Using CFD to assess the Impact of different design variations for water mist systems

Max Lakkonen
www.ifab-fire.com

ASKING - ANALYSING - ANSWERING

IFAB

Content

- CFD general
- CFD in fire protection
- CFD and water mist
- An example project – Using CFD to assess changed design parameters
- Conclusions

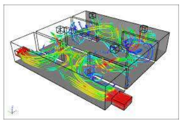
ASKING - ANALYSING - ANSWERING

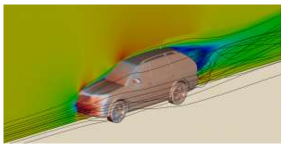
IFAB

CFD

- Computational Fluid Dynamics:
  - Fluid dynamics that uses numerical analysis to solve problems
  - Methodology
    - Varies depending on the different discretization methods
    - Varies depending on the different turbulence models
  - Typical codes used in fire protection:
    - FDS, Openfoam, (Fluent / Star / Kobra etc.)

- CFD is used:
  - Fluid dynamics
  - Aviation / aerodynamics
  - Automobile industry
  - Weather forecast
  - Heat & combustion in engines
  - Marine applications
  - HVAC





ASKING - ANALYSING - ANSWERING

IFAB

Benefits of CFD in fire protection

- Produce data without destroying anything
- Cost saving compared to fire tests
- Possibility to optimise the fire safety concept easily
- Recognised approach / tools especially to certain areas e.g. ventilation design

ASKING - ANALYSING - ANSWERING

IFAB

Challenges of CFD in fire protection

- CFD is based on complex physics which results requires knowledge from user
  - Heat transfer (in gas, liquid and solid phase)
  - Radiation
  - Mass transport
  - Fluid dynamics
  - Multi phase flows
  - Chemical reactions
  - Phase changes (vaporisation, condensation, melting, …)
- Validation requires experimental data

ASKING - ANALYSING - ANSWERING

IFAB

Challenges of CFD in fire protection

- Scale differences
  - Small scale effects (e.g. turbulence, combustion) in large scale applications (e.g. buildings, even forests)
- High variation of velocities, especially with water mist systems or jet fires
- Simulation times often very long (compared to simulated tim steps)
- High computational costs / long simulation times

ASKING - ANALYSING - ANSWERING

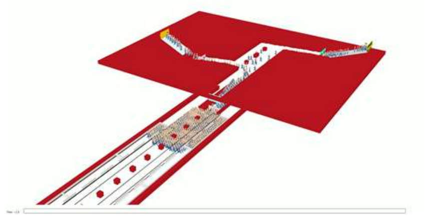
IFAB

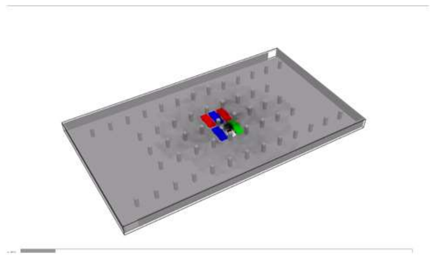
CFD examples in fire protection

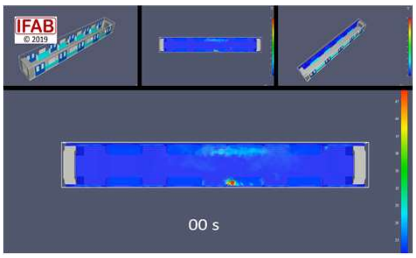
- IFAB uses CFD for example in following ways:
  - Smoke extraction / ventilation
  - Evacuation design
  - Fire fighting system efficiency studies (interpolation)
  - Fire detection system efficiency studies
  - Heat transfer (combined with FEM)

ASKING - ANALYSING - ANSWERING

Examples of CFD







ASKING - ANALYSING - ANSWERING

CFD and water mist systems

- Water mist is modelled by lagrangian particles: a number of representative droplets is simulated individually. Each particle has its own:
  - Velocity
  - Temperature
  - Dimension
  - Mass
- Water droplets can interact with gas and solid phase

ASKING - ANALYSING - ANSWERING

IFAB

CFD and water mist systems

- „Easy“ applications (simple validation data):
  - Comparing investigation with single parameter change
  - Geometrical changes
  - Spray patterns in interaction with ventilation
  - Activation of glass bulbs
- „Medium“applications (requires more validation data):
  - Temperature and smoke distribution
  - Influence to humans (visibility, toxicity)
- „Difficult“ applications (extremely lot validation requreid):
  - Fire spread simulation
  - Combustion (=> Extremely difficult)

ASKING - ANALYSING - ANSWERING

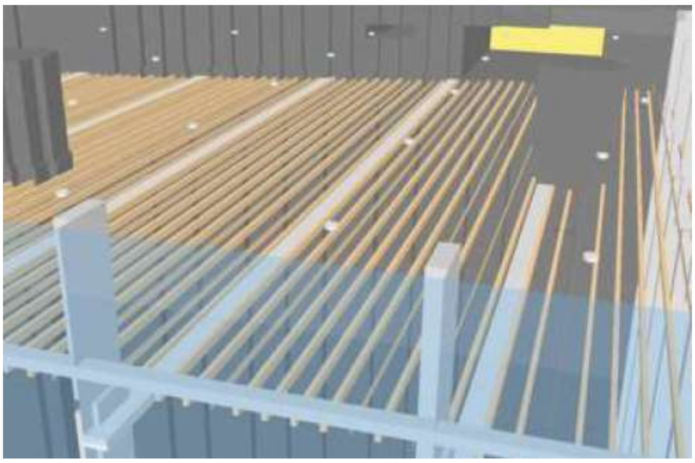
IFAB

Example project – High-rise building (atrium)

- The problem was to study the effect of increased ceiling height and obstruction
  - 15.5 m instead of 12 m (testing as per IMO Res.A800)
  - Decorative false ceiling at 14.1 m height (nozzle installation) – blockage level of 30%
  - Water mist system lay-out had been changed more concervative to compensate additional effects
- Additionally to study evacuation conditions

ASKING - ANALYSING - ANSWERING

IFAB



ASKING - ANALYSING - ANSWERING

IFAB

Research questions

- Does the extended ceiling height and false ceiling delay the activation of the water mist system? (quantified time)
- How will the ventilation system influence the water mist system and what are the conditions for evacuation?
- There were some other detailed questions that were studied.

ASKING - ANALYSING - ANSWERING

IFAB

Approach

- Normal performance based approach
  - Detailed tasks:
    - Defining design objectives
    - Defining the CFD process
    - Design fire analysis / HRR curves
    - Detailed information of water mist system (droplets, velocities, geometry, RTI)
  - Recognised challenges:
    - False ceiling
      - dimension (4 cm wide opening) -> high number of cells
      - temperature evaluation
    - High velocities in ventilation and through false ceiling
    - Wide dimensions of lobby
    - Complex geometry
    - Conservativeness level of design parameters

ASKING - ANALYSING - ANSWERING

IFAB

CFD process

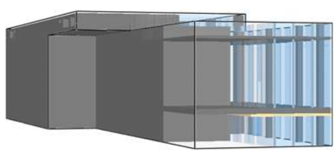
- CFD process (simplified)
  - building geometry and material properties
  - Including false ceiling and all obstructions in detailed level
  - Ventilation
    - Correct parameters
  - Modelling of water mist
    - spray pattern
    - droplet size distribution and velocities -> PIV measurements
    - RTI algorithm
  - Adding “measurements devices” for:
    - visibility
    - smoke layer height
    - temperature
    - pressure
    - velocity
    - wall temperature
  - Include activation mechanics
    - activation of water mist and ventilation
  - Boundary conditions
  - Validation and verification
  - Reporting

ASKING - ANALYSING - ANSWERING

IFAB

Geometry

- Number of cells: 1,726,554
- Number of meshes: 13
- Number of CPU-cores: 18
- RAM: 24 GB
- Simulated time: 430 s
- Simulation duration per scenario: 12 days



Time: 370.0

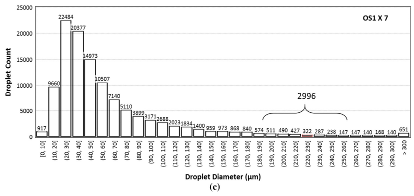
ASKING - ANALYSING - ANSWERING

IFAB

Water mist modeling

- Particle image velocimetry data gives droplet information (speed and size distribution)
- Implementation of spray pattern charasteristics
- Glass bulb simulation (RTI algorithm)

$$F(d) = \begin{cases} \frac{1}{\sqrt{2\pi}} \int_0^d \frac{1}{\sigma d'} e^{-\frac{[\ln(d'/d_m)]^2}{2\sigma^2}} \mathrm{d}d' & (d \le d_m) \\ 1 - e^{-0.693\left(\frac{d}{d_m}\right)^\gamma} & (d_m < d) \end{cases}$$



$$RTI = \frac{-t_r (u)^{0.5}(1+C/u^{0.5})}{ln[1-\Delta T_{ea} \quad (1+C/(u)^{0.5})/\Delta T_g]}$$

ASKING - ANALYSING - ANSWERING

IFAB

CFD simulations

- Case 1 – Validation
  - Simulating fire test scenario
  - Comparing the activation times between CFD and real fire test (12 m ceiling height)
  - Results:
    - Deviation was in range of 5-8 seconds (CFD faster)

ASKING - ANALYSING - ANSWERING

IFAB

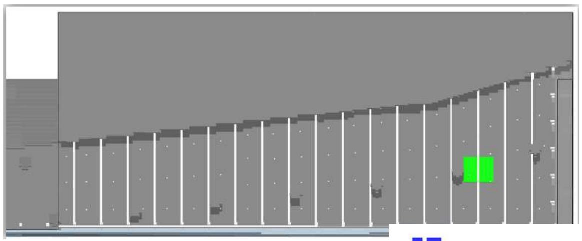
CFD simulations

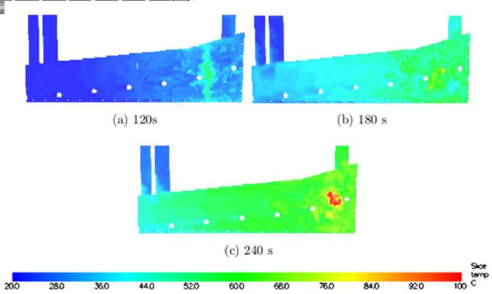
- Case 2 – Activation times with ceiling obstructions and elevated height
  - Simulating real scenario
  - Seeing influence of the obstruction / increased ceiling height

ASKING - ANALYSING - ANSWERING

IFAB

Results





ASKING - ANALYSING - ANSWERING

IFAB

Results

- Results:
  - The activation is delayed with 30 seconds compared to the fire tests due to the obstructions / ceiling height
    - Plausability simulations
  - Multiple nozzle activation was noticed to be likely (2 nozzles cooled so much that 3rd nozzle activation was very unlikely)
    - Recommendation to dely start of emergency ventilation system with 30 seconds

ASKING - ANALYSING - ANSWERING

IFAB

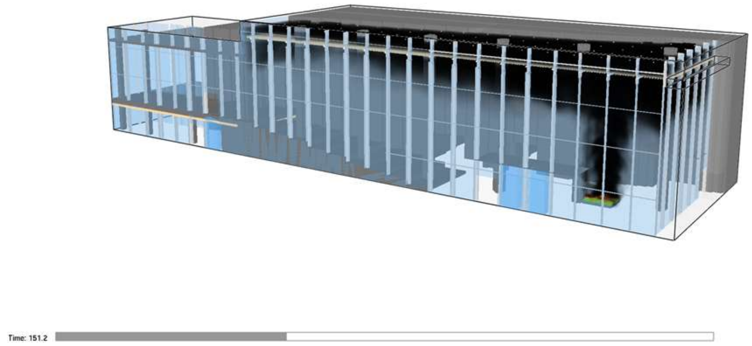
CFD simulations

- Case 3 – „Freeburn“ test
  - Simulating freeburn scenario and especially smoke / temperature conditions for evacuation
    - „Freeburn“ represents most concervative approach as water mist system is not considered to influence fire development at all (reality is always easier)
    - Maximises the amount of smoke / heat produced by the fire

ASKING - ANALYSING - ANSWERING

IFAB

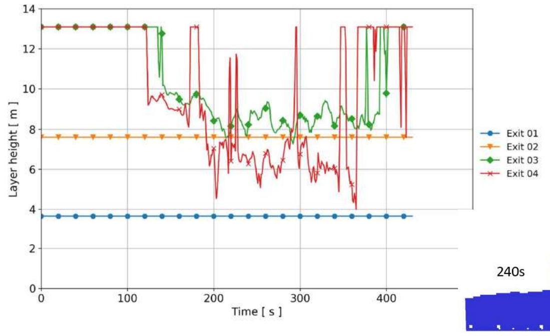
Results

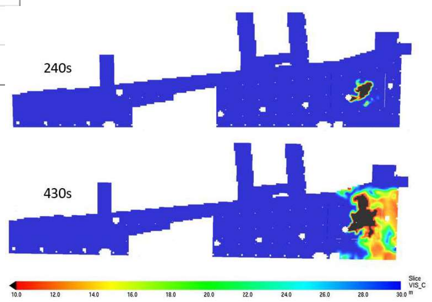


ASKING - ANALYSING - ANSWERING

IFAB

Results





ASKING - ANALYSING - ANSWERING

IFAB

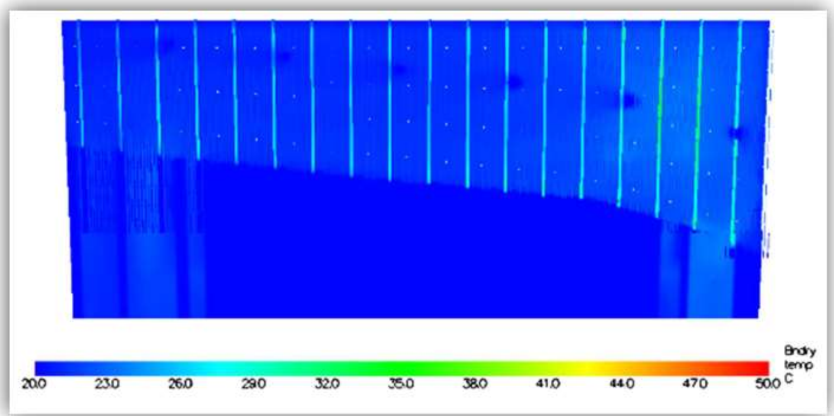
Results

- Smoke layer is not affecting 2 emergency exits at all.
- Two emergency exits are influenced, but smoke layer stays in 4m height or higher (2 meter is the limit)
- The visibility is only influenced close to teh fire (10m visibility was the limit)
- Additional information:
  - The false ceiling temperatures were low and ignition possibility can be neglected

ASKING - ANALYSING - ANSWERING

IFAB

Results



ASKING - ANALYSING - ANSWERING

IFAB

Conclusions

- CFD is accepted design tool in various application fields in other industries
- CFD is also used in fire protection industry, especially in special application like ventilation design
- Using CFD with water based fire fighting systems is still challenging, especially related to the combustion modeling
- CFD can well be used for the assessment of secondary effects like output of fire (heat & smoke) especially to interpolation of the results to different geometries
- The user competence is normally most limiting factor using CFD

ASKING - ANALYSING - ANSWERING

IFAB

Conclusions

- CFD normally needs a validation data to ensure accuracy
- Given example showed how water mist system could be evaluated in terms of activation time with different installation height and obstructions.
- The results showed that activation is delayed by 30 s which was acceptable
  - Further recommendation for operating emergency ventilation system was given
- Evacuation conditions were additionally assessed using CFD and the results showed that the intended system fulfilled the requirements with good safety margin

ASKING - ANALYSING - ANSWERING

IFAB