Validation of CFD for the Flow Around a Computer Simulated Person in a Mixing Ventilated Room

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Personal Micro-Environment (PME) involves complex geometry and many complex fluid dynamics phenomena (low Re flow, thermal buoyancy, PM behavior)

To better design the personal indoor environment, detailed studies using state-of-the-art measurement and modeling techniques are necessary to tackle these difficult issues.

As a result two concerns need to be addressed:

1. Validation of existing airflow, turbulence, PM transport, etc. models
2. Modify existing or develop new models where necessary
Motivation and Objectives

- Investigate performance of CFD and verify what needs to be done to improve them – validation needed
- Benchmark cases are needed for proper validation
- Important parts:
  1. **Grid Study**
     - Number of cells required for grid independence
     - Resolve the boundary layer
     - Topologies
  2. **Turbulence Models**
     - Typical RANS models (standard $k-\epsilon$)
     - New RANS models ($v^2-f$)
     - Validate with existing experimental data
  3. **Boundary Conditions**
     - Inlet/outlet conditions (velocities, turbulence, concentrations)
     - Wall conditions (temperature/heat-flux, particulate matter)
Mixing Ventilation

- Approximated from recirculating flow
- Steady-state, uniform 0.2 m/s inlet, TI = 40%, l = 0.5 m
- Test data – velocity magnitude

Seated Thermal Mannequin in **Mixing Type** Ventilation

Convective Heat-flux = 38 W
In general, CFD results in the far-field flow compare to data well.

Care must be exercised when taking data.

Non-uniform velocity inlet profile re-constructed using data.

Velocity Magnitude Behind Manikin: blue – uniform inlet; purple – non-uniform inlet; circles - data.

Reconstructed Inlet Profile.
Grid Dependency

- Grid independence achieved with 2-3 million cells - including BL grid near manikin
- Wake behind manikin not resolved with Grid A (1.2 million)

Grid Dependency: Streamlines from Shoulder

Velocity Mag. Behind Manikin
Turbulence Model

- Velocity away from manikin not sensitive to turbulence model
- More variations between models near the manikin surface – $v^2$f matches best with data

Vertical Velocity Near Manikin Mouth: solid – $v^2$f; dashed – standard k-ε; dotted – low Re k-ε; circles - data
“Mixing” ventilation is not fully mixed – significant gradients in concentration still exist.

Concentration ratio is far from unity (“perfectly” mixed): 1-2 orders magnitude lower in the breathing zone.

Boundary layer resolution near floor affect the mass-flux; therefore exit concentrations differ.

$CO_2$ Concentration:
50ppm source at floor
Summary

- More information needed at inlet plane (velocity components and turbulence quantities)
- Higher fidelity data throughout flow-field needed
- Grid resolution around and on manikin important – care must be taken
- $v^2-f$ best overall RANS turbulence model
- Characterizes a mixing ventilation scenario