LES Simulation of Transient Fluid Flow and Heat Transfer in Continuous Casting Mold

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Acknowledgements

- Professor B.G.Thomas & Professor S.P. Vanka
- Accumold
- AK Steel
- Columbus Stainless Steel
- Hatch Associates
- National Science Foundation
- National Center for Supercomputing Applications

Previous Work

- LES flow and heat transfer simulations of an unconstrained impinging cylindrical jet.
- LES flow simulations had insufficient grid refinement near walls for heat transfer.
- High grid density needed near the impingement plate in order to get correct prediction of heat transfer rate without wall models.

Objectives

- Study transient fluid flow in continuous casting mold region: (eg. AK Steel thin slab mold).
- Study turbulent heat transfer in the casting mold liquid pool.

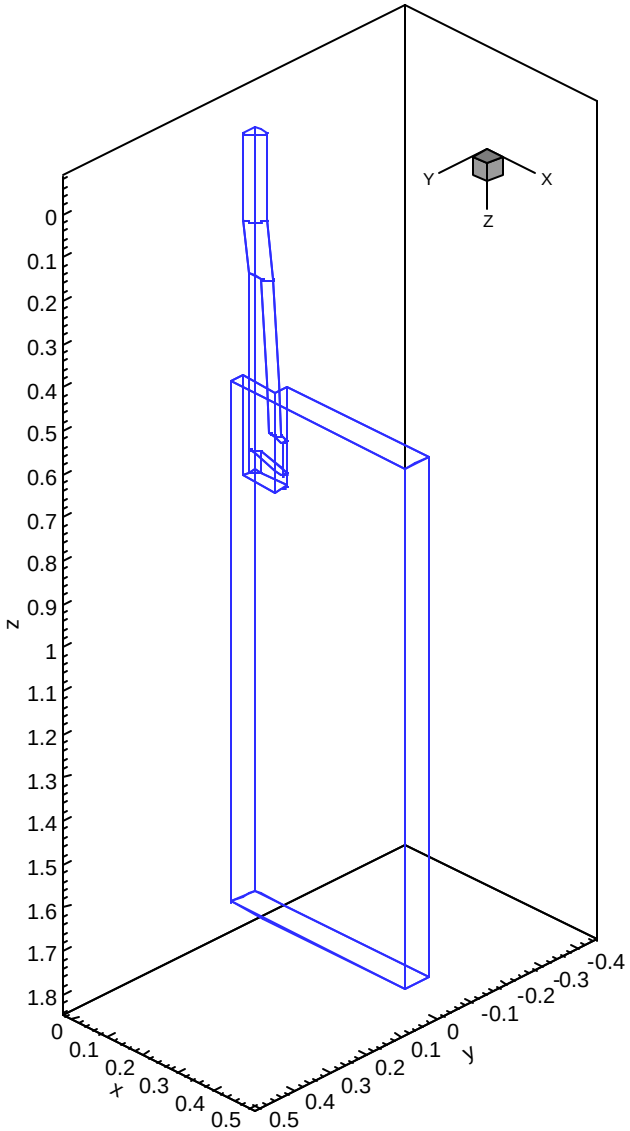
Simulation of Fluid Flow and Heat Transfer in the AK Steel Thin Slab Mold

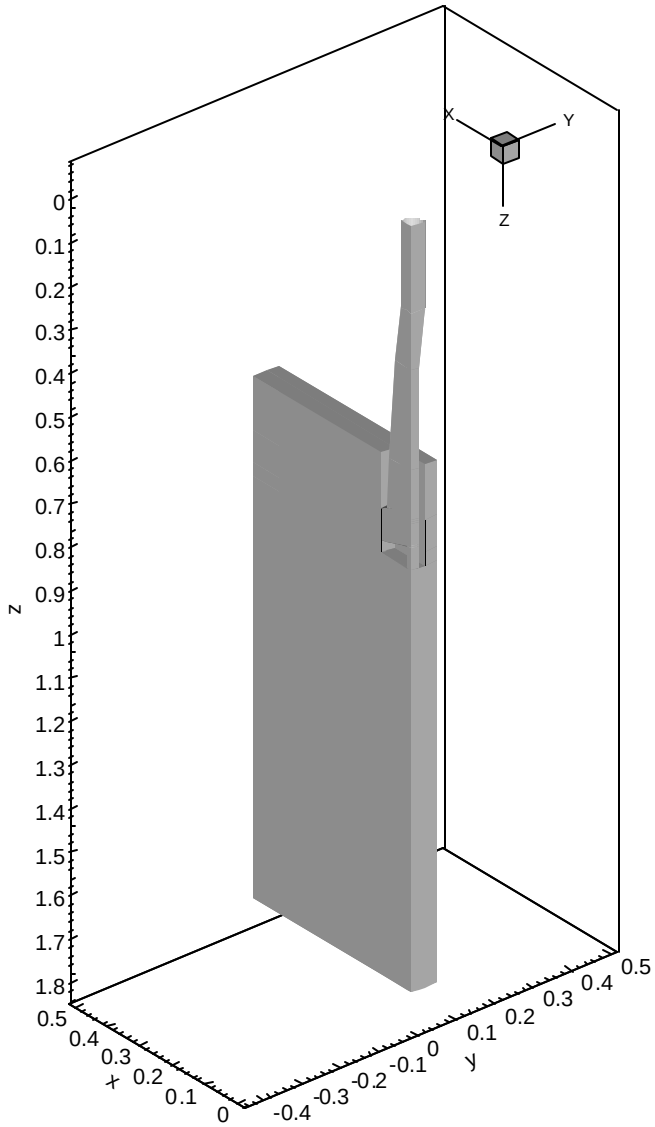
¼ mold simulation

Computational details

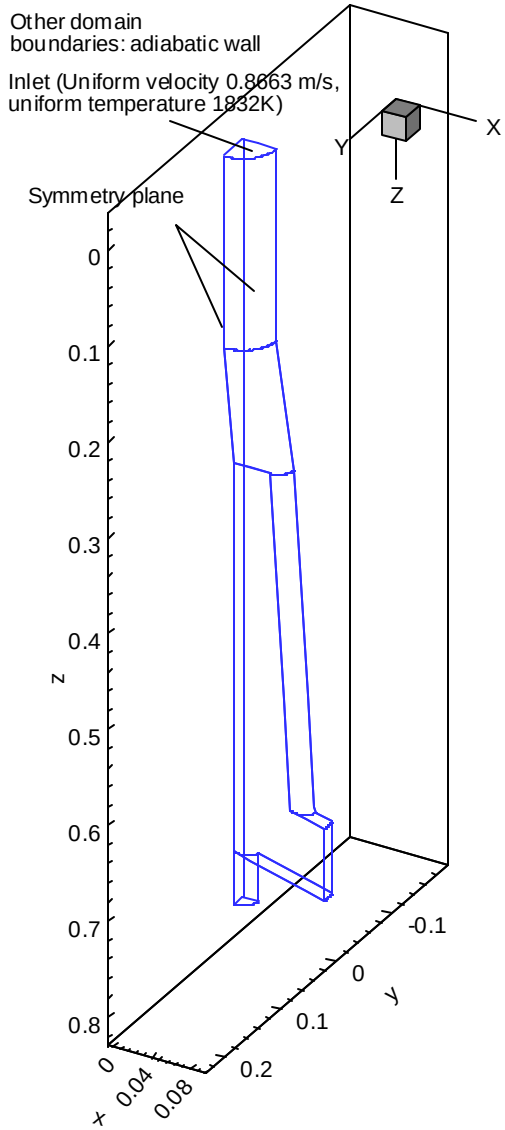
- Solving 3D transient Navior-Stokes Equations
- Second Order accuracy in space and time
- Non-Structured Cartesian collocation grid
- Algebraic Multi-Grid (AMG) solver is used to solve pressure Poisson Equation
- No sub-grid model (Coarse Grid DNS)
- 3D flux-limited advection scheme
- 852,442 finite volume cells
- Time step 0.0005s

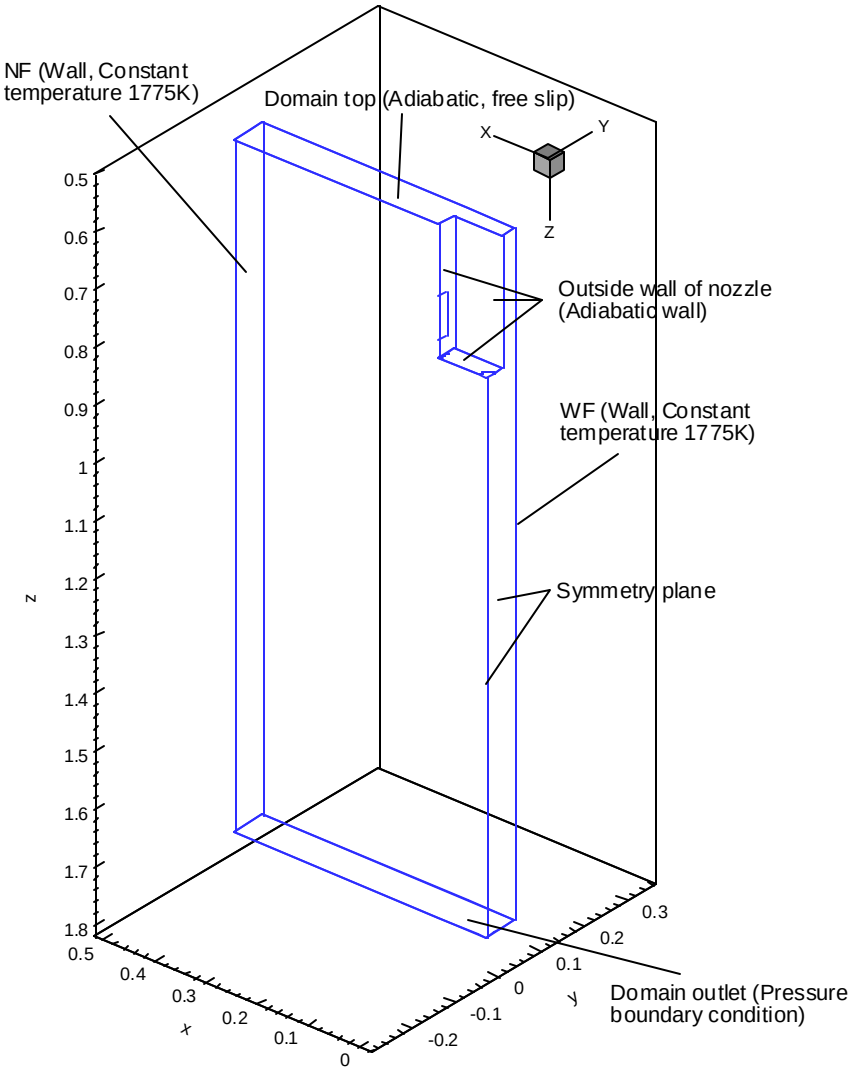
Simulation domain





Boundary conditions



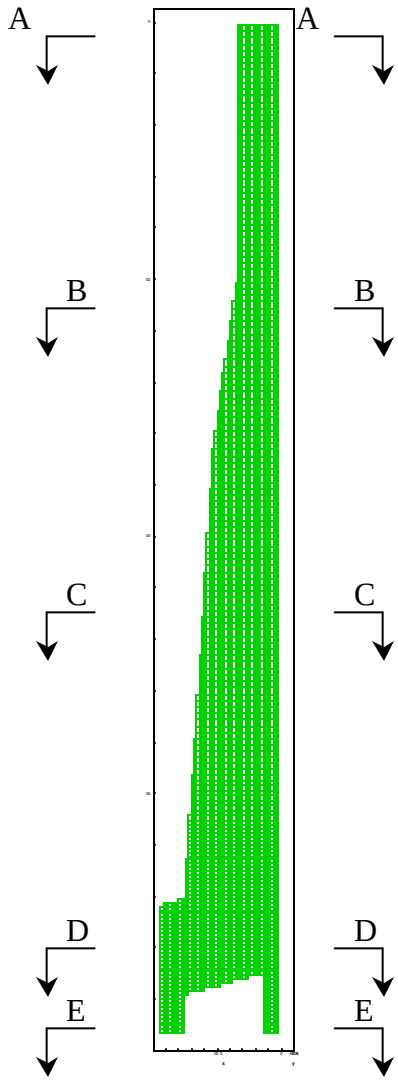


Simulation parameters

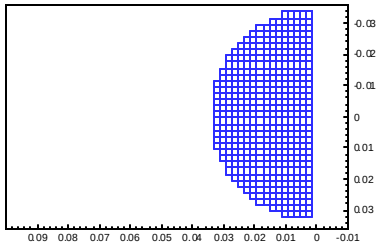
Casting speed	25.4 mm/s
Mold thickness	132 mm
Mold width	984 mm
Mold length	1,200 mm
Nozzle inlet diameter*	70 mm
SEN submerge depth	127 mm
Pouring temperature	1832 K
Solidifying temperature	1775 K
Steel density	7020 kg/m^3
Molecular viscosity	0.0056 kg/m·s
Heat conductivity	26 W/m·K
Prandtl number	0.1

* Nozzle geometry based on blueprints

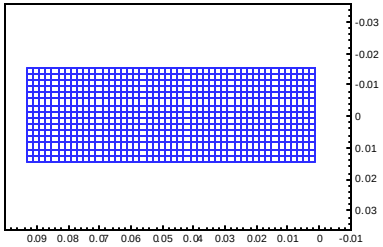
Mesh for the nozzle part



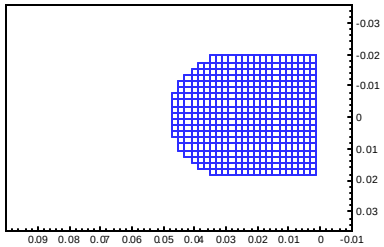
A-A



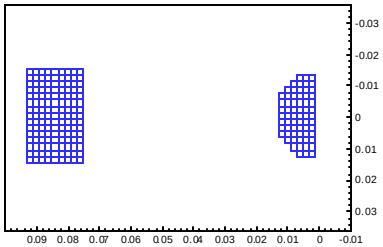
D-D



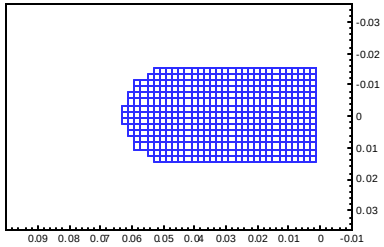
B-B



E-E

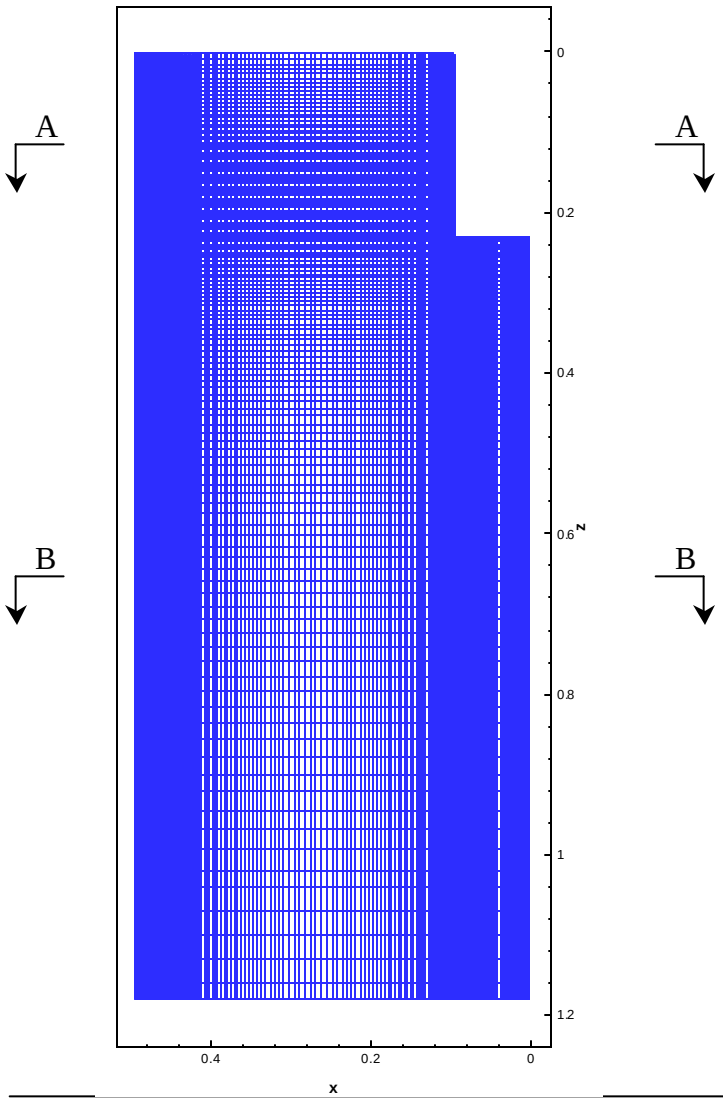


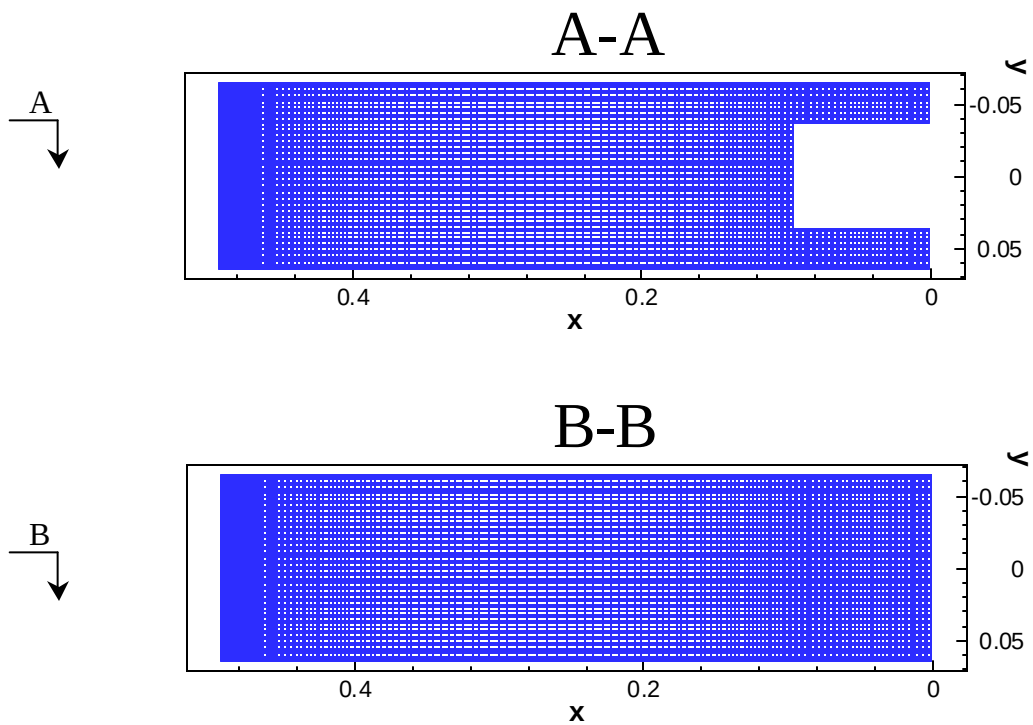
C-C



*note: mesh of half of the mold, ¼ actually used in the simulation.

Mesh for the mold part





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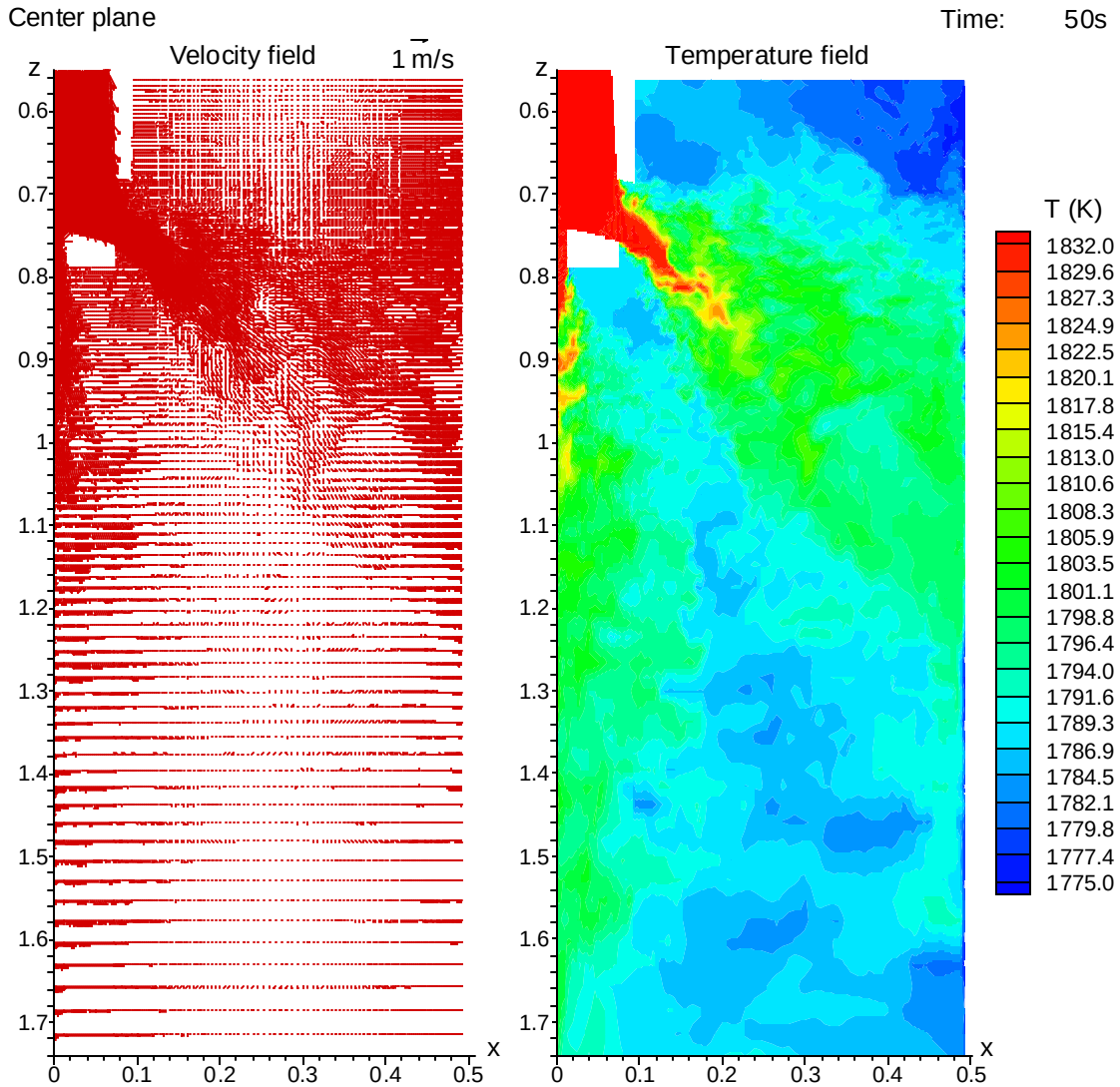
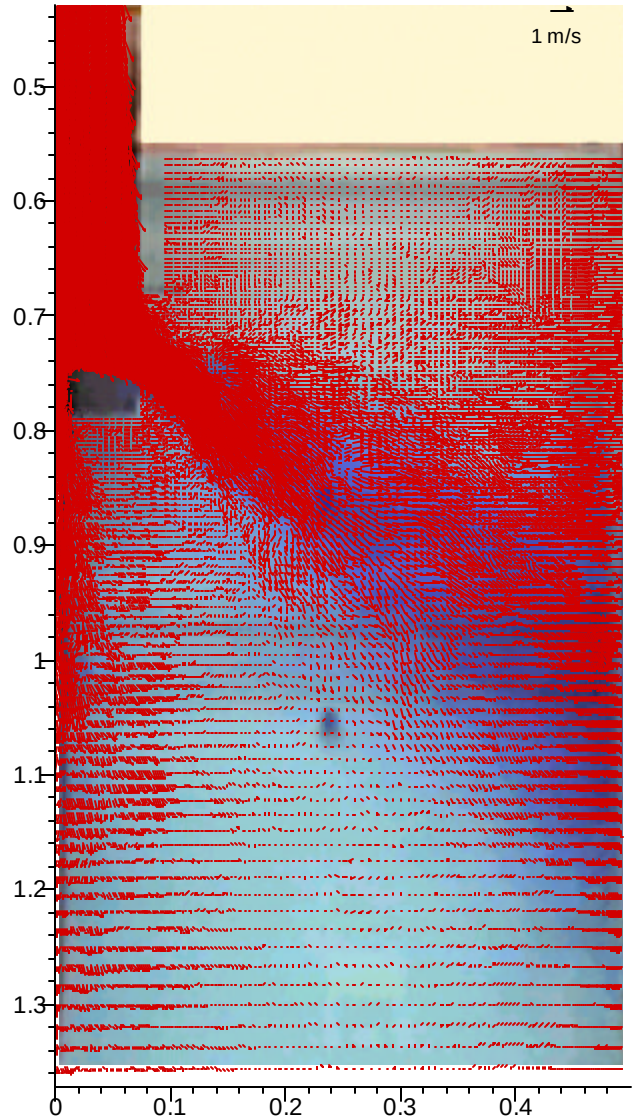
¼ actually used in the simulation.

Instantaneous velocity and temperature



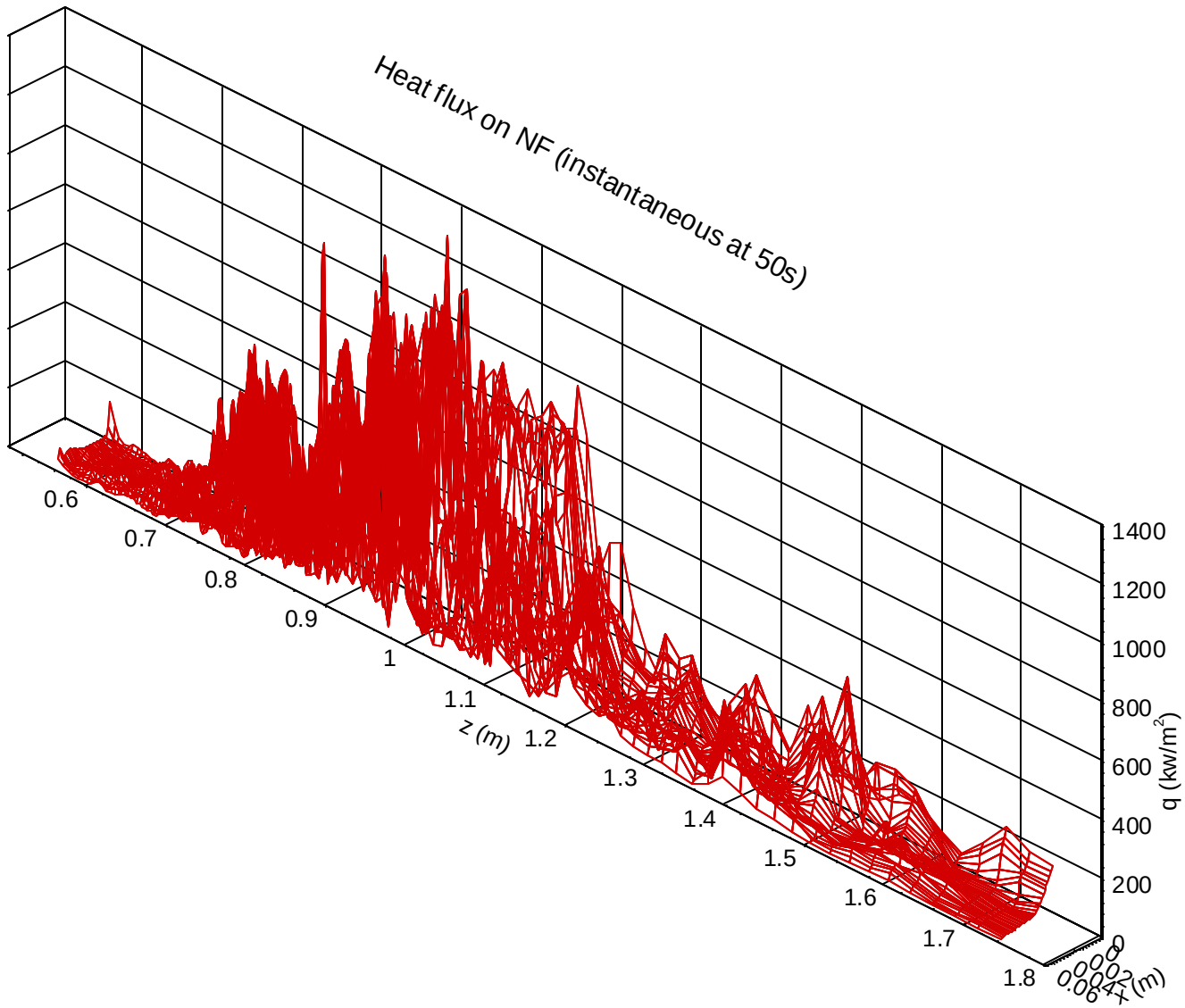
Instantaneous velocity vs. dye injection experiment



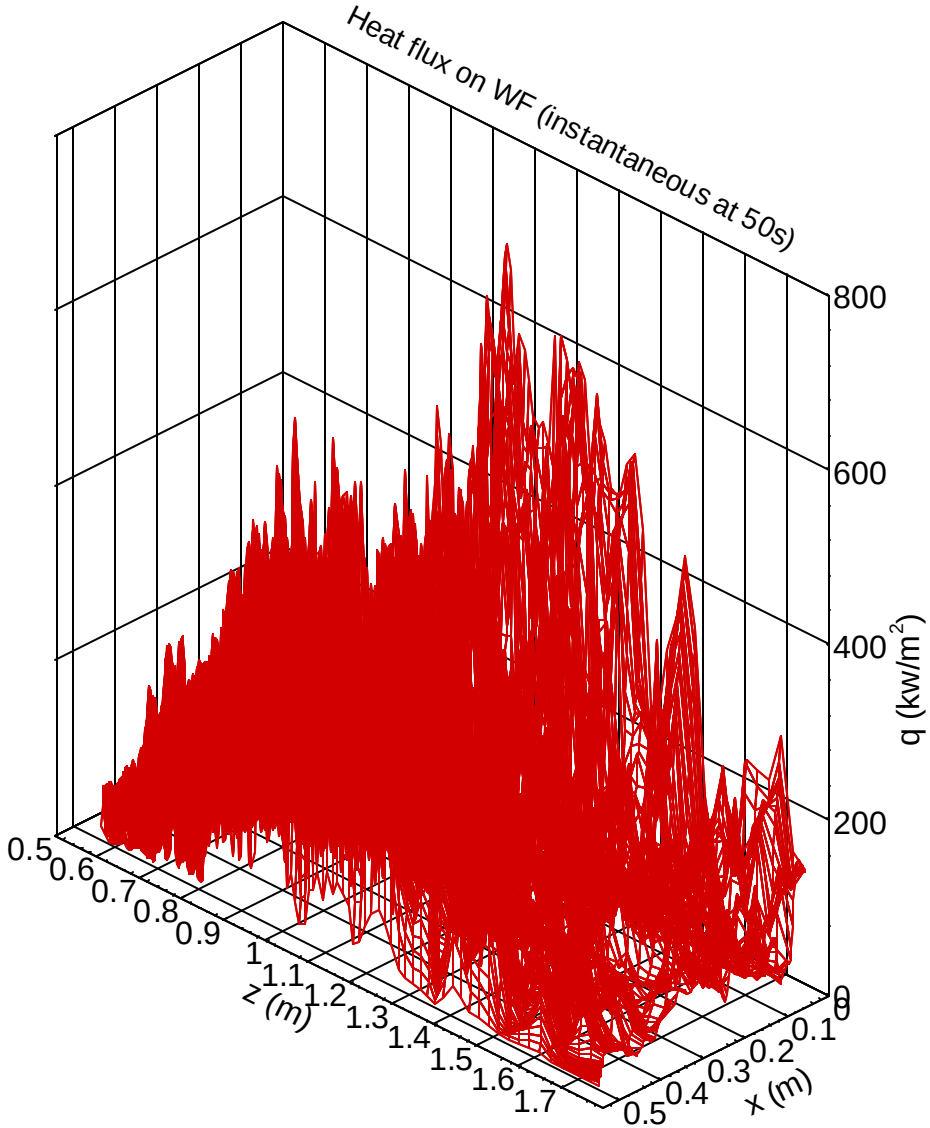
Instantaneous velocity field at 50s

Dye injection experiment by R. O'Malley (Armco, Inc)

Instantaneous heat flux on narrow face

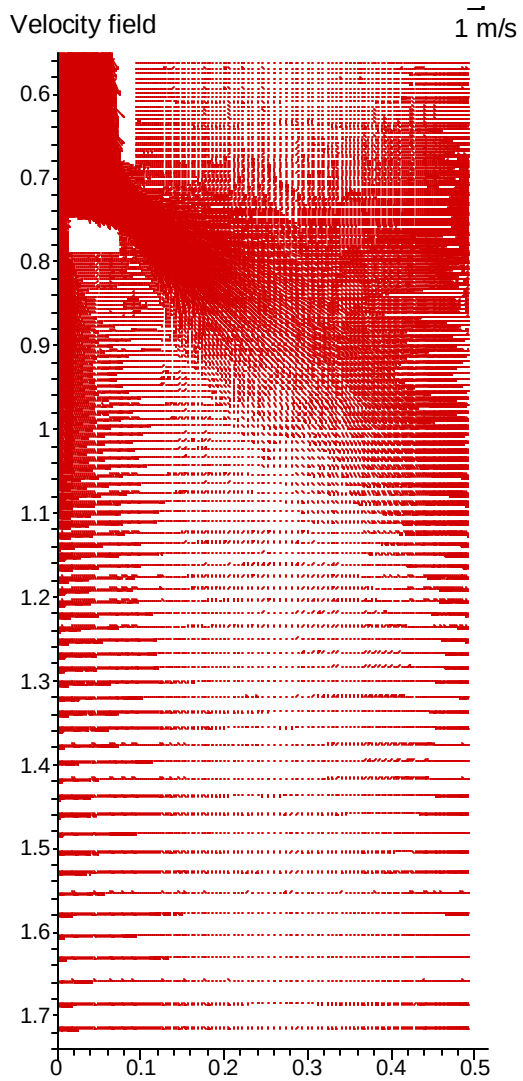


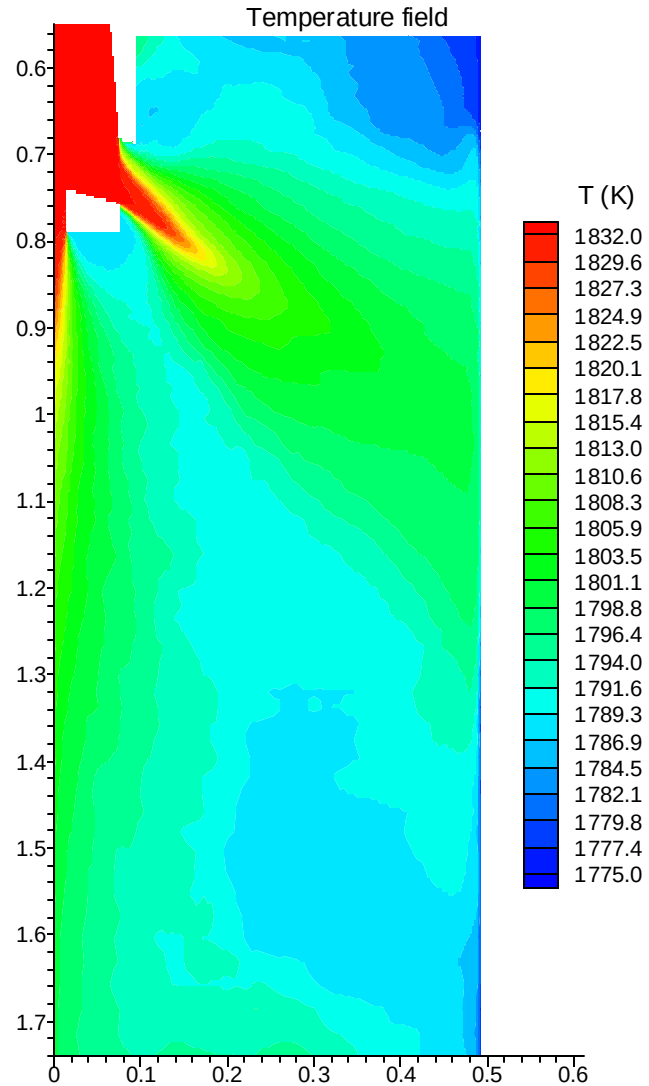
Instantaneous heat flux on wide face



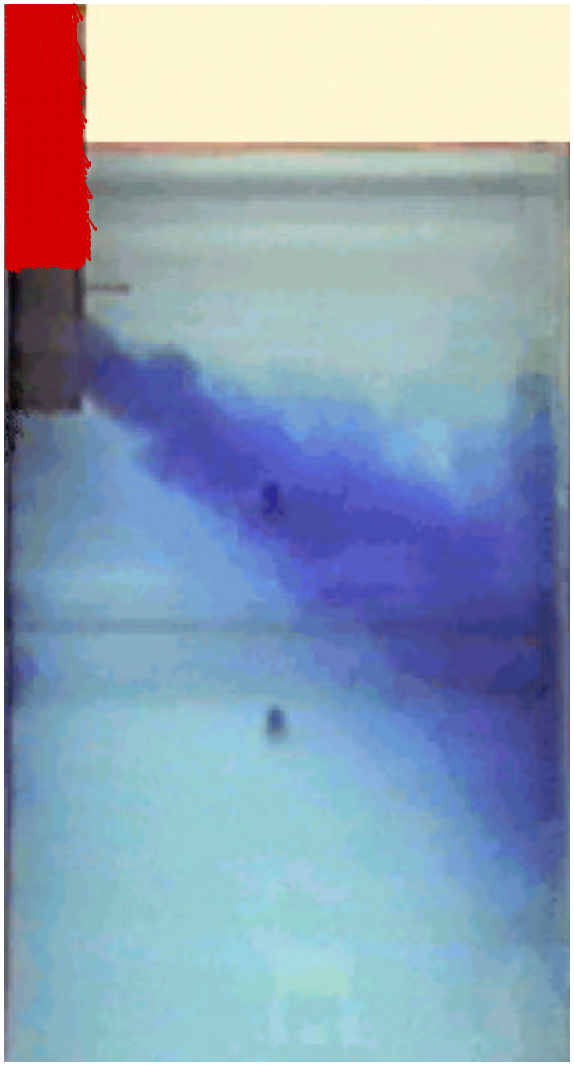
Time-averaged fields

(averaged from 30s to 50s)





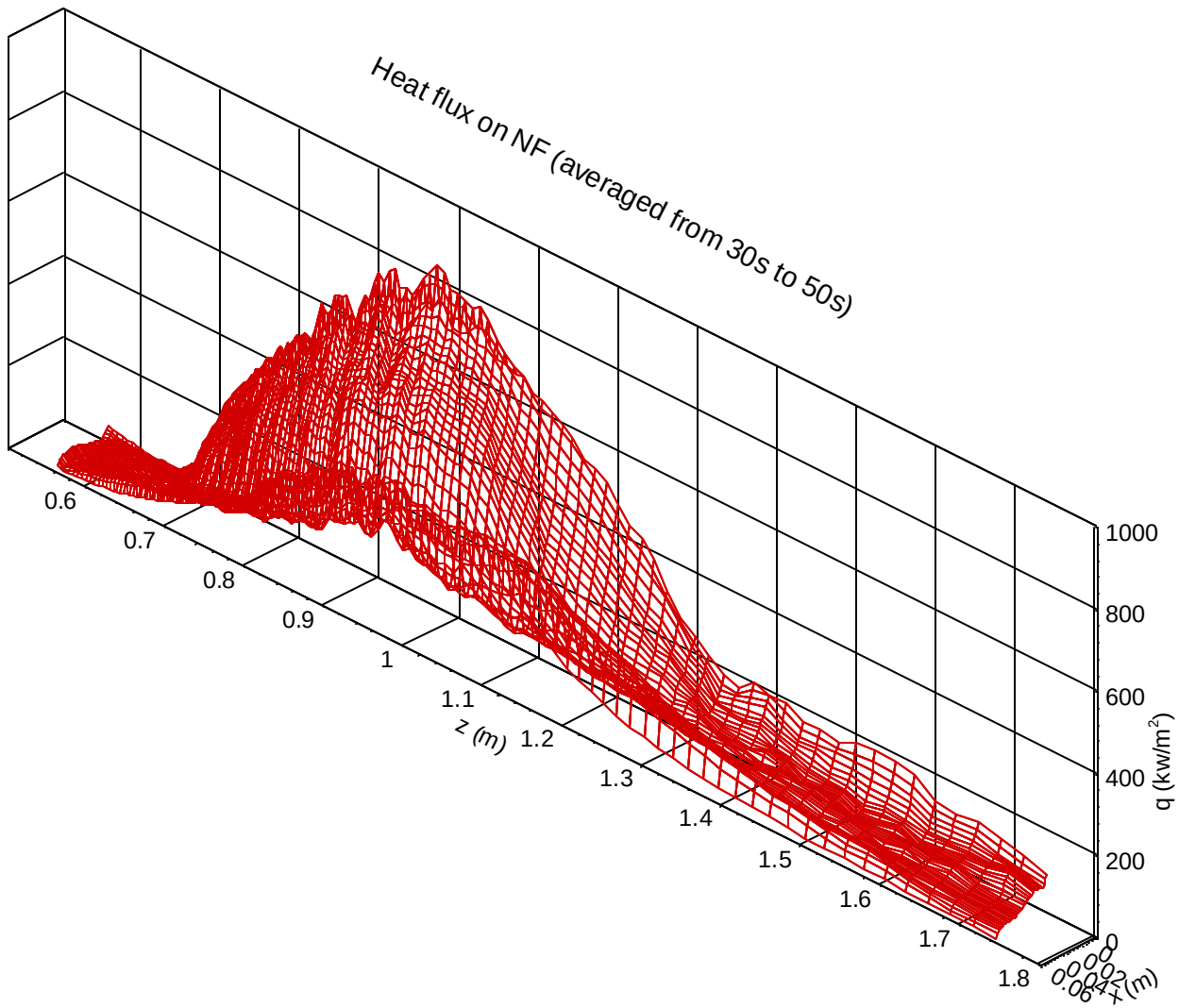
Time-averaged velocity vs. dye-injection experiment



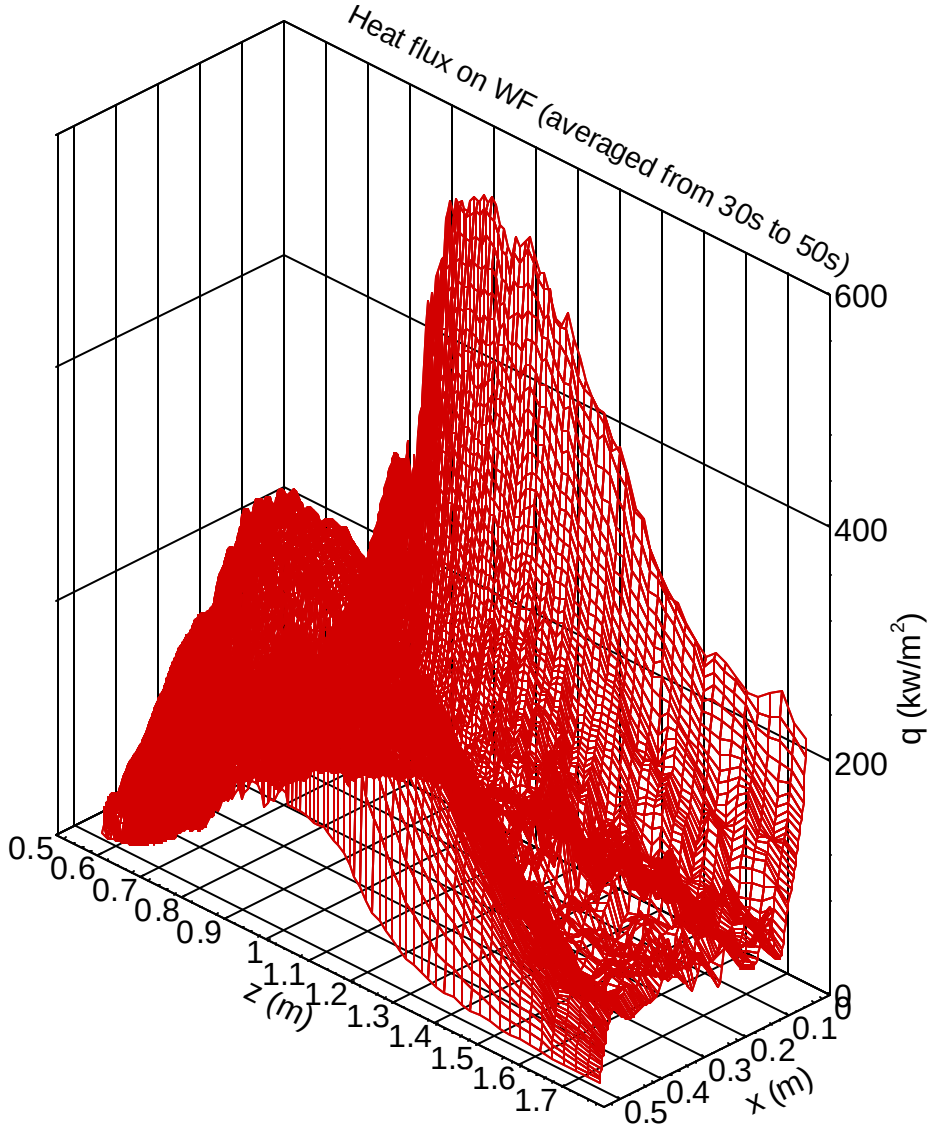
Velocity field averaged from 30s to 50s

Dye injection experiment by R. O'Malley (Armco, Inc)

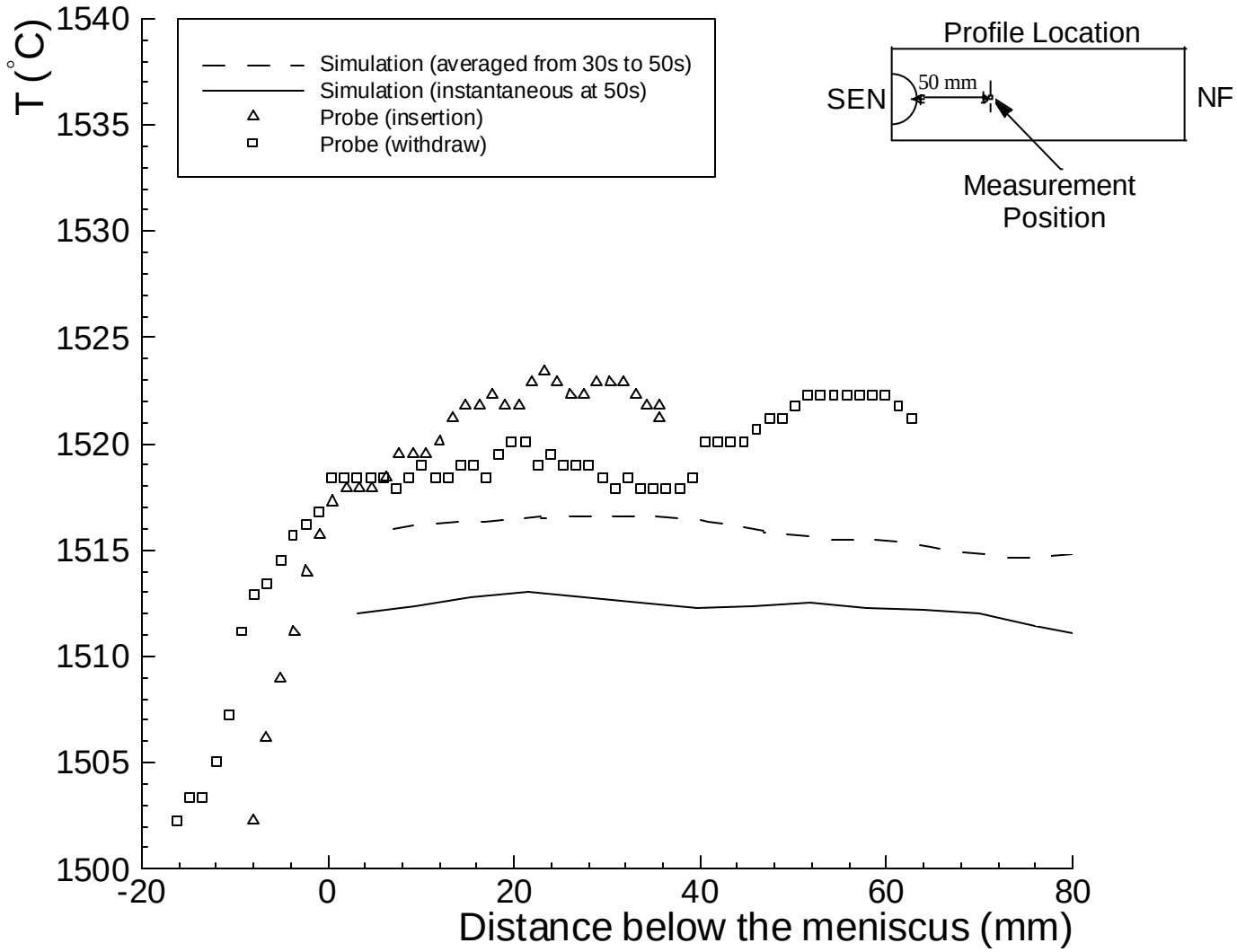
Time-averaged heat flux on narrow face



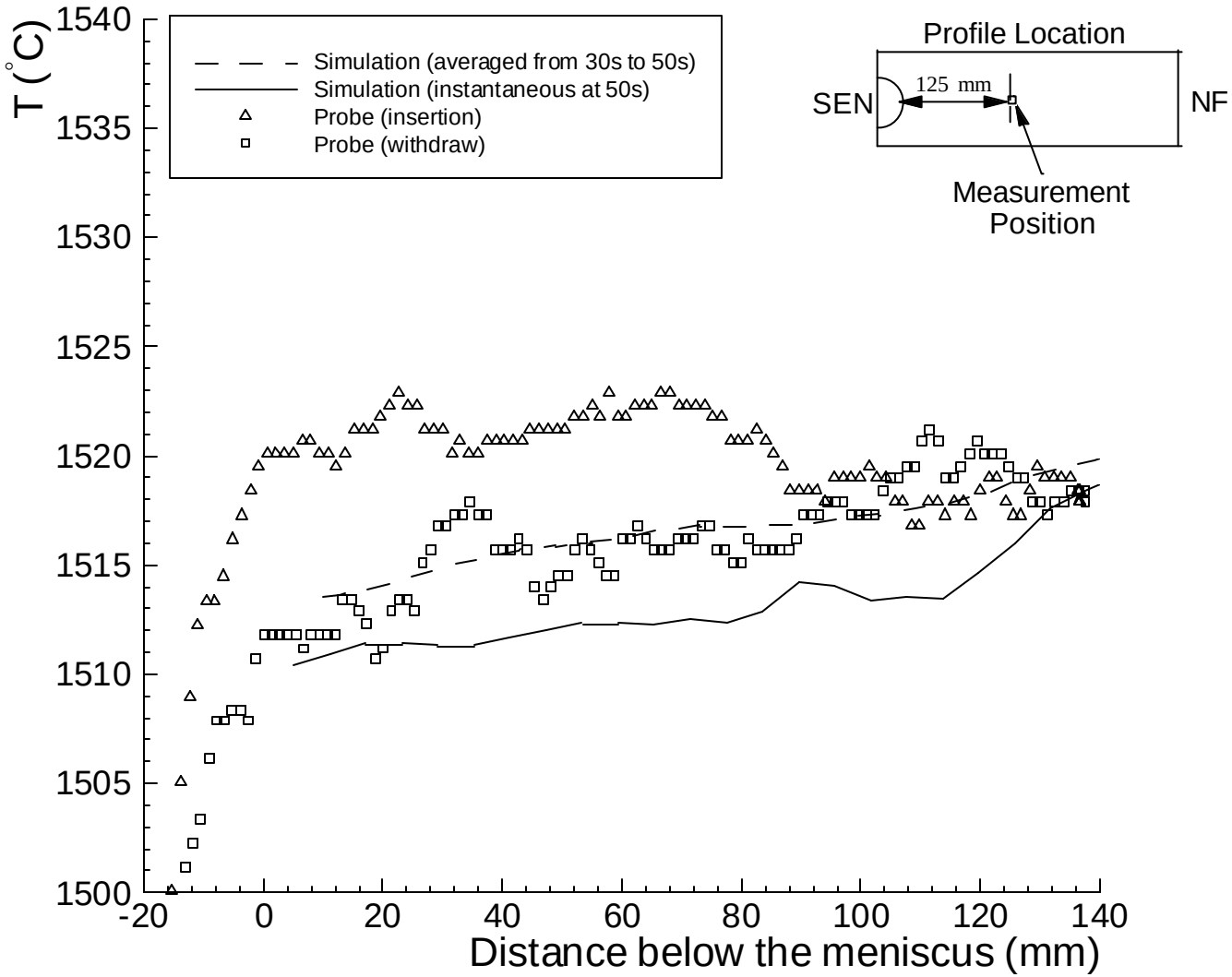
Time-averaged heat flux on wide face



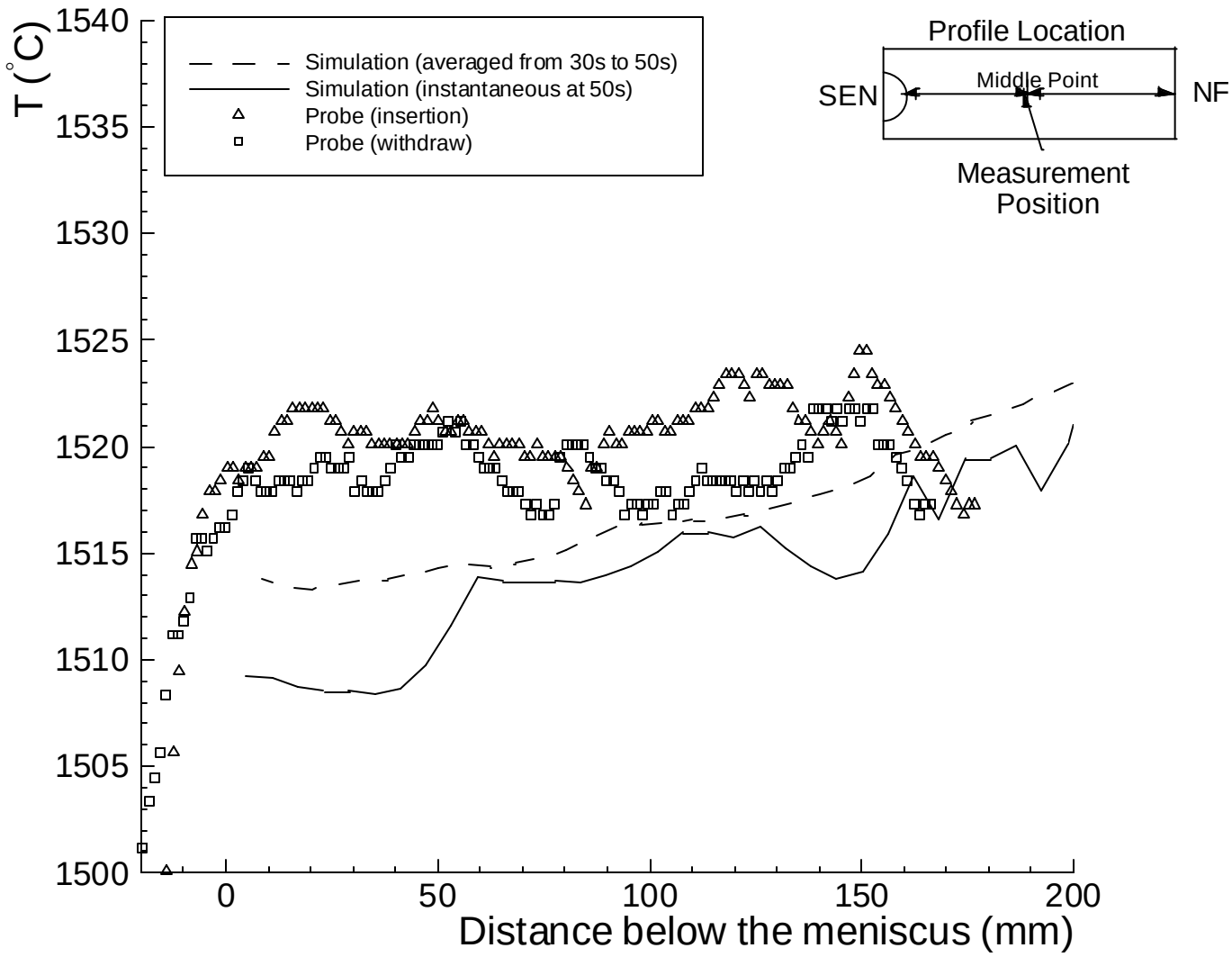
Temperature comparison (I)



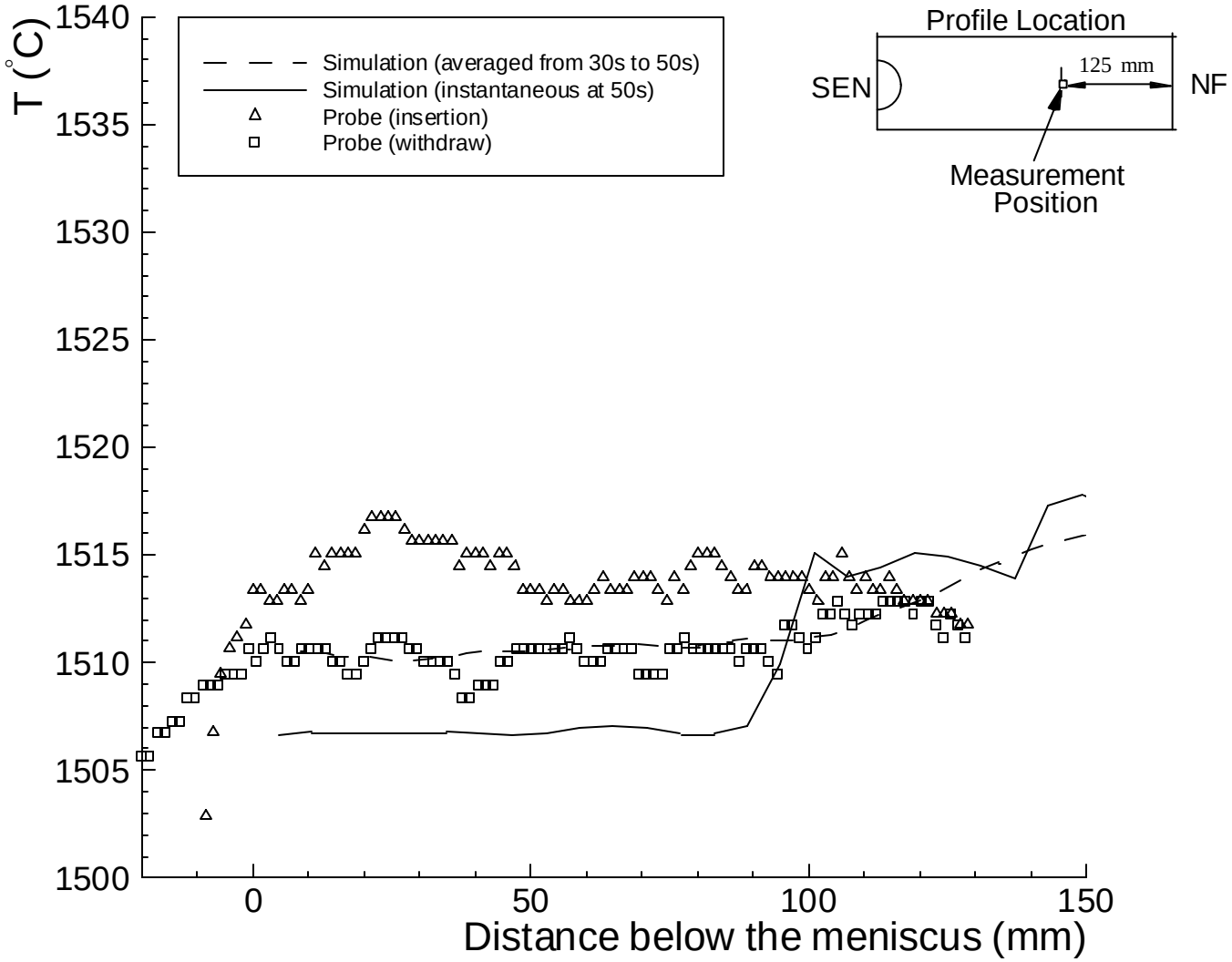
Temperature comparison (II)



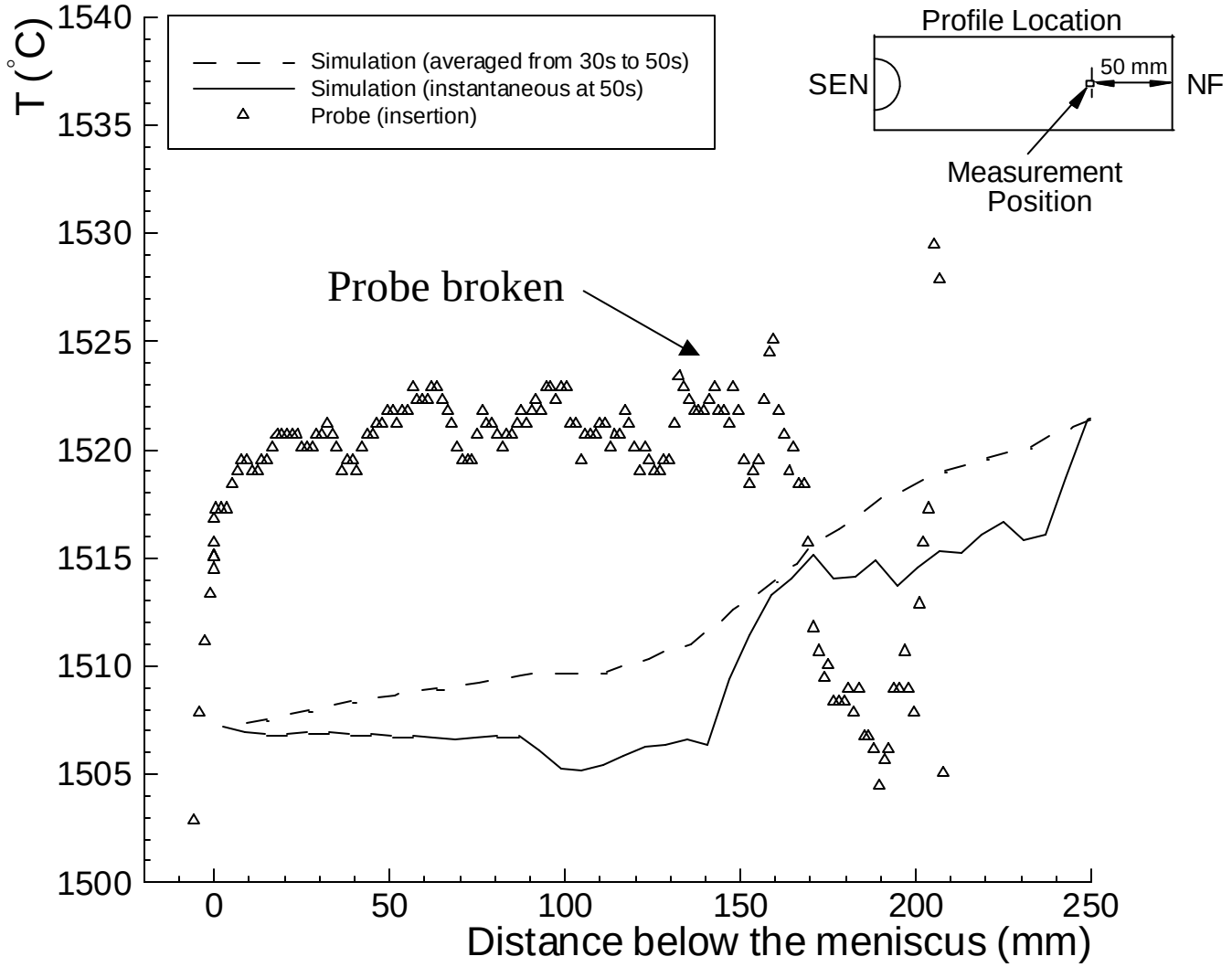
Temperature comparison (III)



Temperature comparison (IV)



Temperature comparison (V)



Observations

- NF heat flux may be a little lower than reality .
- Heat flux peak at NF impingement is 800 kw/m^2, instantaneously reaches 1,300 kw/m^2; peak at small jet impingement point on WF is 500 kw/m^2 , instantaneously reaches 700 kw/m^2 .
- No upper roll in the flow field.
- Temperature in the upper corner region is too low.
- Jed diffuse a lot in the vertical direction, resulting in weak impingement and low NF heat flux.

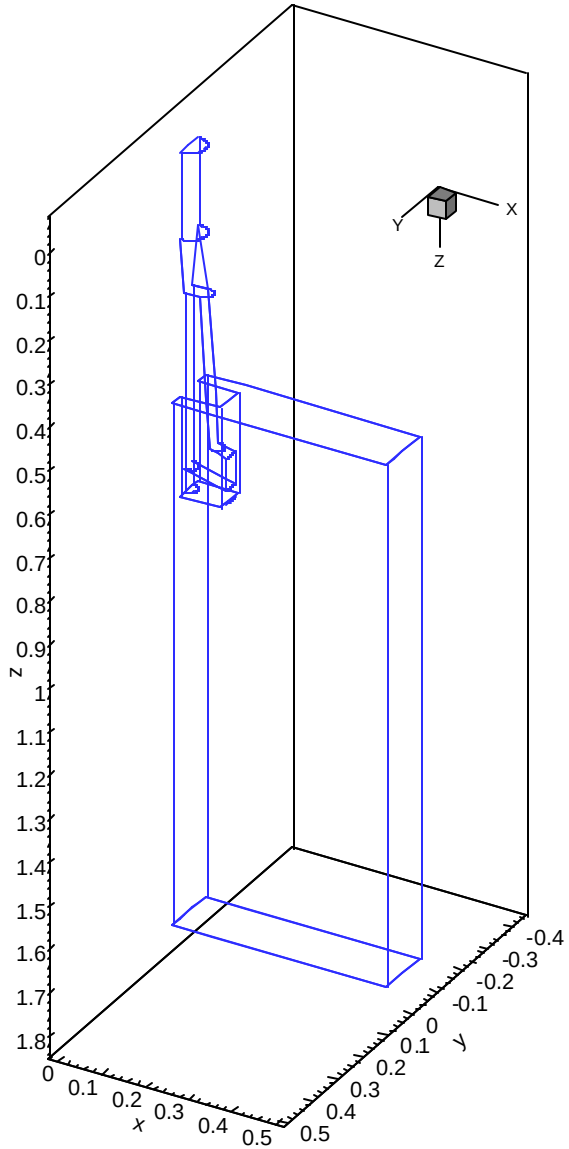
Simulation of Fluid Flow and Heat Transfer in the AK Steel Thin Slab Mold

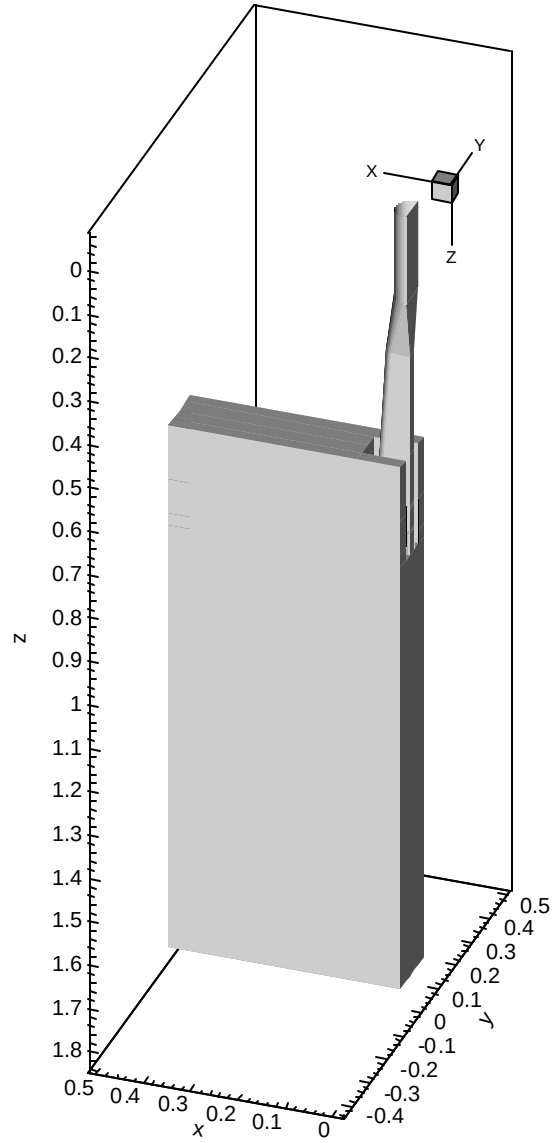
½ mold simulation

Computational details

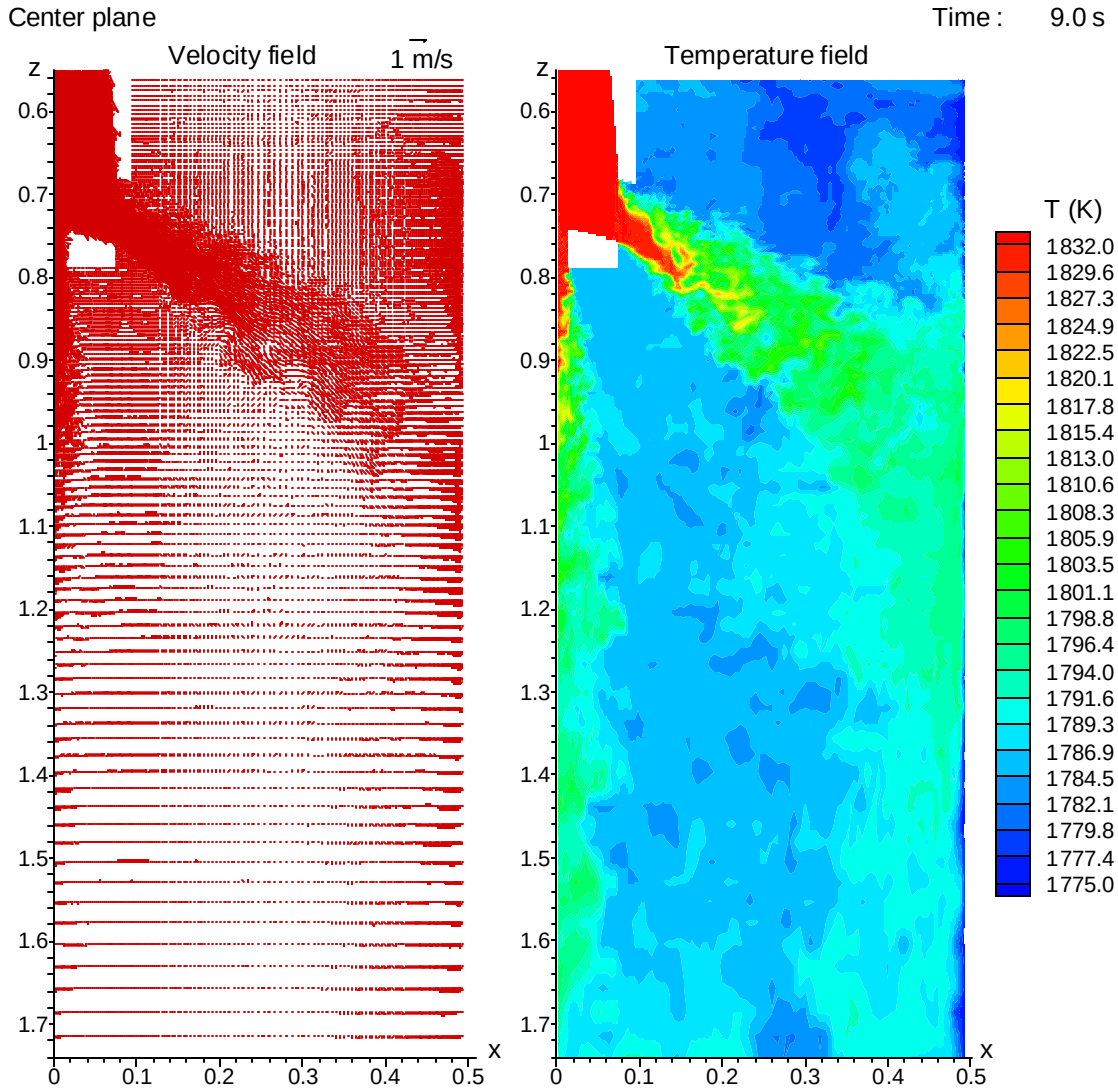
- Mesh: doubled (reflected) ¼ mold domain & mesh.
- 1,651,710 finite volume cells.
- Use the result of ¼ mold simulation as initial condition.
- Other parameters and conditions are identical to the ¼ mold simulation.

Simulation domain

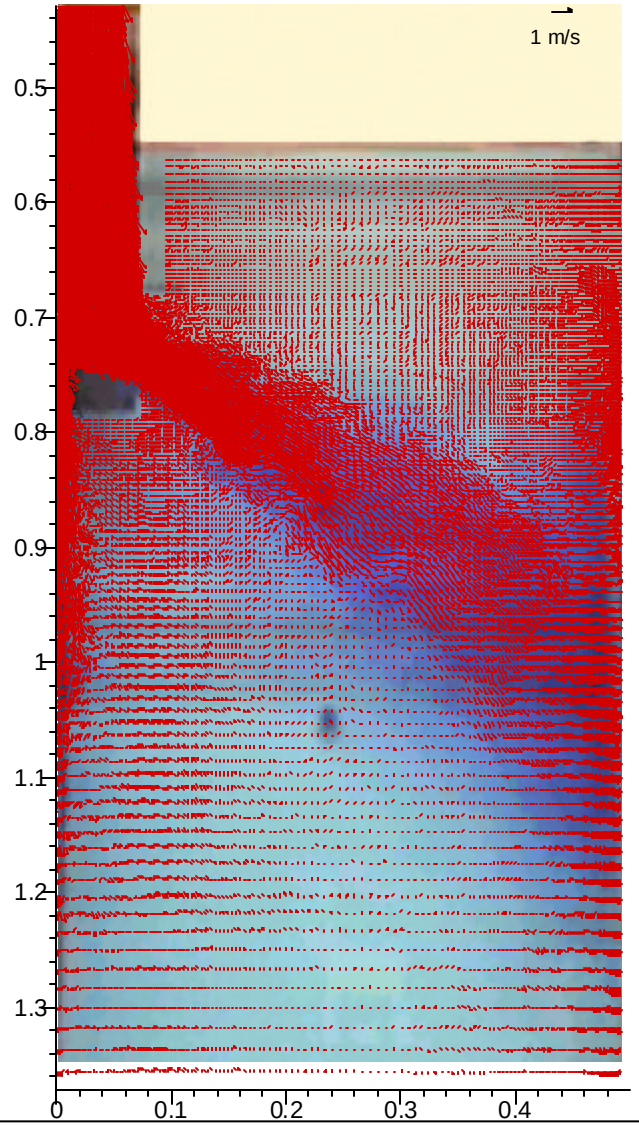




Instantaneous velocity and temperature



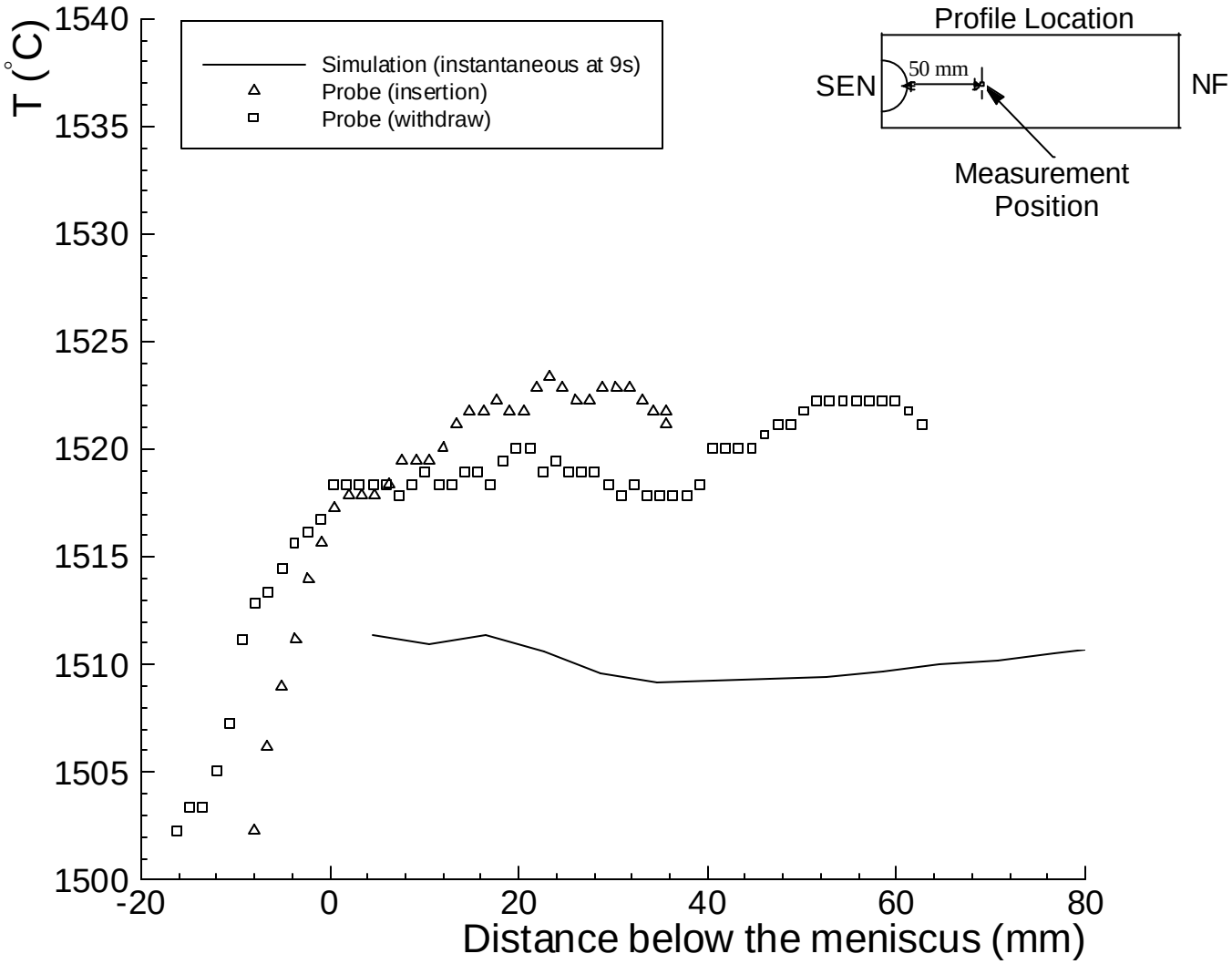
Instantaneous velocity field v.s. dye injection experiment



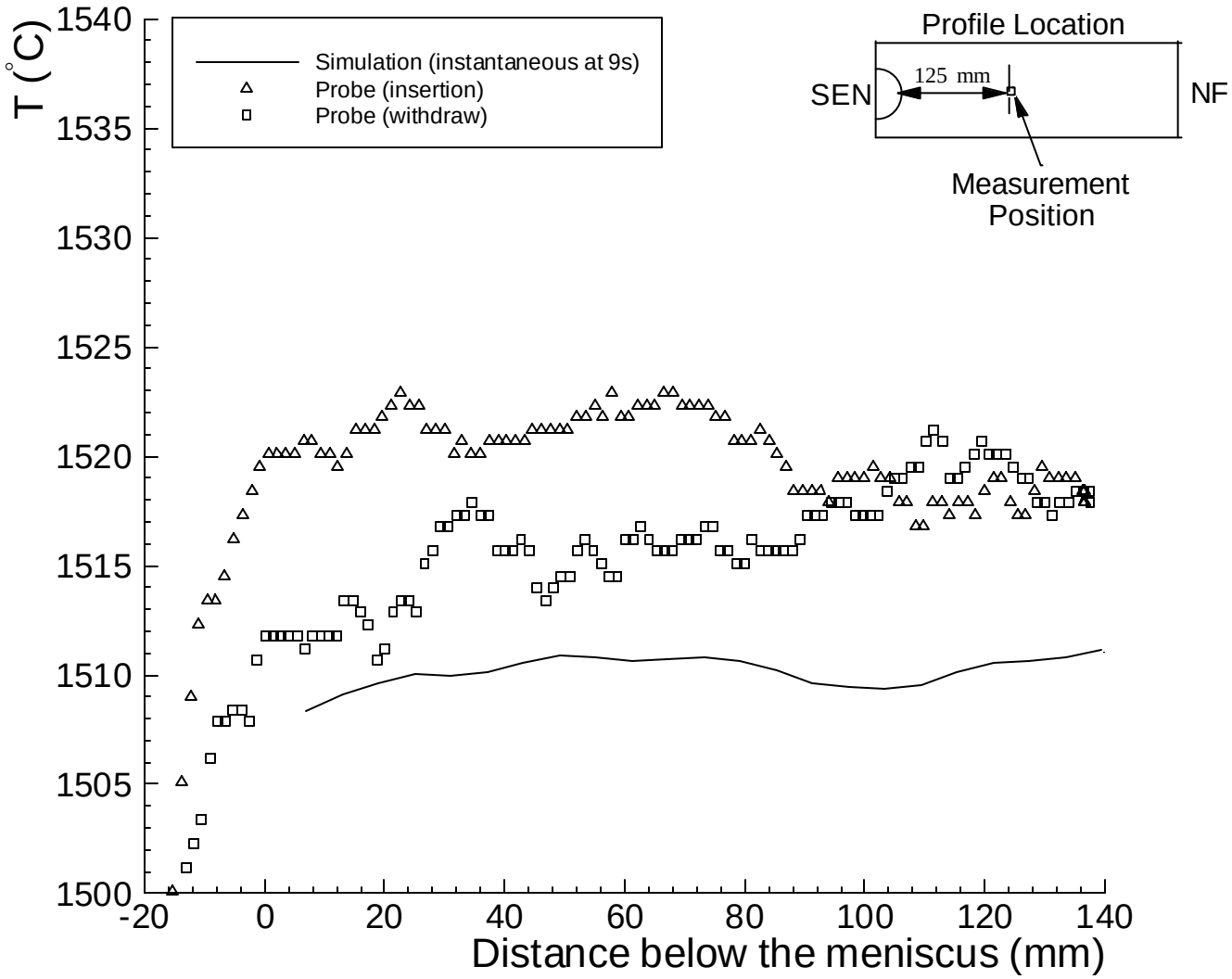
Instantaneous velocity field at 9s

Dye injection experiment by R. O'Malley (Armco, Inc)

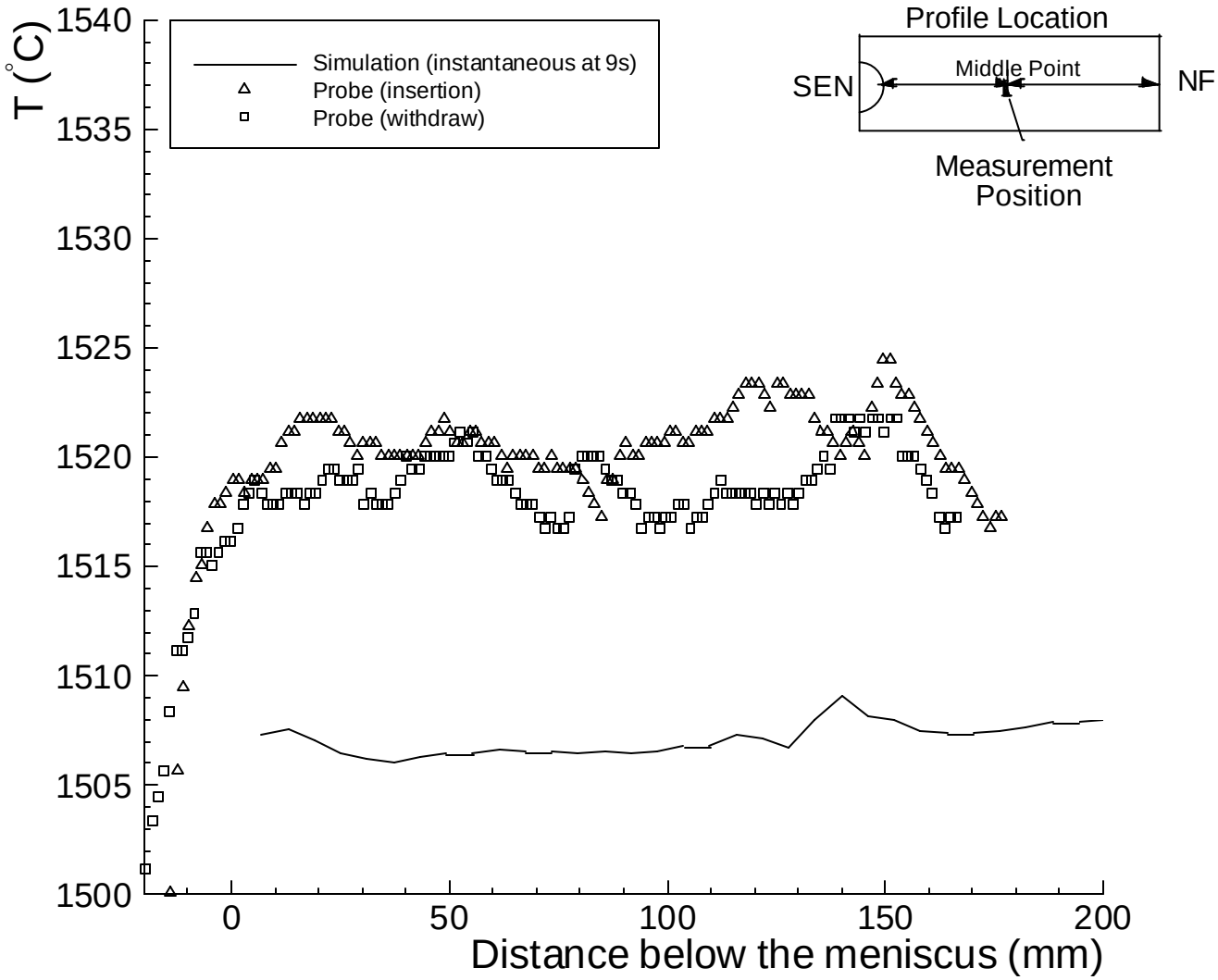
Temperature comparison (I)



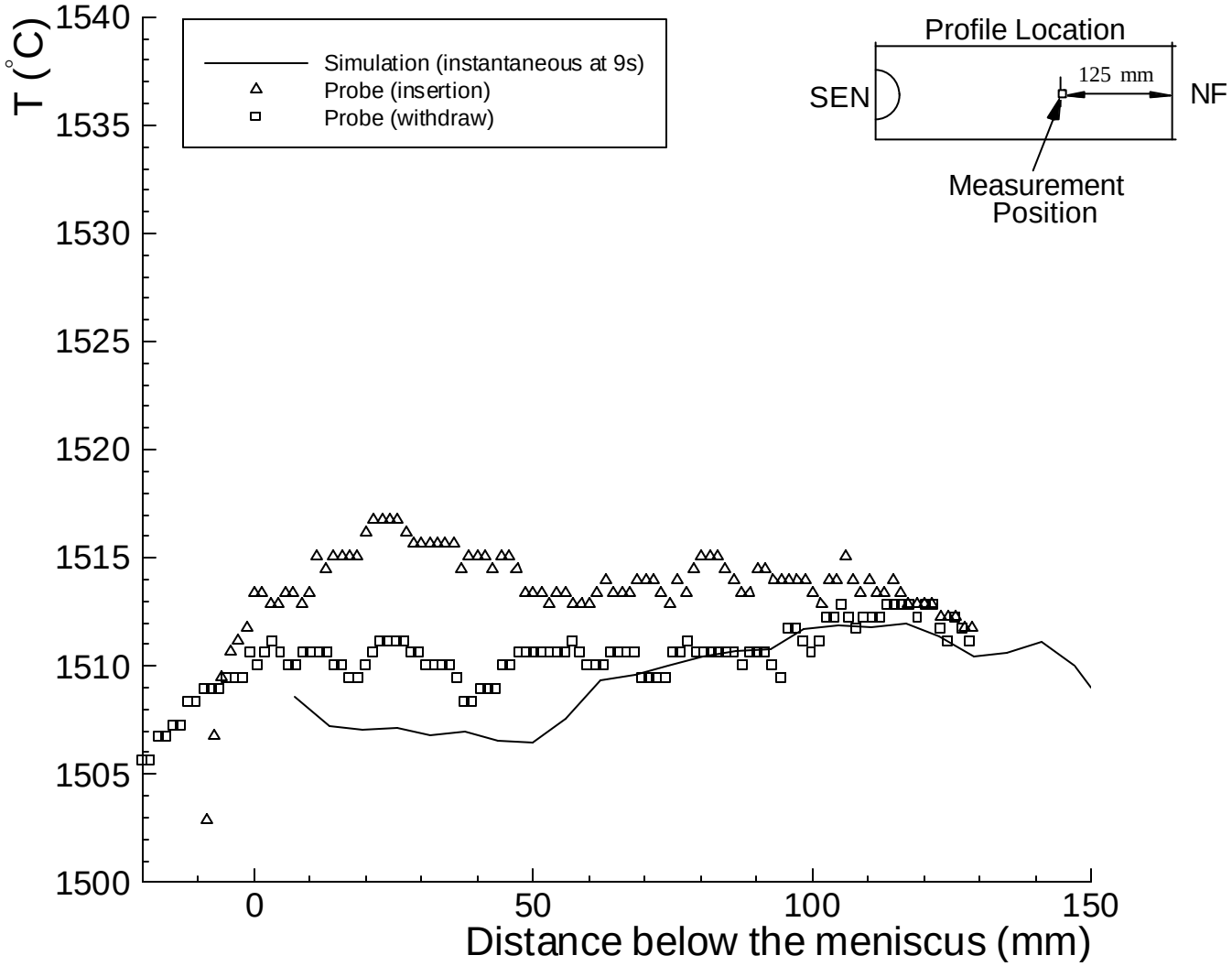
Temperature comparison (II)



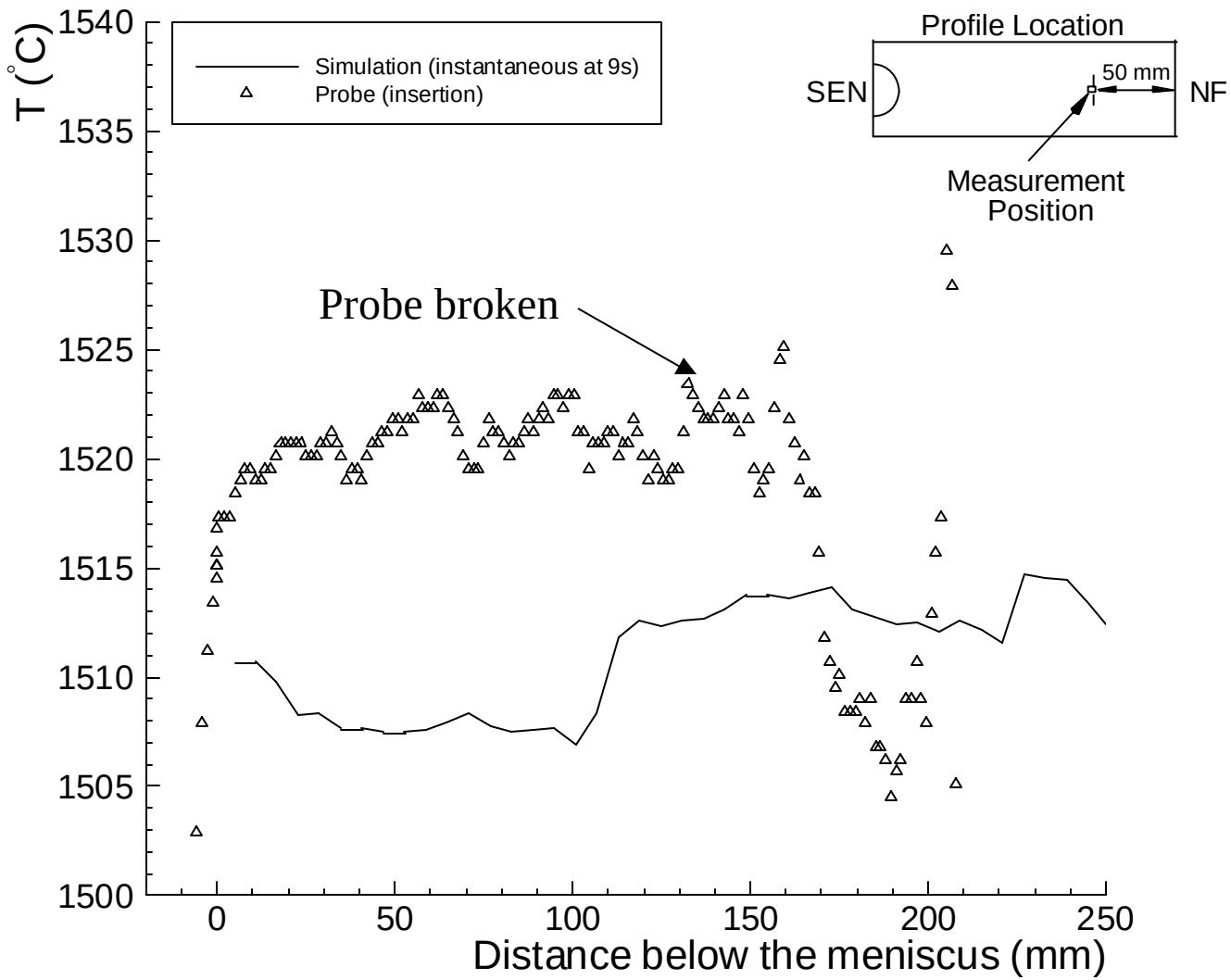
Temperature comparison (III)



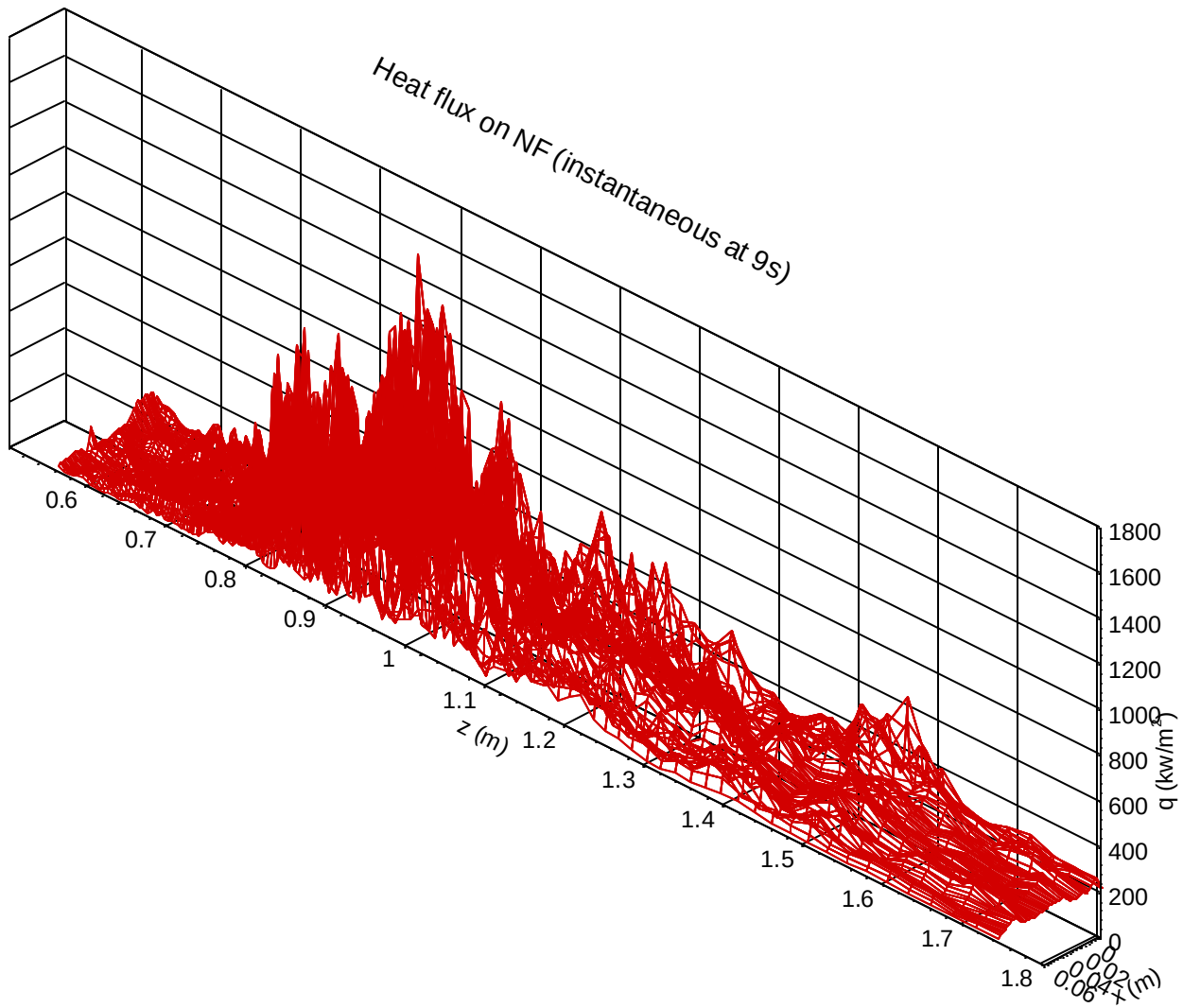
Temperature comparison (IV)



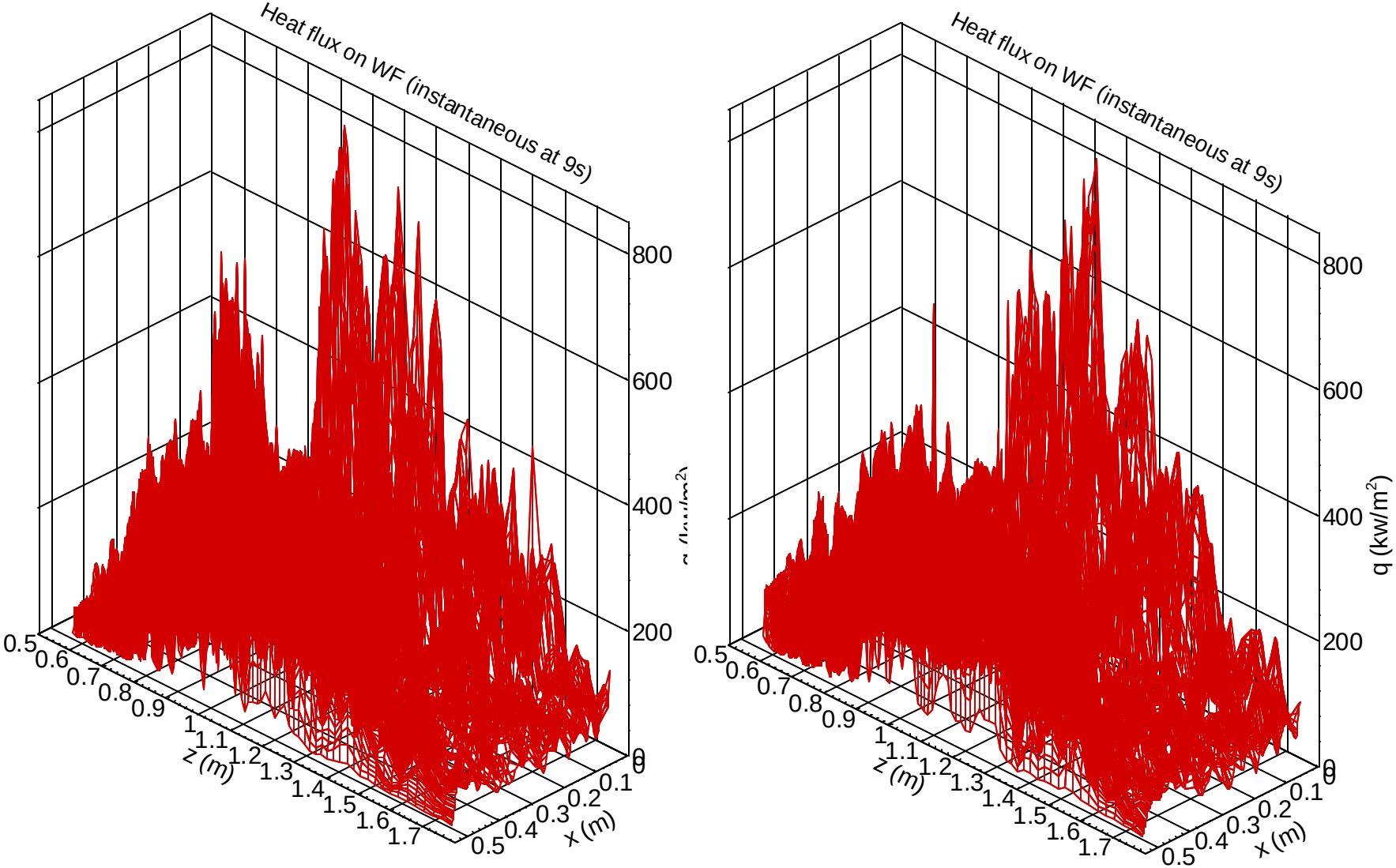
Temperature comparison (V)



Instantaneous heat flux on narrow face



Instantaneous heat flux on wide face



Observations

- The flow field now shows tendency towards an upper roll.
- The jet has less diffusion in the vertical direction compared to the ¼ mold simulation: ie. has more penetration power.
- Applying WF-WF symmetry (cutting through a jet) is inappropriate for transient simulations.

Future Work

- Continue the ½ mold simulation.
- Add shell shape into the simulation.
- Investigate thermal buoyancy