Review of the research at the Institute of Thermal Machinery

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presentation outline

1. Main research areas at the Institute of Thermal Machinery
2. Fundamental numerical –LES and experimental studies of cold and hot jet instability, LES modeling of active jet control
3. Two-phase flow modeling: Euler/Euler approach based on coupled Volume of Fluid and Level-Set methods, Euler/Lagrange modeling of dispersed phase
4. LES combustion modeling in aeroengine combustors – some preliminary ignition and light-across studies
5. Numerical studies on oxy-combustion in circulating fluidized bed and pulverized coal boilers in the context of CCS technology

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Faculty of Mechanical Engineering and Computer Sciences

- *Institute of Computer and Information Sciences*
- ***INSTITUTE OF THERMAL MACHINERY***
- *Institute of Internal Combustion Engines and Engine Control*
- *Institute of Mathematics*
- *Institute of Mechanics of Solids and Systems*
- *Institute of Plastic Forming, Quality Engineering & Biomechanics*
- *Institute of Production Technology and Automation*
- *Chair of Steam Boilers and Thermodynamics*
- *Chair of Plastics and Production Management*
- *Division of Welding*

Main research areas
at the Institute of Thermal Machinery

1. Fundamental problems of fluid dynamics: stability and transition of free flows and boundary layer, turbulent boundary layer, coherent structures, two-phase flows, atomization, evaporation and spray dynamics in turbulent flows, secondary droplet break-up, metrology of turbulent flow,
2. Numerical modeling of turbulent flows: RANS and LES, combustion and two-phase flows modeling,
3. Turbomachinery: numerical and experimental studies of unsteady phenomena in turbomachinery bladings, wake induced transition, rotor-stator interaction,
4. Environmental aerodynamics, aeorodynamics of built areas, pollution diffusion in the wind field,
5. Heating and power boilers: solid fuel combustion in the circulating fluidized bed, oxy-combustion, biomass combustion
6. Comminution and classification processes analysis

SAILOR (Spectral And Compact DIfferences High Order Code for LOw Mach NumbeR LES) computer code

Code characteristic:

- ***applicable to simple geometries***
- ***prediction of turbulent variable/constant density flows by LES and DNS***
- ***Cook&Riley (JCP, 1996) algorithm for low Mach number approximation of the Navier-Stokes equations***
- ***various SGS models implemented:***
    - ***- Smagorinsky***
    - ***- Germano***
    - ***- filtered/selective structure function***

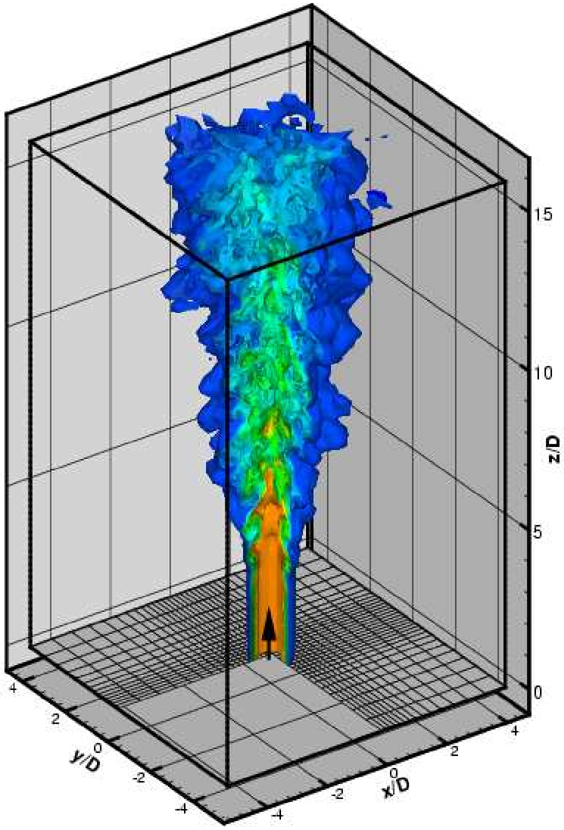


Fig.1 Temperature isosurfaces (density ratio 0.7)

Numerical algorithm and discretization method:

projection method for pressure solution

- *cartesian non-uniform meshes*
- *pseudospectral method in two directions based on the Fourier approximation (periodic boundary assumed)*
- *VIth order compact approximation in third direction (boundary closure: 3-4-6-4-3)*
- *IIIth order low storage Runge-Kutta and Adams-Bashforth method implemented*

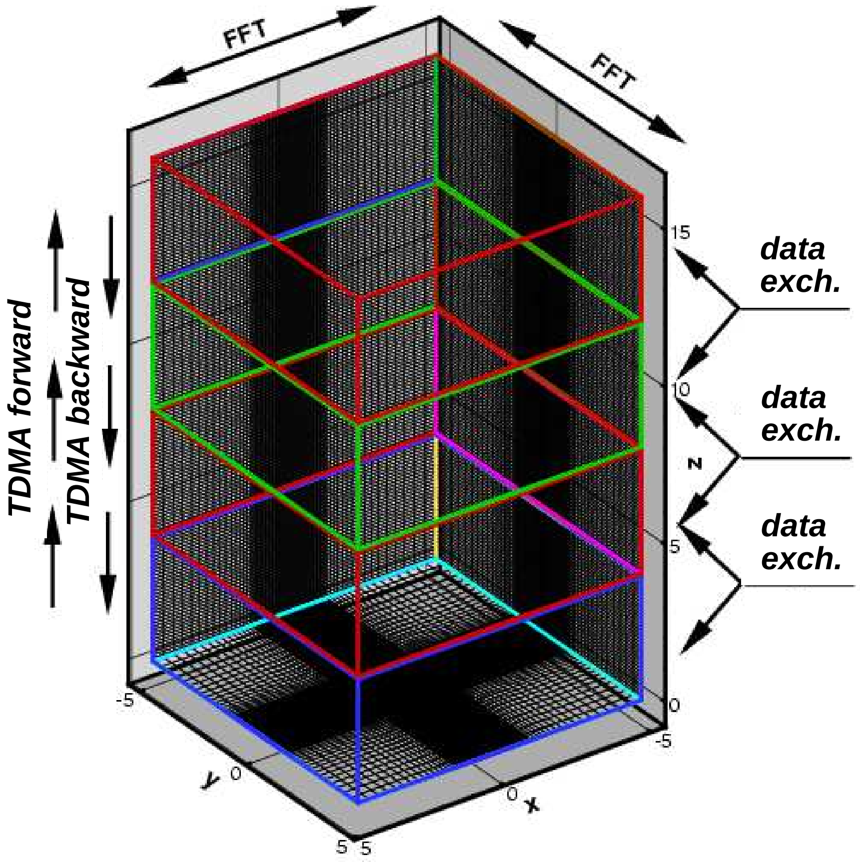


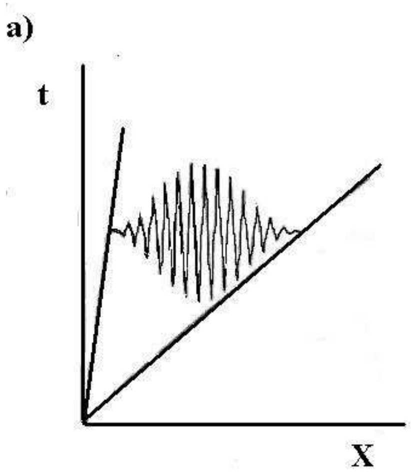
Fig.2 Domain decomposition

Parallel computations:

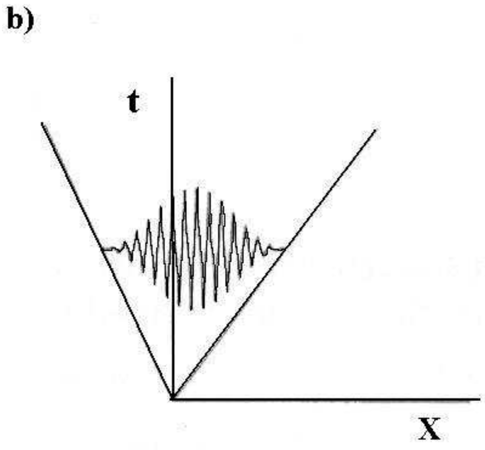
- *MPI library for data exchange*
- *domain decomposition in direction where compact approximation is applied*
  (require paralelisation of TDMA)

Absolute and convective instability of variable density jets

Convective instability



Absolute instability



Experimental part

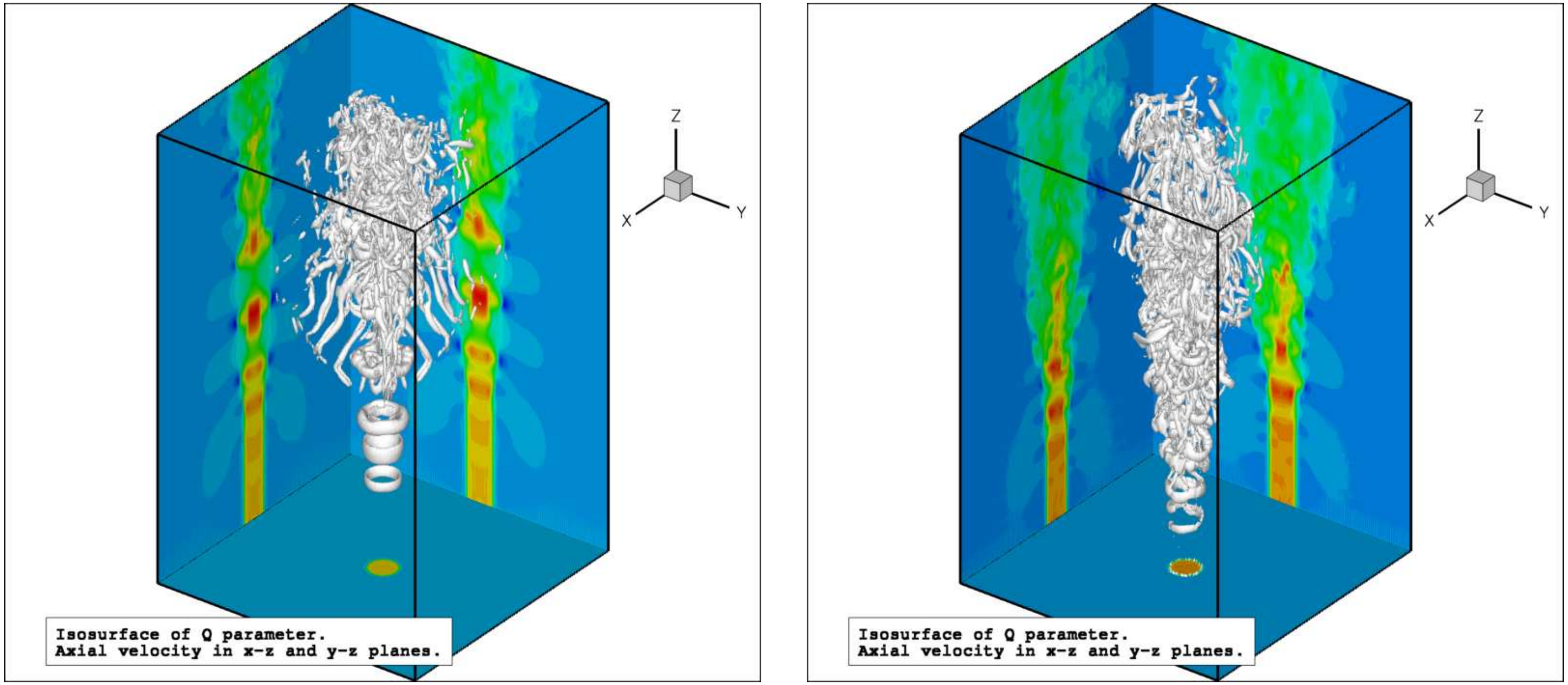
Variable density round jets – experimental results

Monkewitz et al. (J. Fluid Mech. 1990)

- Critical density ratio S_{cr}=0.73, below which self-exciting oscillations appear
- Two unstable modes exist: Mode I – St_D=0.3 (S<0.73), Mod II St_D=0.45 (S<0.65)
- Mode I disappears when the density ratio S< 0.55
- Mode II – axi-symmetric – vortex pairing process is observed

Kyle i Sreenivasan (J. Fluid Mech. 1993)

- Critical density ratio S_{cr} =0.6
- Oscillating mode identical to Mode II (Monkewitz et al.)
- Boundary layer thickness - important governing parameter
- For thin boundary layer a *broadband* mode was observed



Isosurface of the instantaneous Q-parameter

for S=1, R/θ=20, TI=10^{-4} % (left figure) and TI=2% (right figure),

mesh 256x160x256

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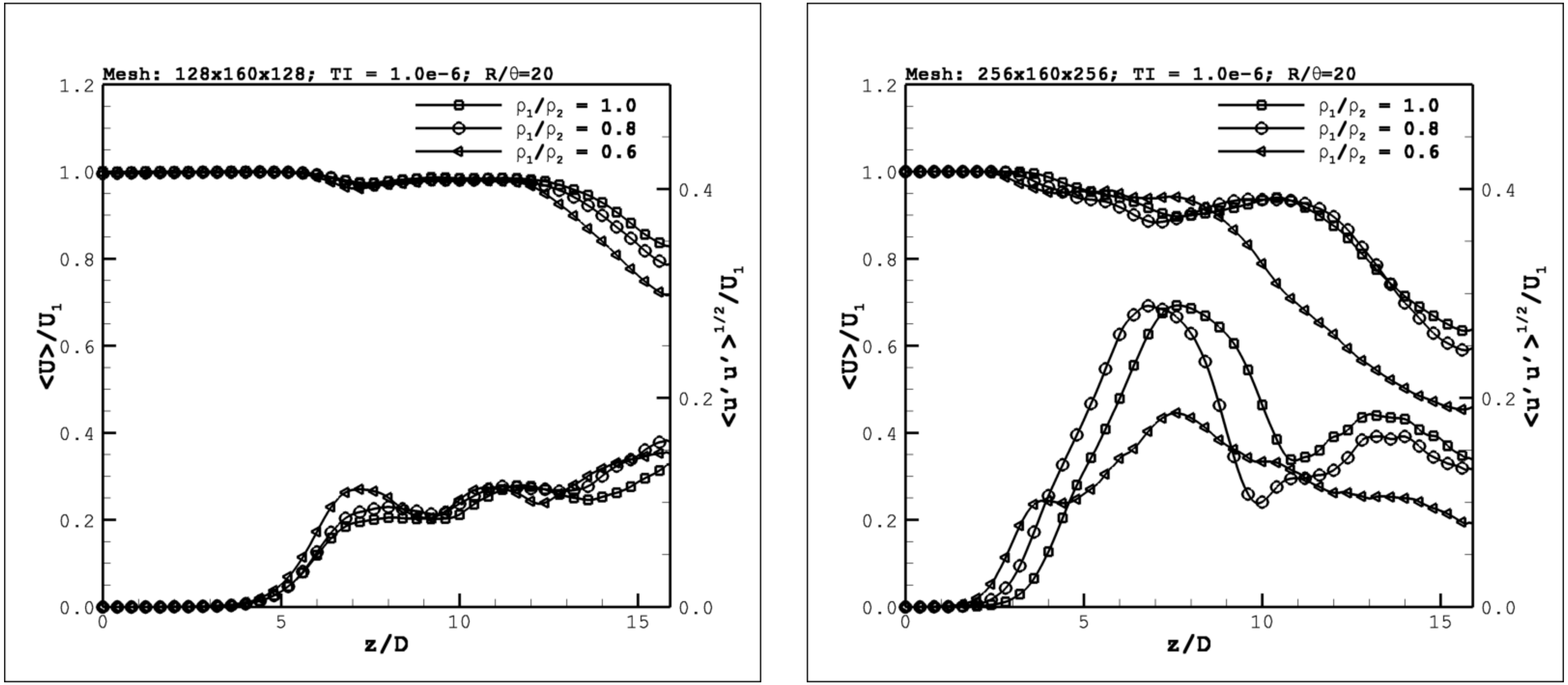


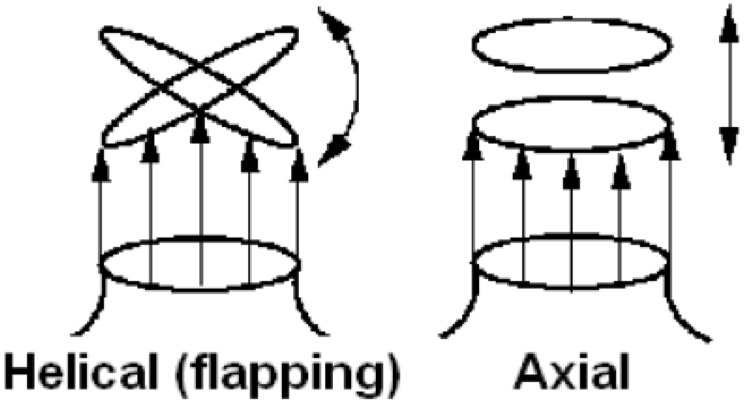
Mean and fluctuating profile of the axial velocity for S=1.0,0.8,0.6, R/θ=20, TI=10^{-4} %, mesh 128x160x128 (left figure) and mesh 256x160x256 (right figure)

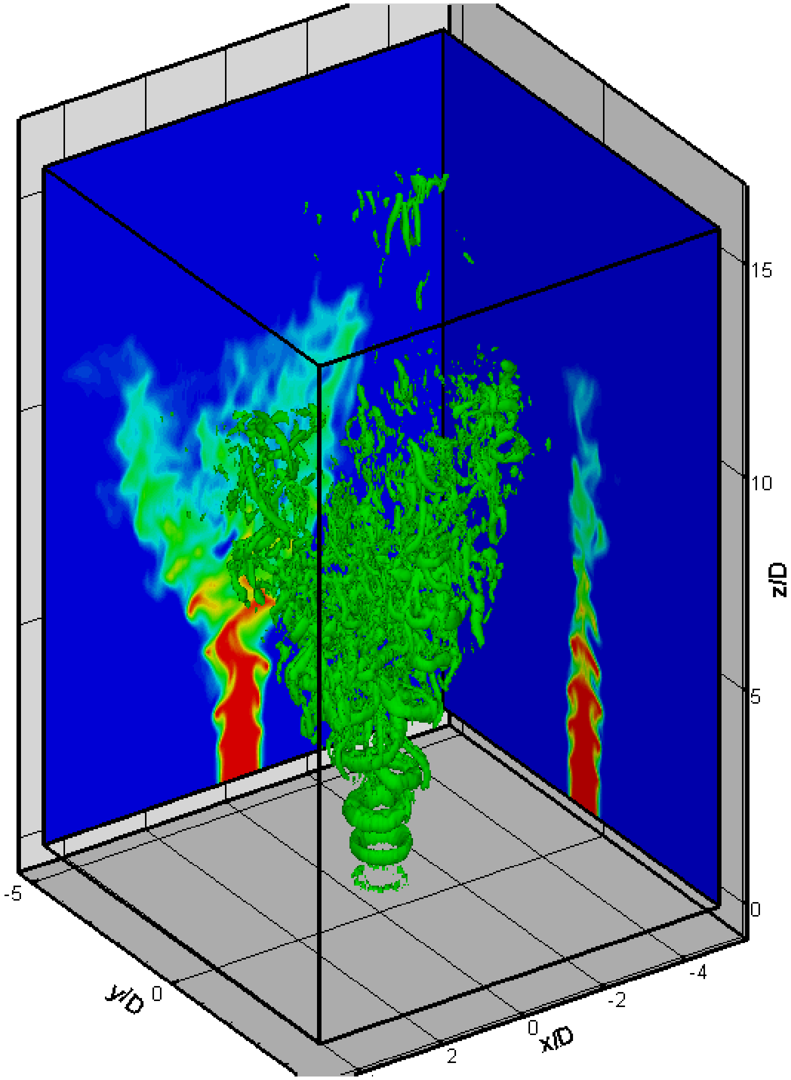
Excited isothermal jet – axial+helical forcing

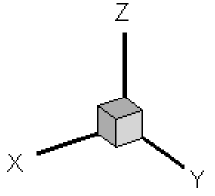
- Excitation parameters:
  - Inlet axial velocity: $u(\vec{x},t) = u_{mean}(\vec{x}) + u_{noise}(\vec{x},t) + u_{excit}(\vec{x},t)$
  - Excitation:

$$u_{excit}(\vec{x},t) = A_a \sin\left(2\pi St_a \frac{U_1}{D} t\right) + A_h \sin\left(2\pi St_h \frac{U_1}{D} t + \frac{\pi}{4}\right) \sin\left(\frac{\pi x}{R}\right)$$

- Known excitation effects:
  - for combination of axial and helical forcing with integer ratio St_a/St_h with $St_a = 0.3 \div 0.7$ the bifurcating jets occur (confirmed experimentally and numerically)
  - for non-integer ratio St_a/St_h blooming jets are observed (confirmed experimentally)







Variable density bifurcating jet (LES results)

Density ratio: 0.6
Mesh: 128 x 128 x 160
LES with Filtered SF model
Excitation: Axial + Helical
Excitation Strouhal numbers:
St_A=1.0, St_A/St_H=2.0
Excitation amplitude: 0.05U

3D view: Q parameter isosurface
2D planes: temperature
- bifurcating plane (x-z cut)
- bisecting plane (y-z cut)

Author: Artur Tyliszczak

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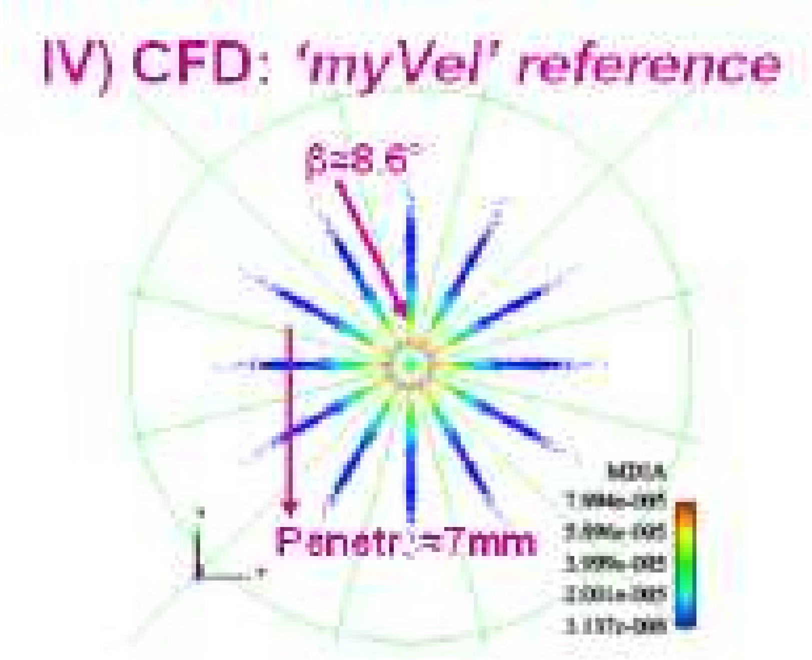
Simulation of the fuel jet atomization in Diesel engine – Huh-Gosman model

project in cooperation with Reanult



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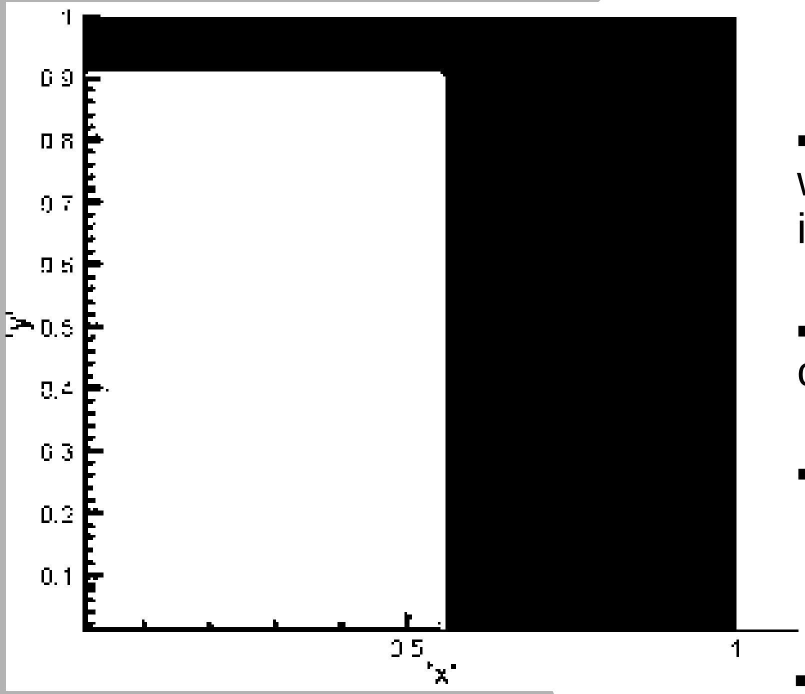
Advantages of VoF method.



„DRIFTER” DNS Solver with VoF/PLIC advection/reconstruction scheme, simulating the 'Broken Dam' problem for two phases with different density.

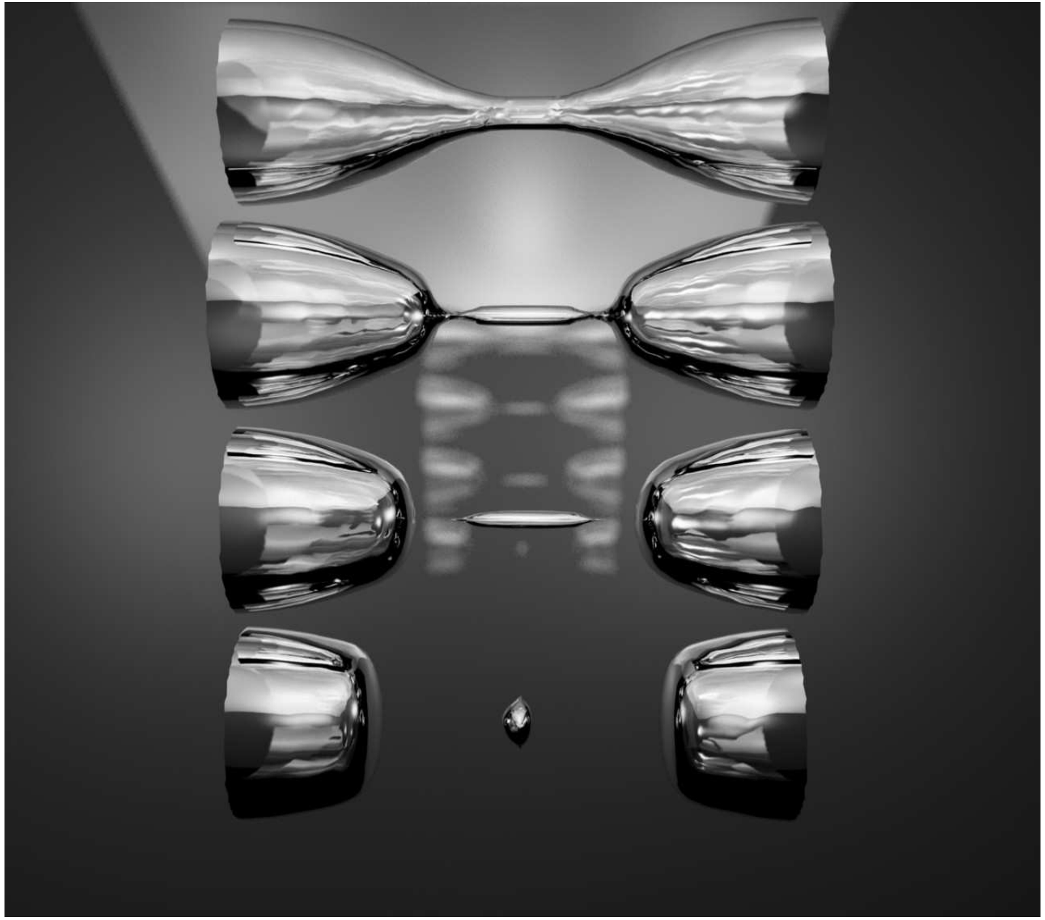
VOF Advantages

- Simulated „mass” of traced fluid is conserved, which is implicit in formulation (if properly implemented).
- Topology changes pose no problem. Suitable for complex simulations.
- After slight modifications, VoF can be used to simulate compressible flow.

„Shortcomings”

- Method is relatively hard to implement, especially in 3D, due to geometric reconstruction.
- Elaborate methods (-> Height Functions/Continous Surface Stress) are required for good quality curvature calculation. Therefore, use of combined LS+VoF is justified to calculate surface tension.

SAILOR+CLSVoF



Fluid cylinder breakup under Plateau-Rayleigh instability.
(Uniform 64*64*64 grid, unoptimized). Newer code versions exist with better mass conservaion.

Free jet breakup, density ratio 1:100.
Physical breakup distances are achieved despite very low grid resolution (32*32*256).

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sd1

Combustion modeling
LES solvers applied in computations:

- IInd order finite volume code BOFFIN from Prof. W.P. Jones (IC)
  - stand alone CMC part from prof. E.Mastorakos (Cambridge U.)
  - modified and implemented in BOFFIN by A.Tyliszczak
  - computations performed in 2002 in the framework of the EU MOLECULES project
- IInd order finite volume code from VUB (Sergey Smirnov) parallelized by A.Tyliszczak
  - CMC part very close to the one used in BOFFIN code
  - computations performed in 2007 in the framework of bilateral VUB-UC project
- high order compact(6th)/WENO(5th) code from UC (A.Tyliszczak)
  - CMC part the same as in VUB code, Eulerian stochastic model implemented
  - computations performed in the framework of bilateral VUB-UC project and TIMECOP A.E. FP6 project `

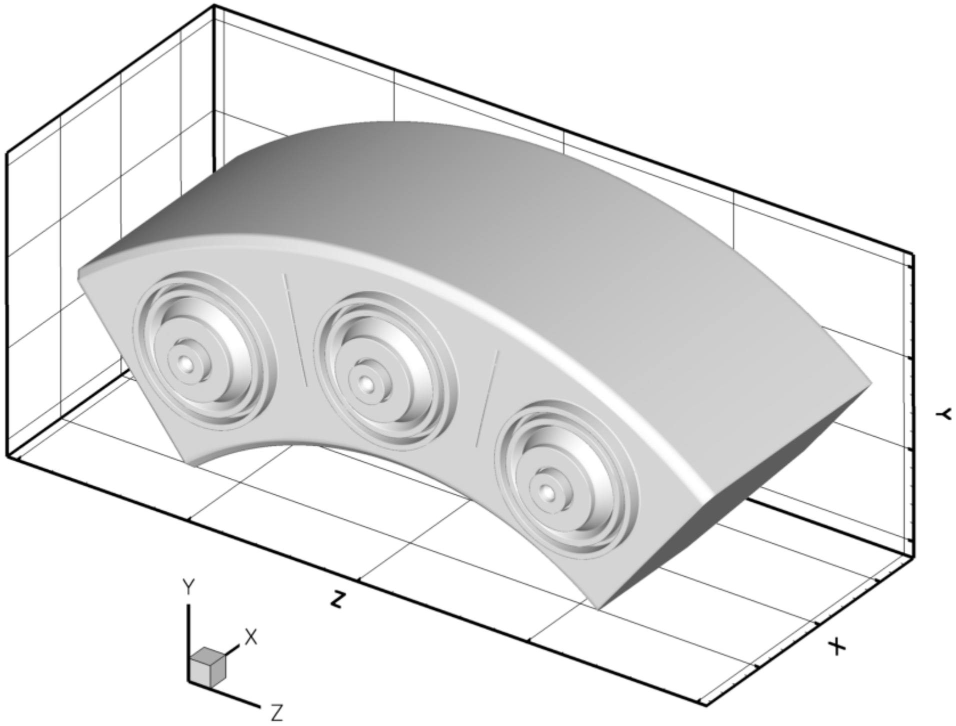
Slajd 15

sd1 modele spalania:
-CMC
-flamelet
dwa pierwsze kody - control volume
drobniak; 2009-01-28

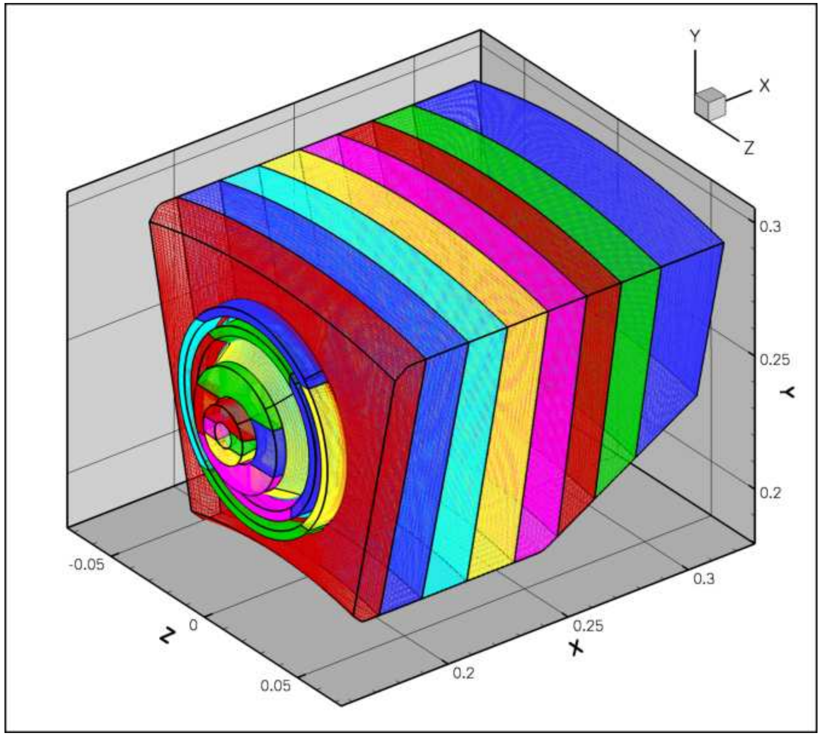
sd5

LES modelling of the spray ignition in real geometry (IC+UC cooperation)

View of the three sector geometry:
- **57 subdomains for injectors**
- **24 subdomains for combustion chamber**



View of the mesh for single sector:
- **colours represent subdomains**
- **two meshes used:**
  - **coarse approx. 1 mln cells**
  - **refined approx. 2.2 mln cells**



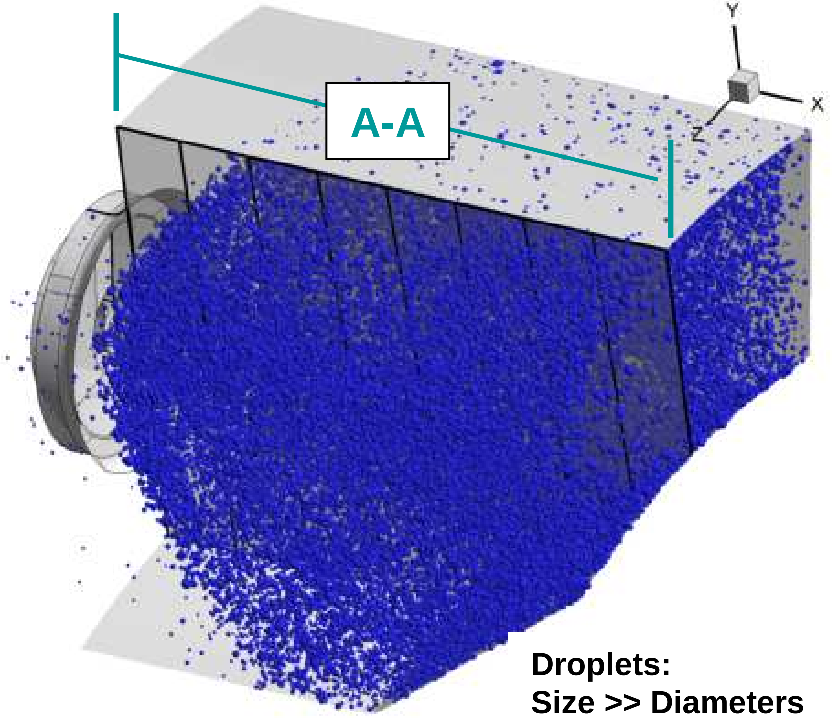
Slajd 16

sd5 INTELLECT, trój i jednosektorowa komora kolory dla podobszzarów przy parallelisation

od zapłonu metanu zaczyna eulerian pdf - 4 pola stochastyczne - dla metanu i nafty 4 stopnowa reakcja dla metanu Jones-Linsted
drobniak; 2009-01-28

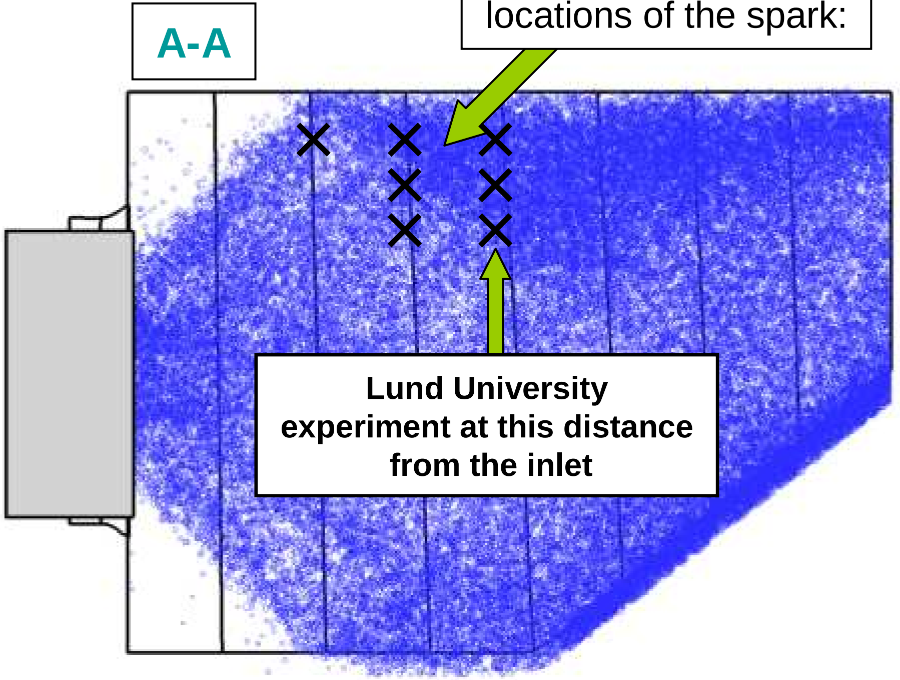
Modeling of the combustion and ignition process were performed within INTELLECT D.M. FP6 project in cooperation with Rolls-Royce Deutschland and Imperial College London on lean combustor geometry delivered by RRD, using the BOFFIN (BOundary Fitted Flow INintegrator)code devdeloped by Professor W.P. Jones, Imperial College, London

View of the instantaneous droplets distribution before ignition



Droplets:
Size >> Diameters

Ignition parameters:
- spark sizes 10 and 15 mm (Gaussian shape)
- exponential growth in time (Tmax=3500K)

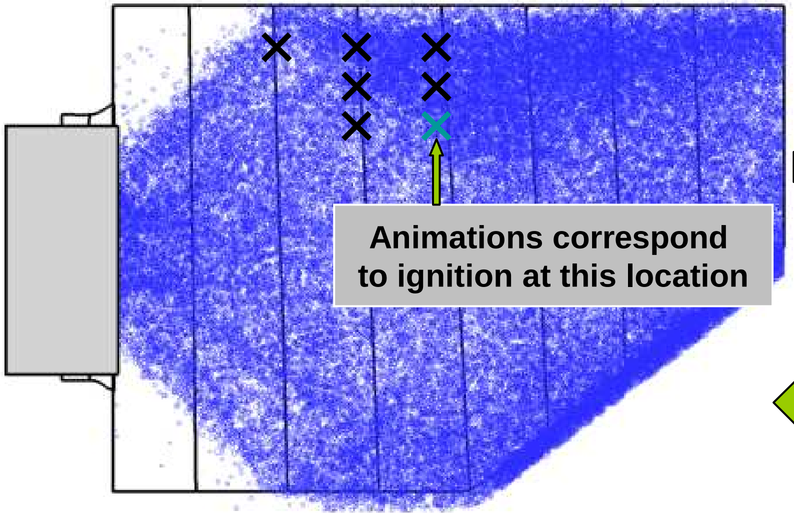


Crosses represent locations of the spark:

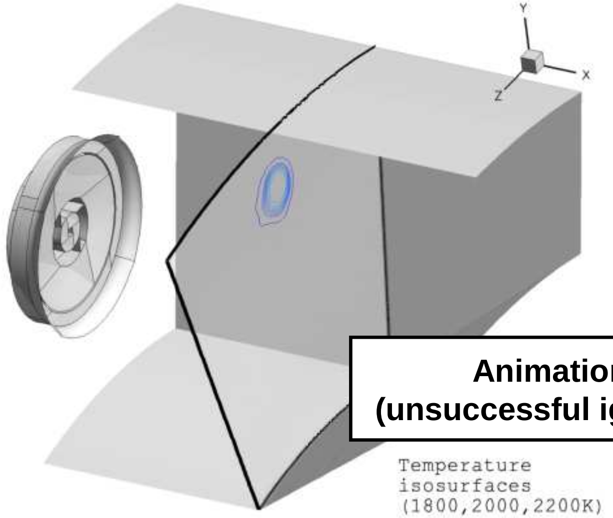
Lund University experiment at this distance from the inlet

sd7

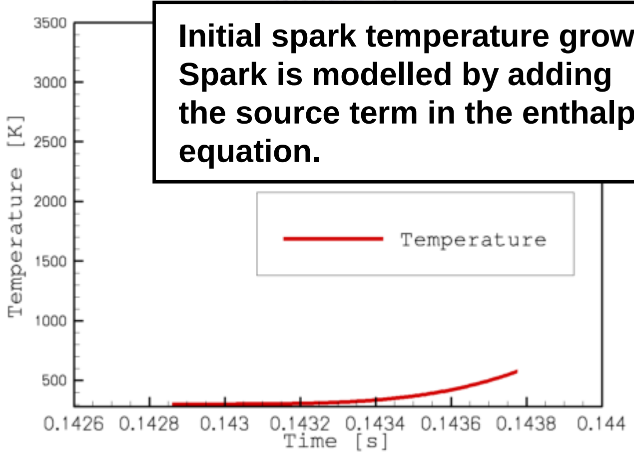
Modelling of the spray ignition:
animations illustrating *unsuccessful*
and *successful* ignition process

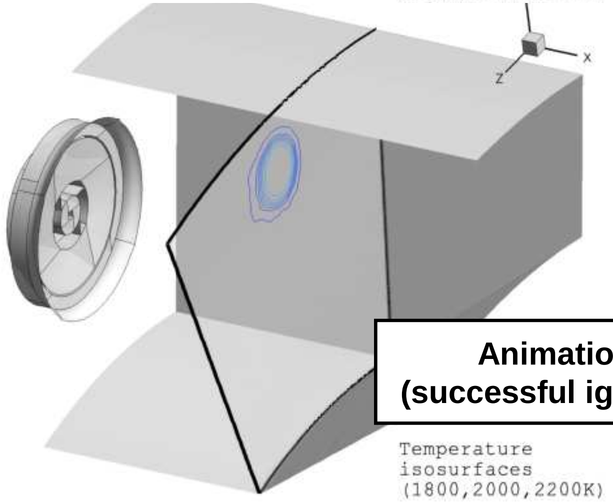

Animations correspond to ignition at this location

SPARK
10mm


Animation (unsuccessful ignition)

SPARK
15 mm


Initial spark temperature growth
Spark is modelled by adding the source term in the enthalpy equation.


Animation (successful ignition)

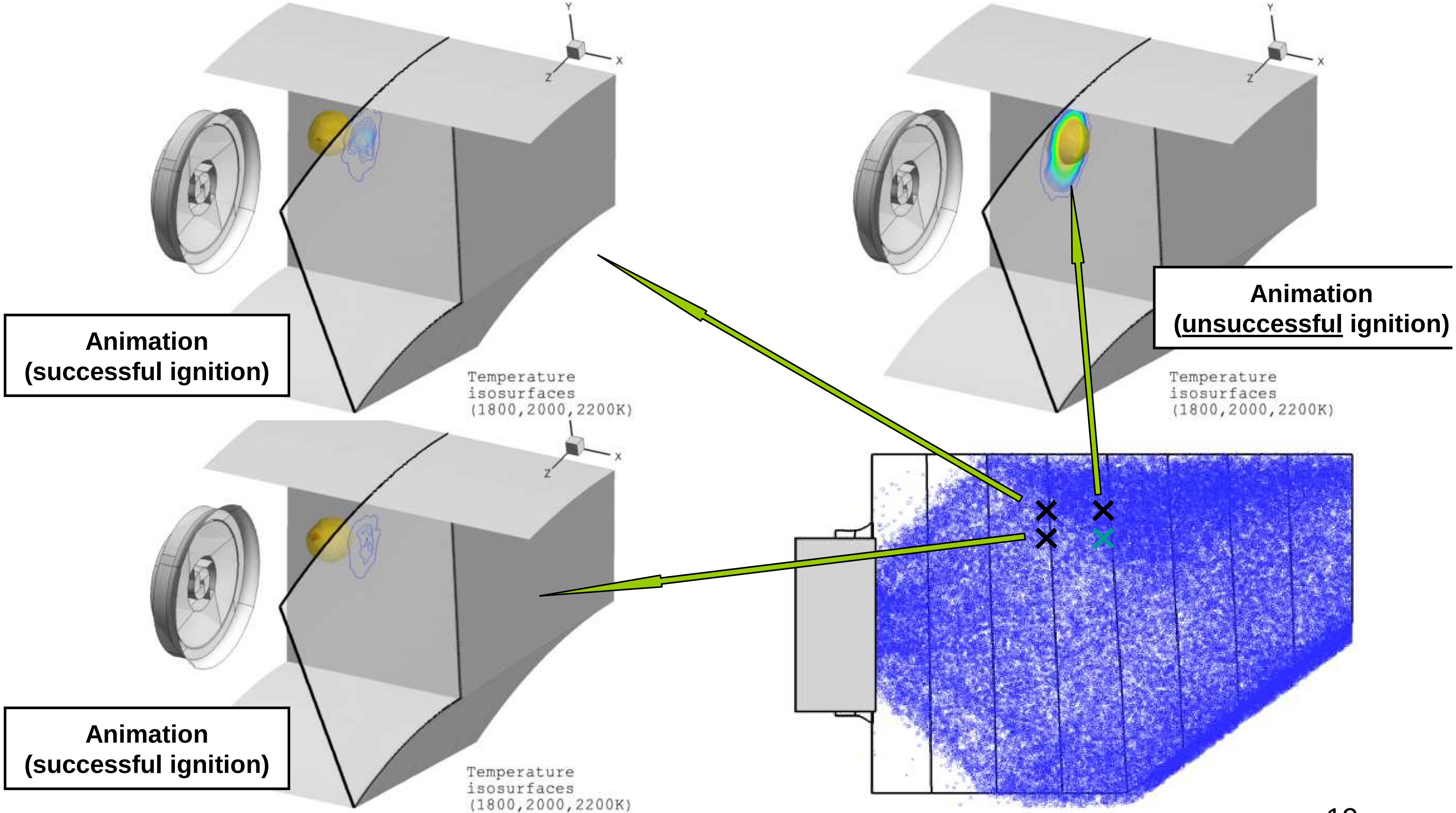
Slajd 18

sd7 trzy izpowierzchnie temeratury - pokazane na lewym, na wykeresie czerwona to maksymalna temperatura w obszarze, iskra za mala

to ze nie dzieje sie nic to nie znaczy się nic nie dzieje bo pokazane izolinie tempweratury tuylko z pewnego zakresu, widać mały obszar palącuch sie kropel zasysanych do strefy recyrkulacji, ktory dopiero powoduje zapłon w calej objetosci
kolory kropel odpowiadaja temeraturze (max 680 k)
drobniak; 2009-01-28

Modelling of the spray ignition:

different spark locations (size 15 mm)



Animation (unsuccessful ignition)

Animation (successful ignition)

Animation (successful ignition)

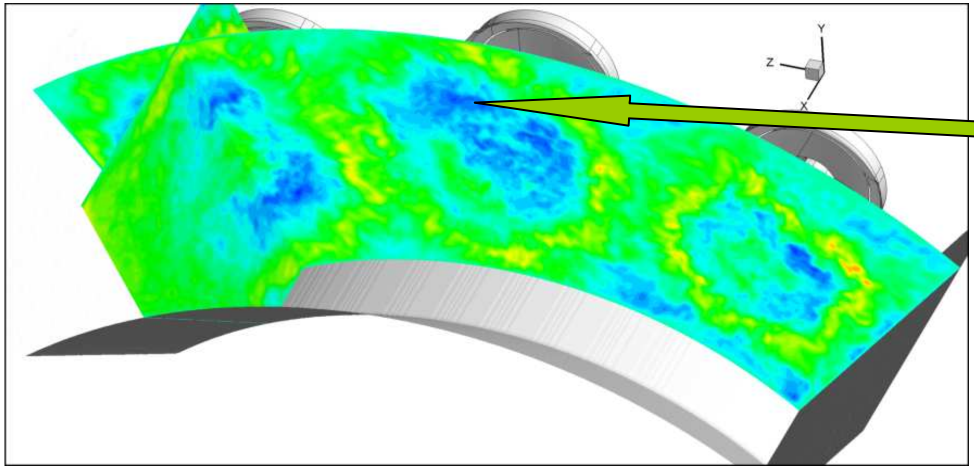
sd9

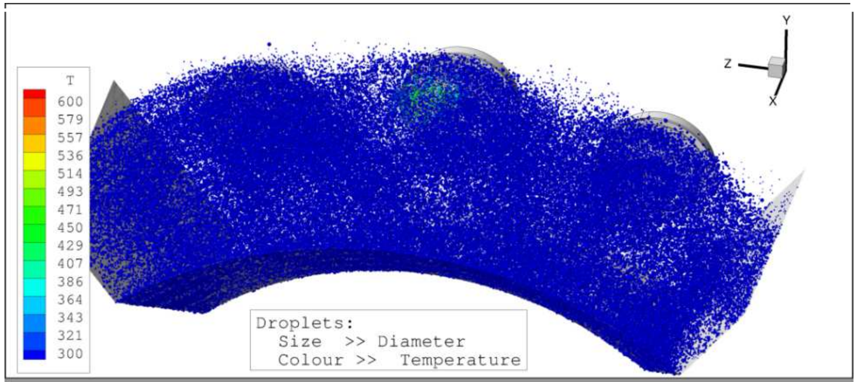
Modelling of the spark ignition and light across using BOFFIN code

- Due to extremely time consuming simulations for three sector configuration the spark parameters (location and size) are chosen such to guarantee successful ignition in selected sector.
- Basing on previous experiments performed for single sector case the spark was located close to the edge of the recirculation zone, the size of the spark was equal to 15 mm.
- Three-steps solution procedure: (cold flow → spray → ignition (flame propagation)) took more than 3 months, this corresponds to less than one second of real life !

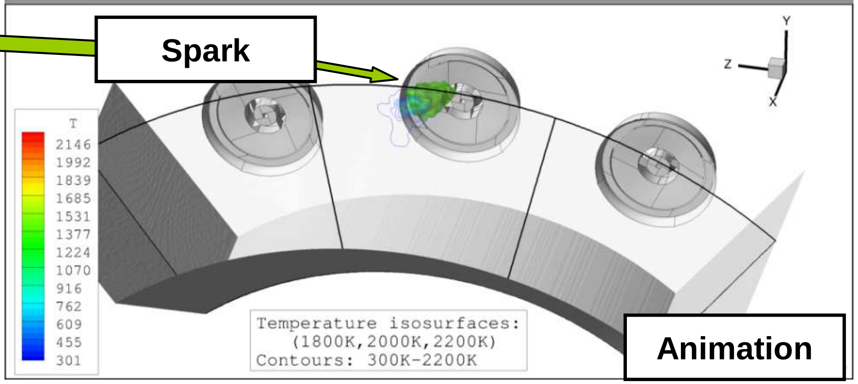
View of the instantaneous droplets distribution and spark kernel just after ignition.

View of the instantaneous axial velocity before ignition. Blue colour denotes negative velocity (recirculation zone).





Spark

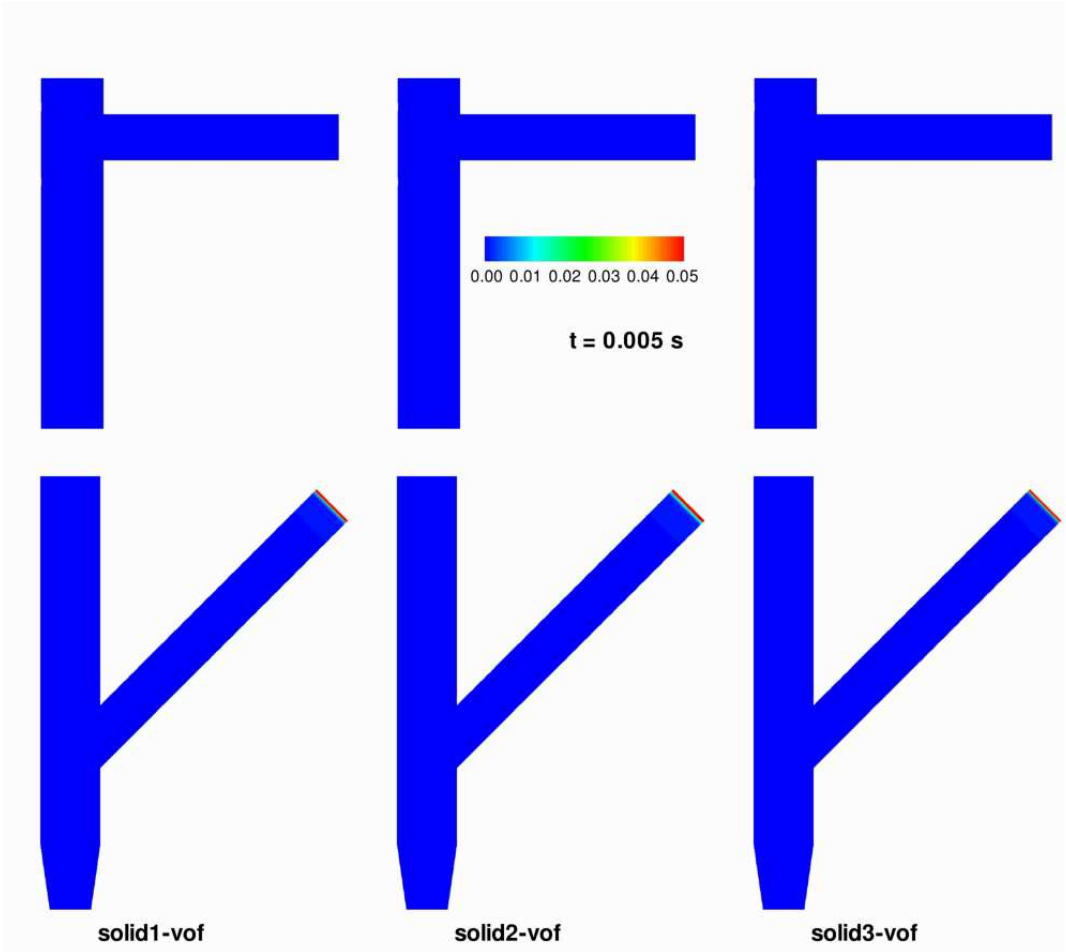


Animation

Slajd 20

sd9 dla 3 sektorów - light across - zapalano tam gdzie na pewno byl zapłon i sprawdzano czy plomień bedzie sie propagowal na inne sektory
48 procesorow 3 miesiace
drobniak; 2009-01-28

Preliminary study of oxy-combustion in CFB-
3D ANSYS-Fluent Euler-Euler simulation of granular phase



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