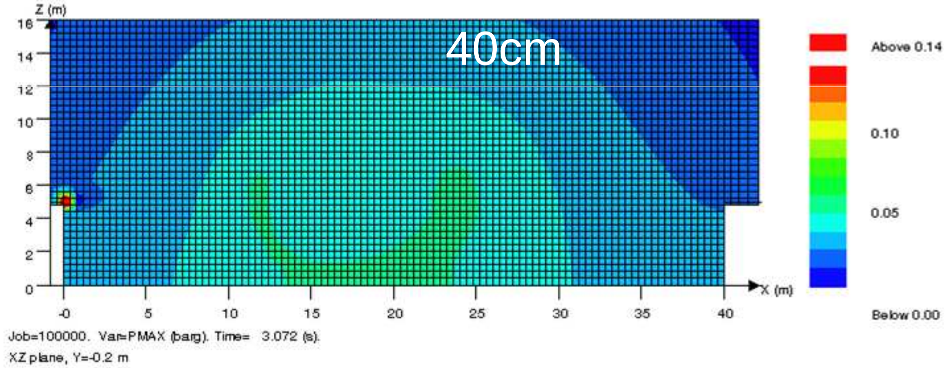
Numerical simulations of MERGE (INERIS) experiment (FLACS)

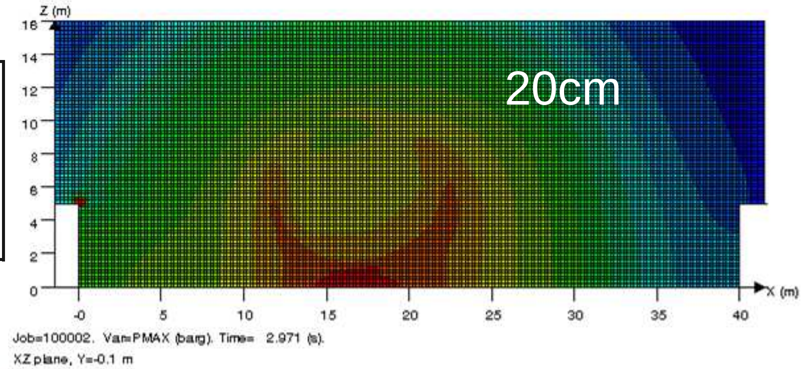
Grid sensitivity for explosion: FLACS guidelines lead to underestimated overpressure



Methane: orifice diameter : 150 mm



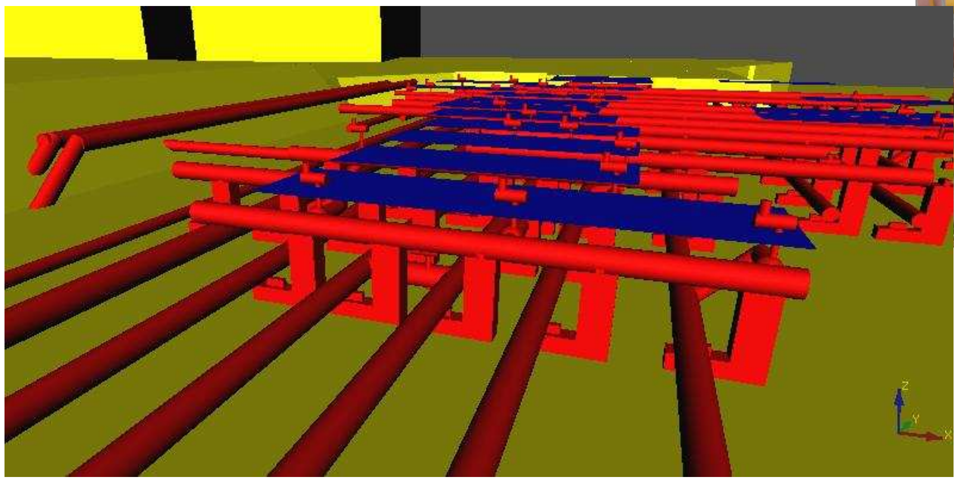




Grid	Pmax	P at Exp.	Experimental measurement P=84 mbar
80cm	25mbar	20mbar	
40cm	50mbar	40mbar	
20cm	130mbar	90mbar	

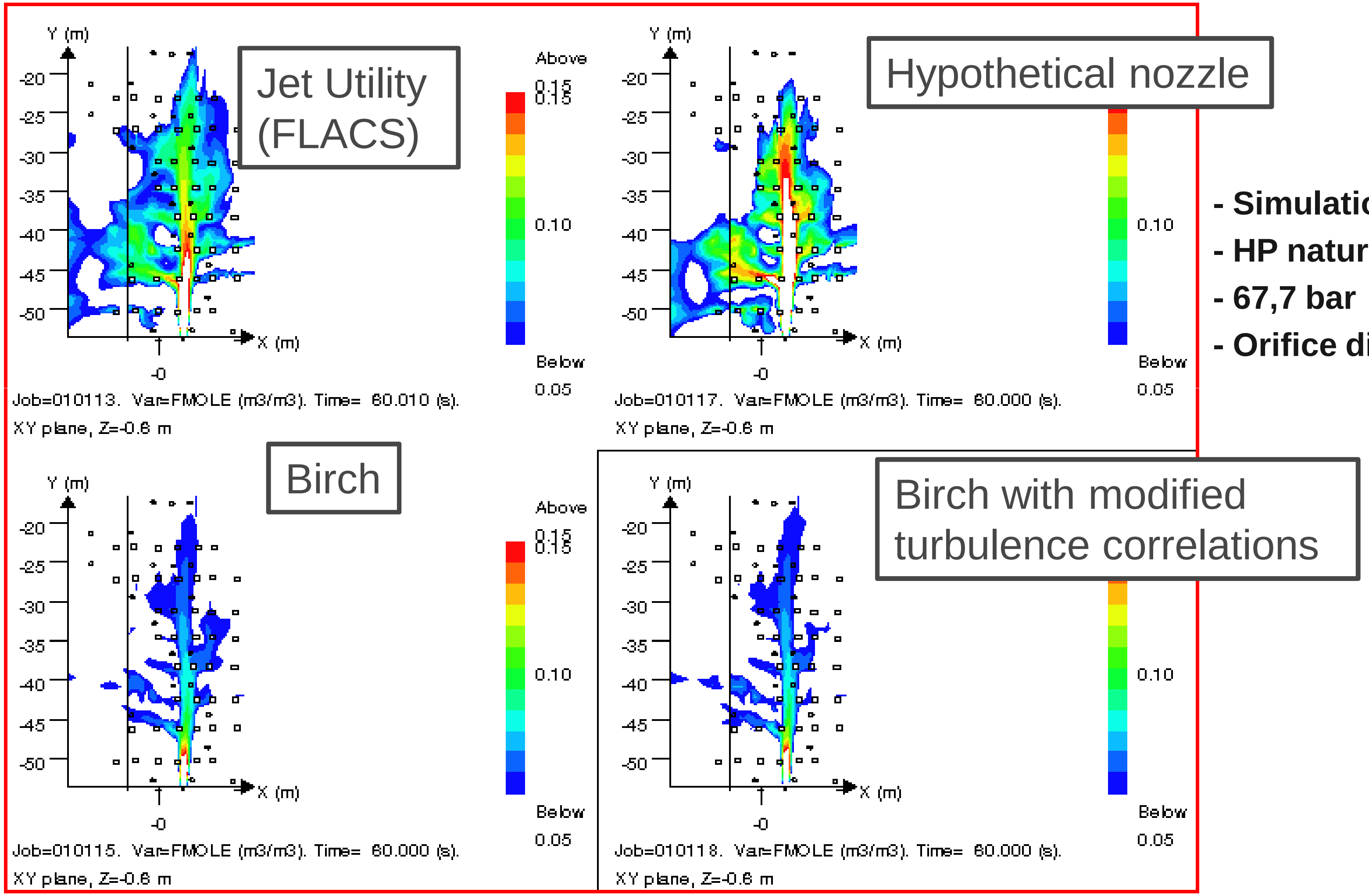
Numerical simulations of an explosion on an onshore site (FLACS)

Topography and buildings are modeled to properly handle wind profile for dispersion simulation.



Numerical simulations of an onshore site (FLACS)

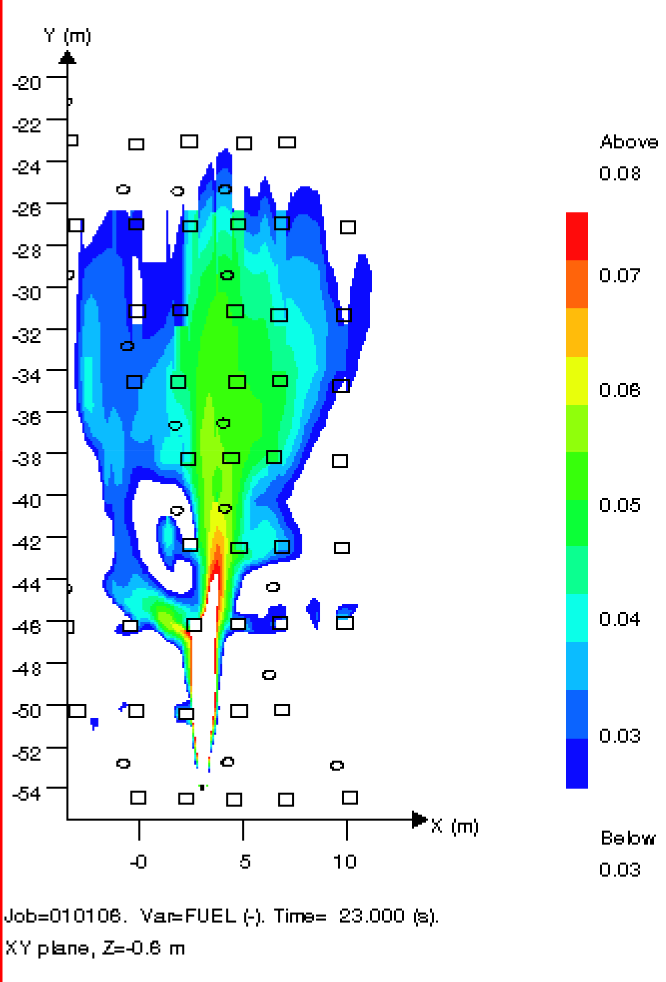
Gas dispersion depends partly on the source-term method



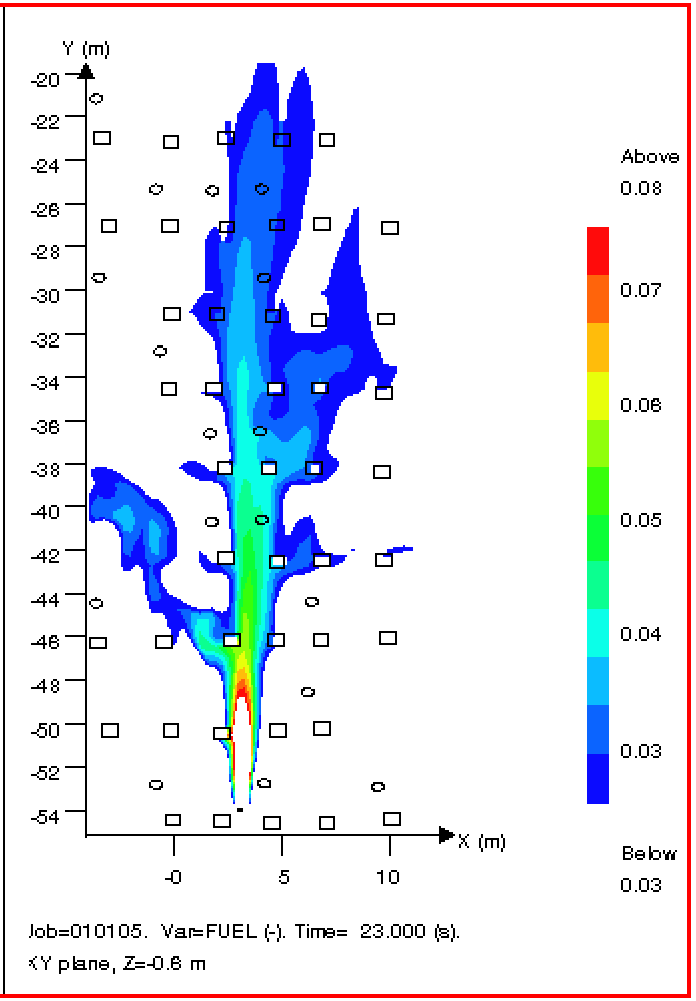
- **Simulation with FLACS**
- **HP natural gas**
- **67,7 bar**
- **Orifice diameter = 25 mm**

Numerical simulations of an onshore site (FLACS)

Grid effect on dispersion with obstacles



12,5 cm cells



25 cm cells

Low influence with free jets (ex : MERGE, Ineris).

<u>But :</u>
Influence of obstacles modeling. (porosity vs obstacles).

Uncertainties on simulations of gas explosions with real releases

1. Uncertainty on gas jet dispersion modeling (source-term method, turbulence modeling, obstacles modeling)

2. Grid sensitivity for jet dispersion in congested area

3. Grid sensitivity for explosion in open field and congested areas

4. Validity of the correlation for Turbulent Burning Velocity: St ?

Proposal for large-scale experiments of ignited gas jets in onshore and offshore environments

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Large real releases and effect of initial turbulence

- **How ?**

Use a facility to generate **horizontal jets with high flowrate (100- 150 kg/s)** of natural gas (100 m - 150 m long, 15-20 m large)

1/ Carry out explosion **tests without congestion**

2/ Carry out explosion **tests with congestion**

Tests in low, medium and high congestion modules

– Measurements :

Obtain a quasi steady-state release for 30 sec

- Concentration measurements

Ignition between stoechiometry and UFL :

- Flame speed
- Overpressure and impulse
- Heat radiation

Environments targeted by GDF SUEZ (1/3)

Low congestion environment : series of pipes - onshore sites

Ex : compressor stations

Ex : underground gas storage sites

Environments targeted by GDF SUEZ (2/3)

Low to medium congestion environment : onshore sites

Ex : interconnection grid of natural gas transportation network

Ex : liquefaction plants

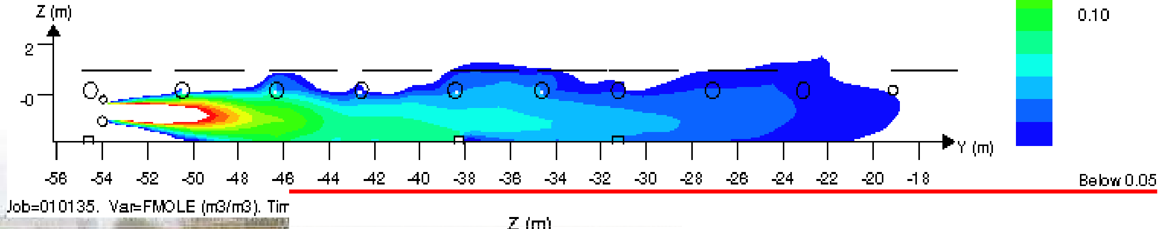
Example of scenario studied by GDF SUEZ

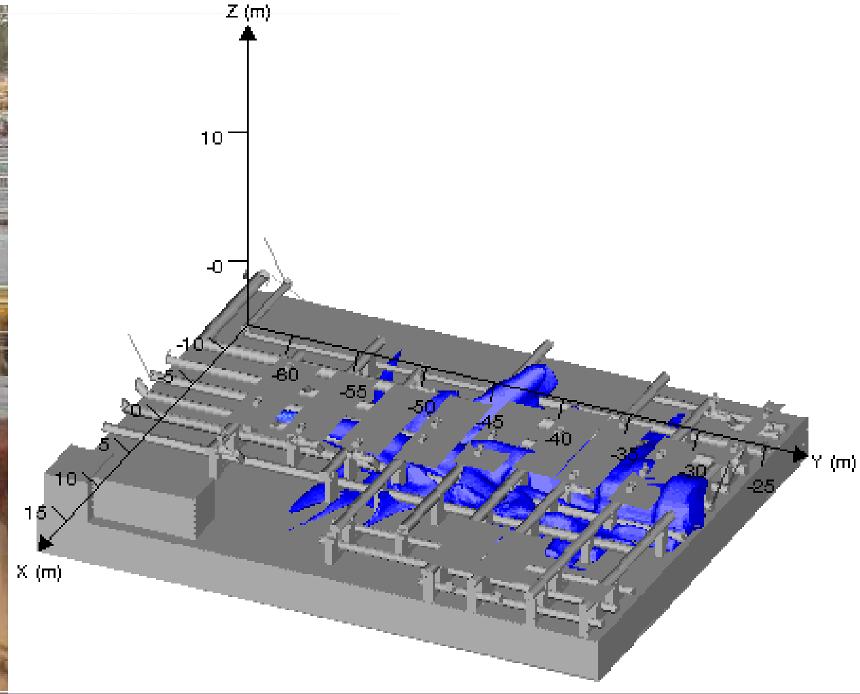
- **50-80 mm leak on HP natural Gas pipeline on onshore sites (80-150 bar) with low to medium congestion**

-> jet with turbulence

-> Large flamable volume in congested area (flamable zone : 40-80 m)

Models of dispersion and explosion validated ?





Environments targeted by GDF SUEZ (3/3)

Medium-High congestion environment : offshore platforms represented by high congestion modules

Ex : FLNG, FPSO…

Ex: Baker Risk modules

Conclusions

1. **Uncertainties on modeling of explosions of gas jets (especially for large release rates):**

- Uncertainty on dispersion modeling (source-term method, turbulence modeling, obstacles modeling)
- Validity of the Q9 method (assuming flammable volume with quiescent gas at stoechiometry) ?
- Grid sensitivity for jet dispersion (and explosion) in congested area: porosity vs obstacles)
- Validity of correlations for Turbulent Burning Velocity: St ?

2. **Need for assessing influence of initial turbulence and congestion on large real releases (for dispersion and explosion)**

3. **Proposal of a partnership on large-scale experiments, with a large scope:**

- Various congestion modules
- Dispersion + flame/overpressures + also heat flux

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