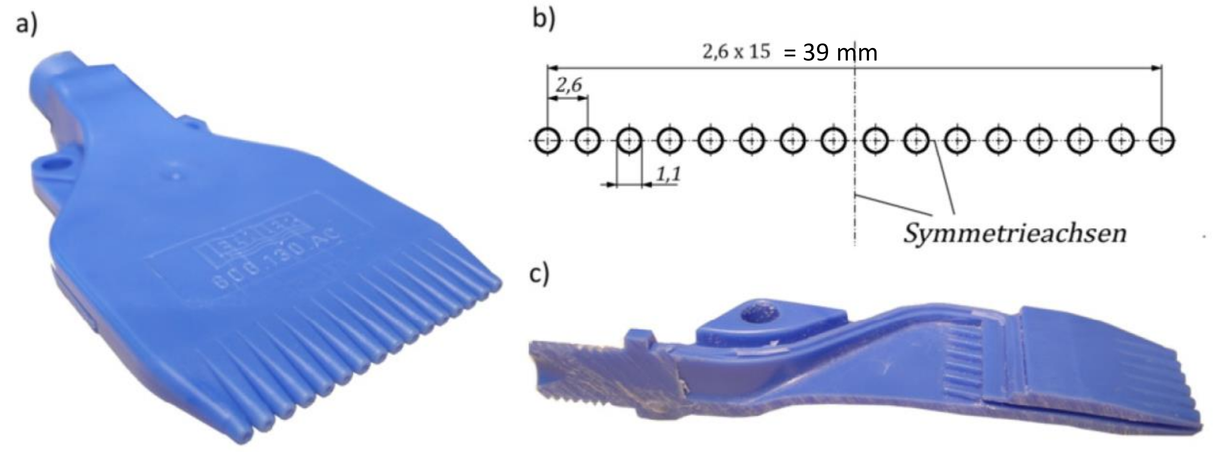
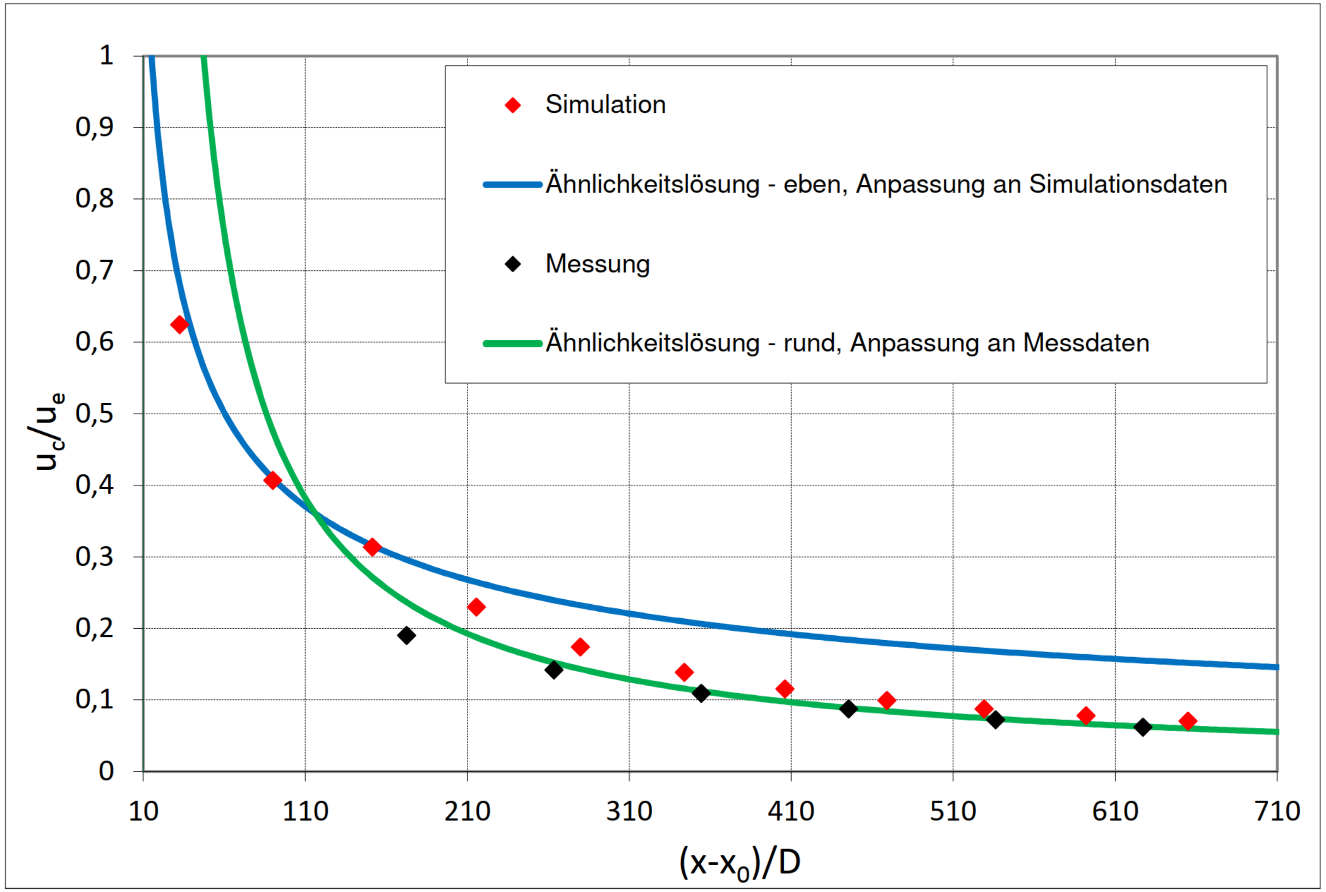
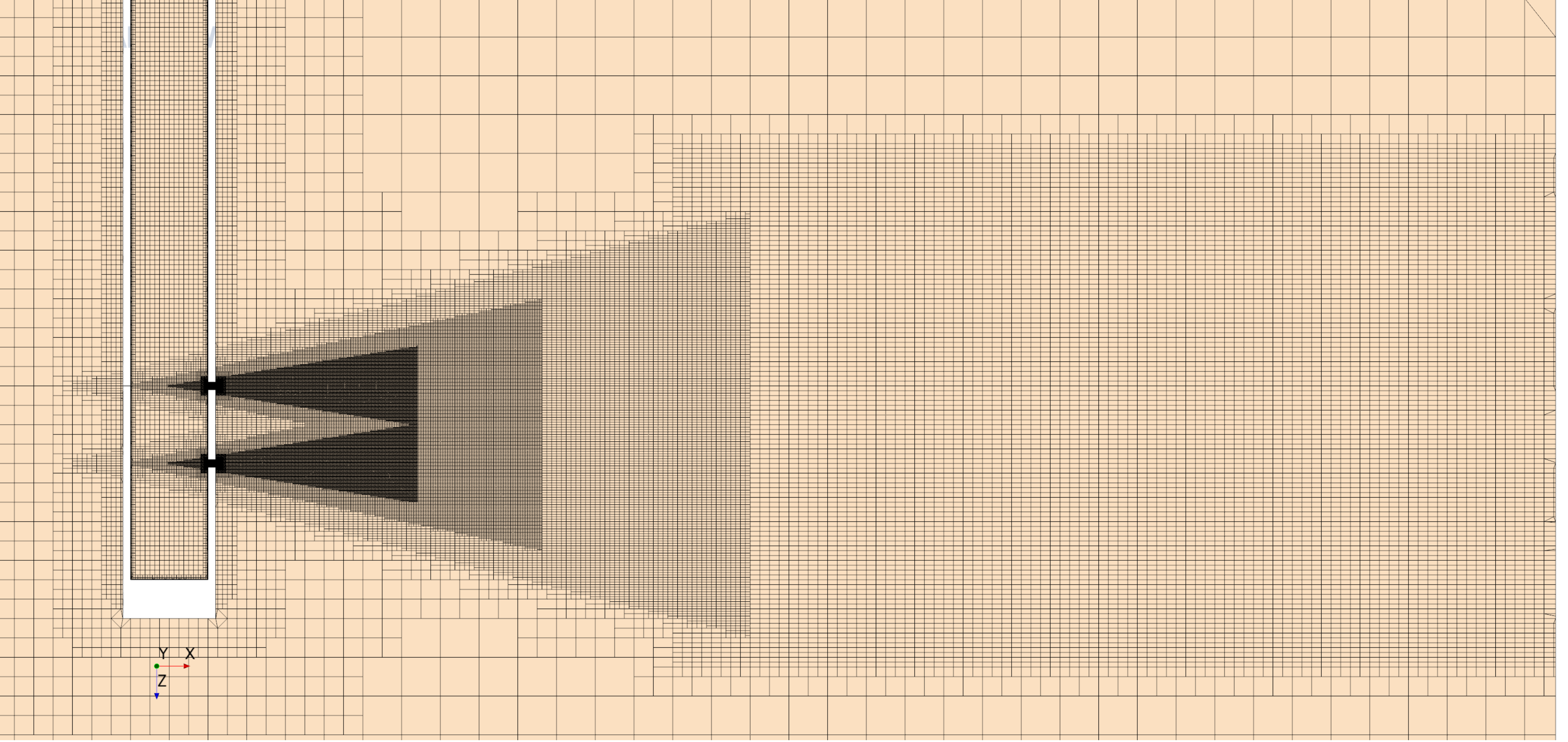


Flat jet can also be created by using many round jets; in car paint drying, such a nozzle consists of round holes with a diameter of 1.1 mm and a distance between hole centers of 2.6 mm; see Fig. 3.3 in Diploma Thesis by N. Kovjenic, TU Graz, 2012.

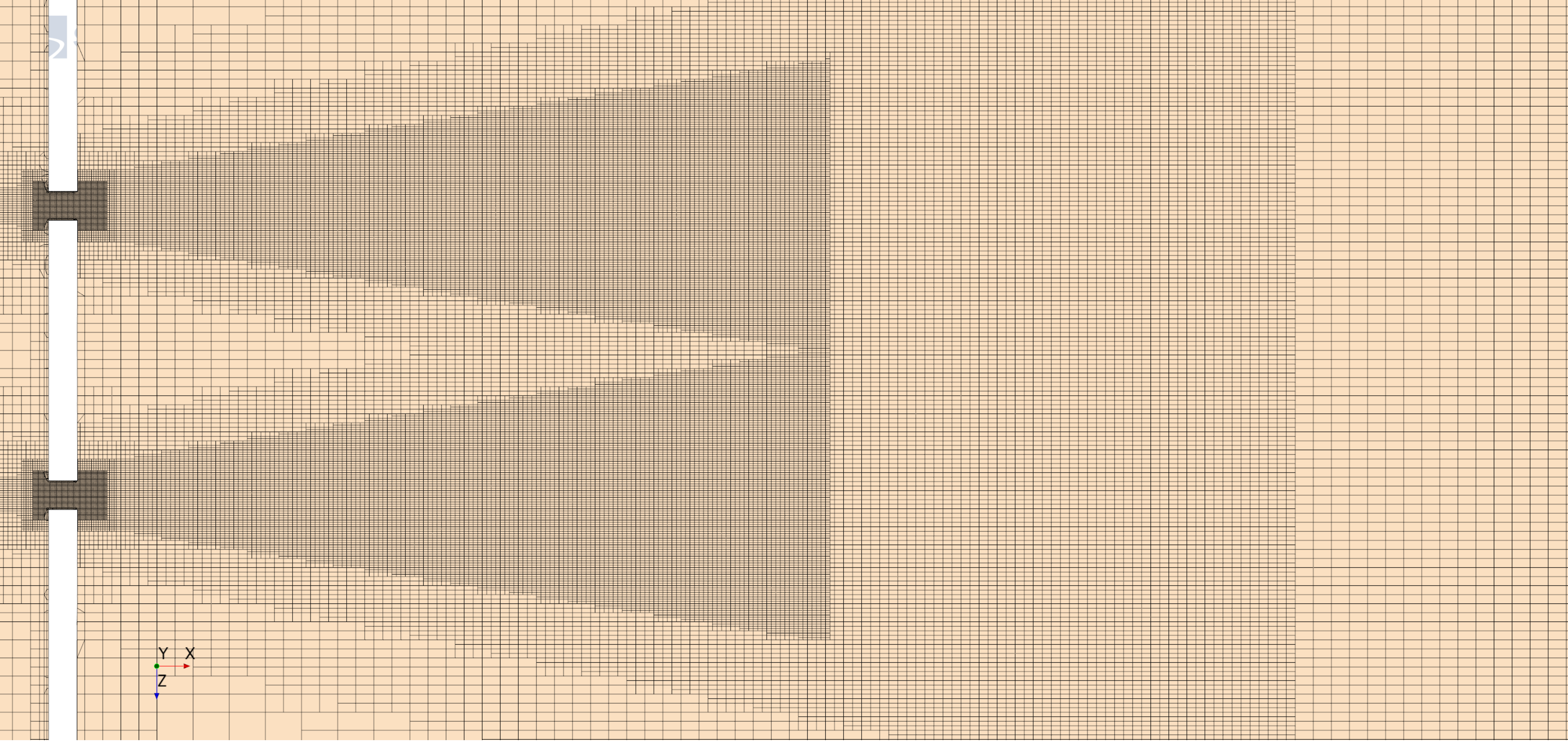


Measured variation of centerline velocity in a free plane jet from the above nozzle (back pressure 6 bar); see Fig. 5.10 in Diploma Thesis by N. Kovjenic, TU Graz, 2012. Up to a distance of ca. 150 D (ca. 165 mm) downstream of nozzle outlet, the velocity variation follows the shape expected of a plane jet; further downstream it behaves like a round jet. This is due to the finite width of the nozzle (initial jet width: B = 40,1 mm): at some distance the yet becomes round… Here it happened at ca. $x = 4B$.

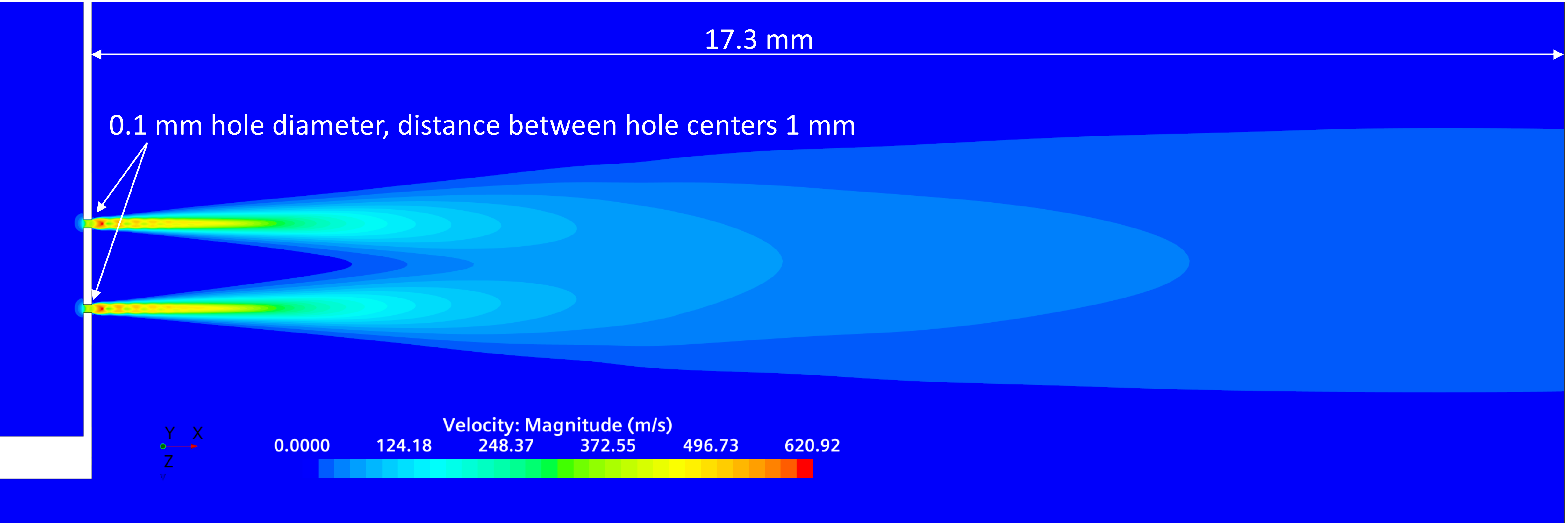
For a nozzle with a width of B = 200 mm and slot height of 0.5 to 1 mm, one can expect that the jet will be “flat” for ca. 400 mm and turn to round at ca. 800 mm distance from nozzle.



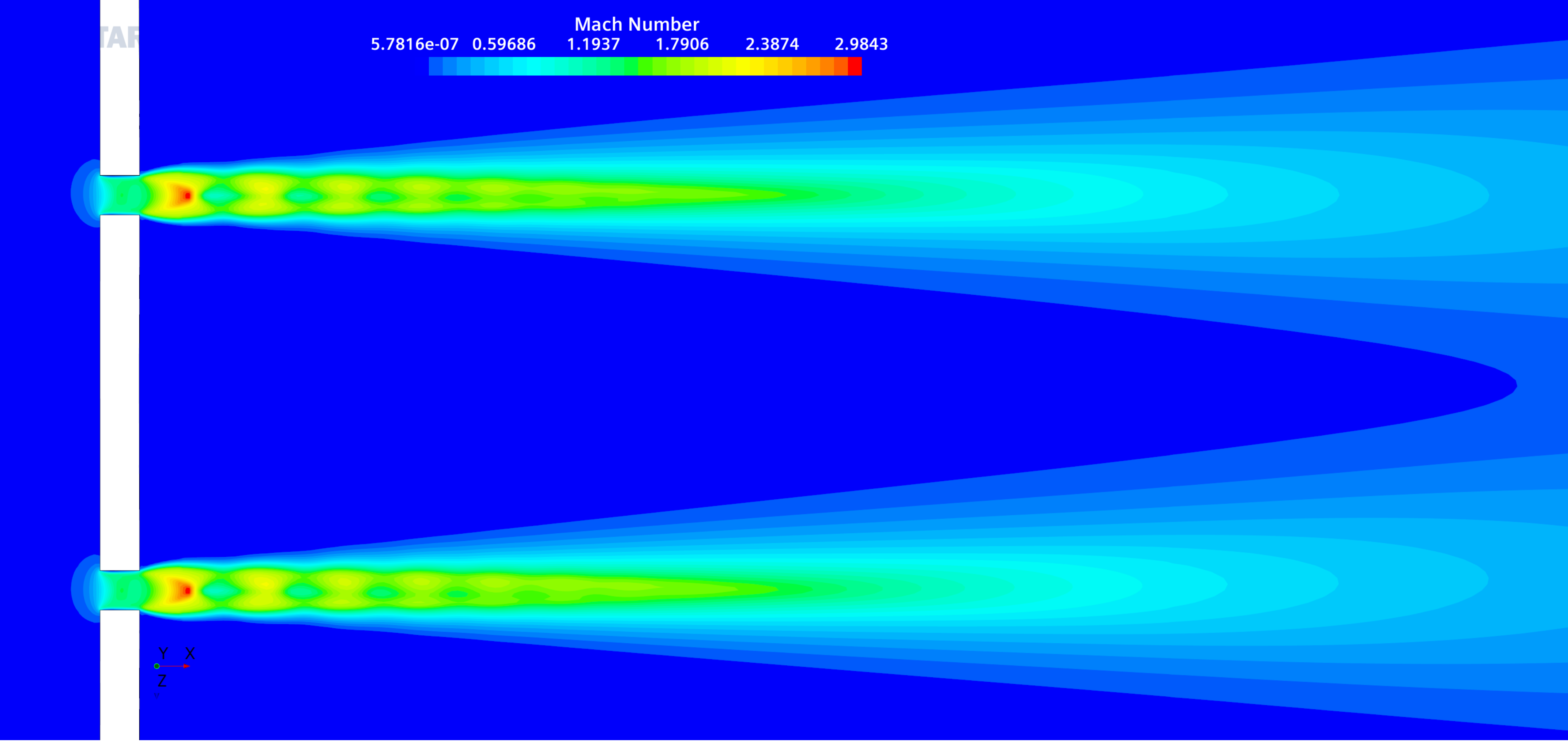
Simulations are performed for the following configuration: pipe inner diameter: 1 mm; two holes with a diameter of 0,1 mm, 1 mm distance; back pressure in pipe (total pressure at pipe inlet): 5 bar above atmospheric. The solution domain is larger than the figure; the outlet is 17.3 mm downstream of holes.



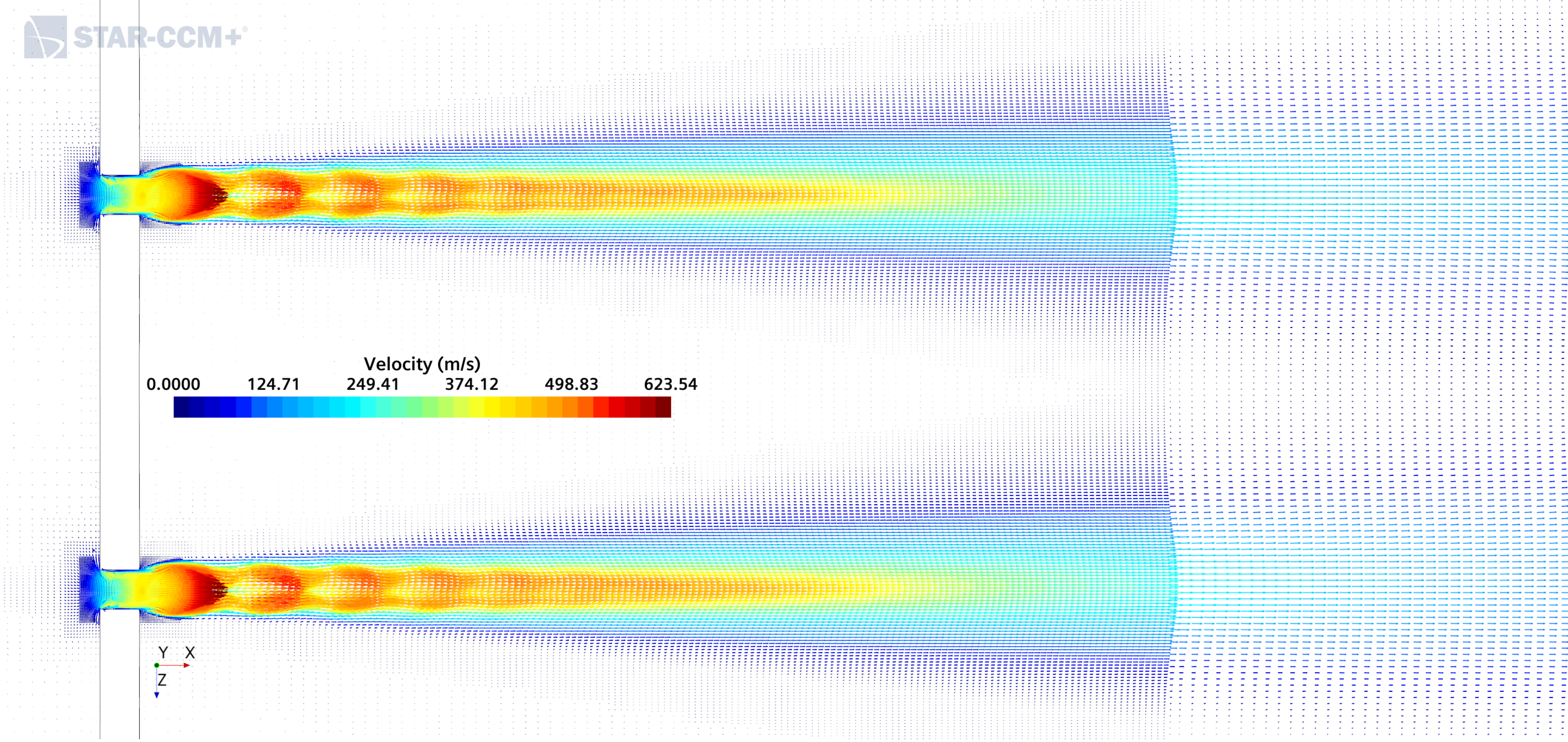
Local grid refinement around holes, in order to better resolve jet development. Total number of cells: ca. 6 million. First a steady-state solution of Reynolds-averaged Navier-Stokes equations is obtained; then the simulation was switched to LES-mode, in order to visualize the unsteady nature of the jets.



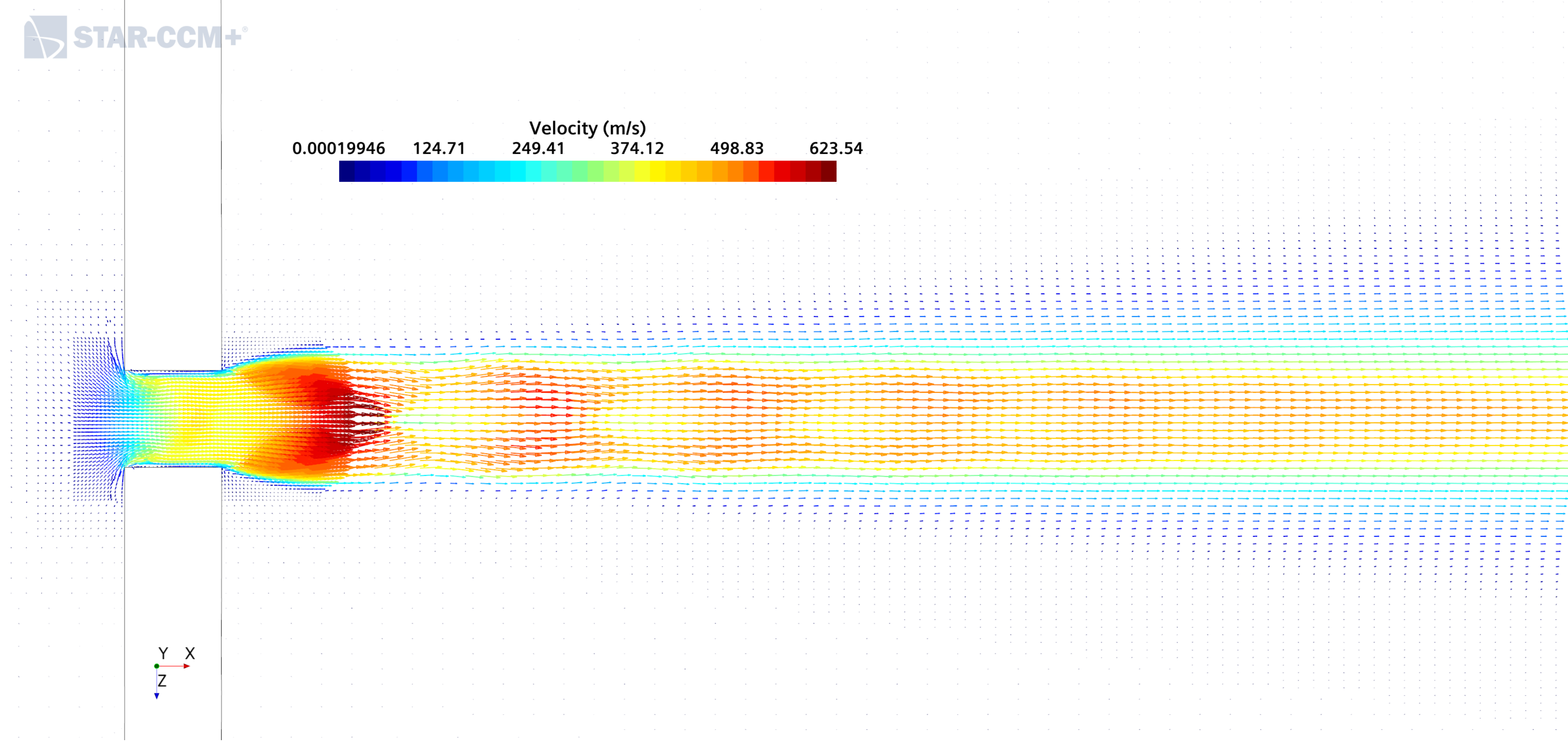
Velocity filed, solution of Reynolds-averaged Navier-Stokes equations, lag EB k-ε turbulence model: the maximum velocity is around 620 m/s, while the velocity at outlet (17.3 mm downstream of nozzle, i.e. 173 diameters downstream) the velocity is around 29 m/s.



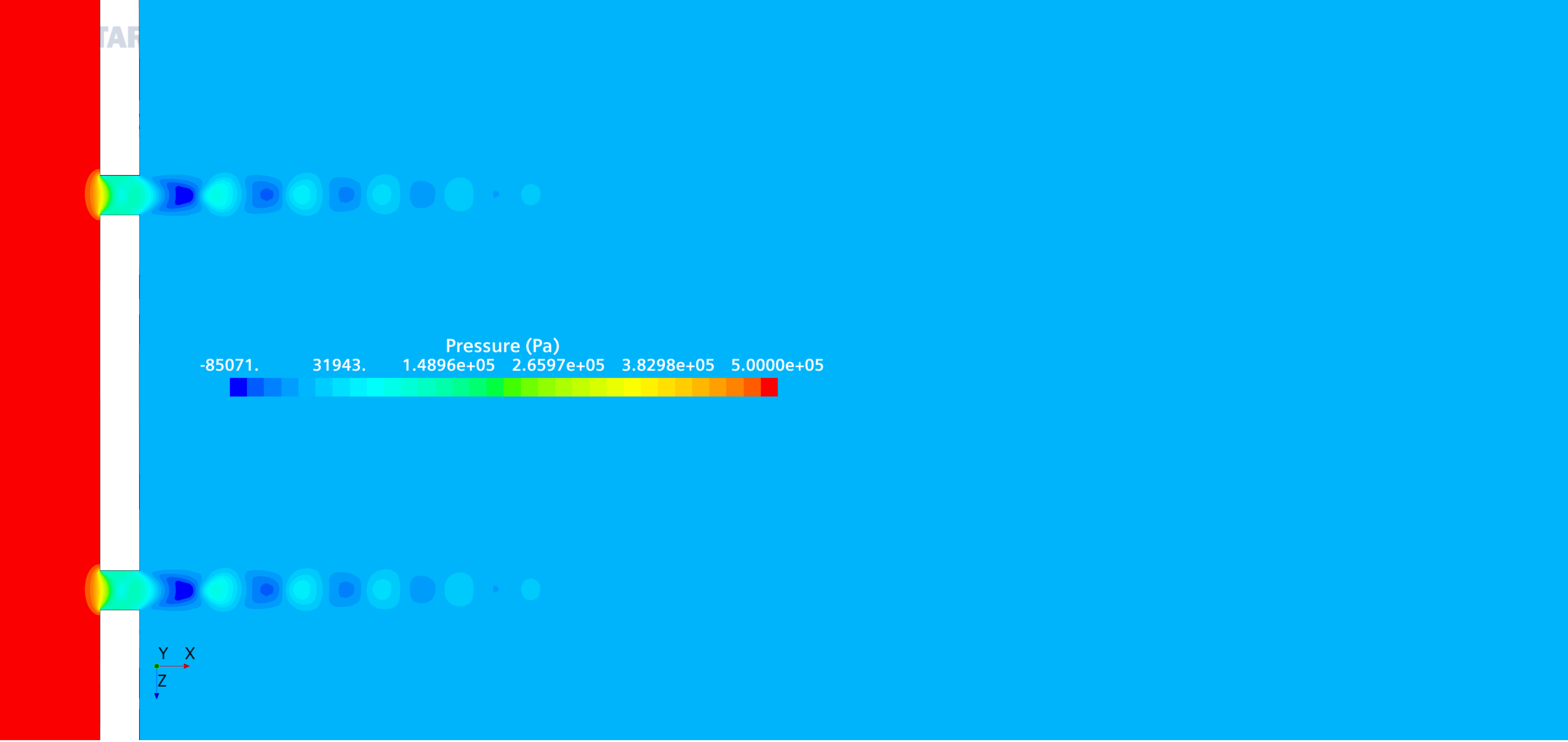
Distribution of Mach number in a section through jets up to ca. 3.5 mm downstream of holes (solution of Reynolds-averaged Navier-Stokes equations): the maximum Mach number is around 3, while at nozzle outlet it is around 1. The bell-shaped expansion is typical for short nozzles. The solution in this part of the domain is independent of the rest of geometry…



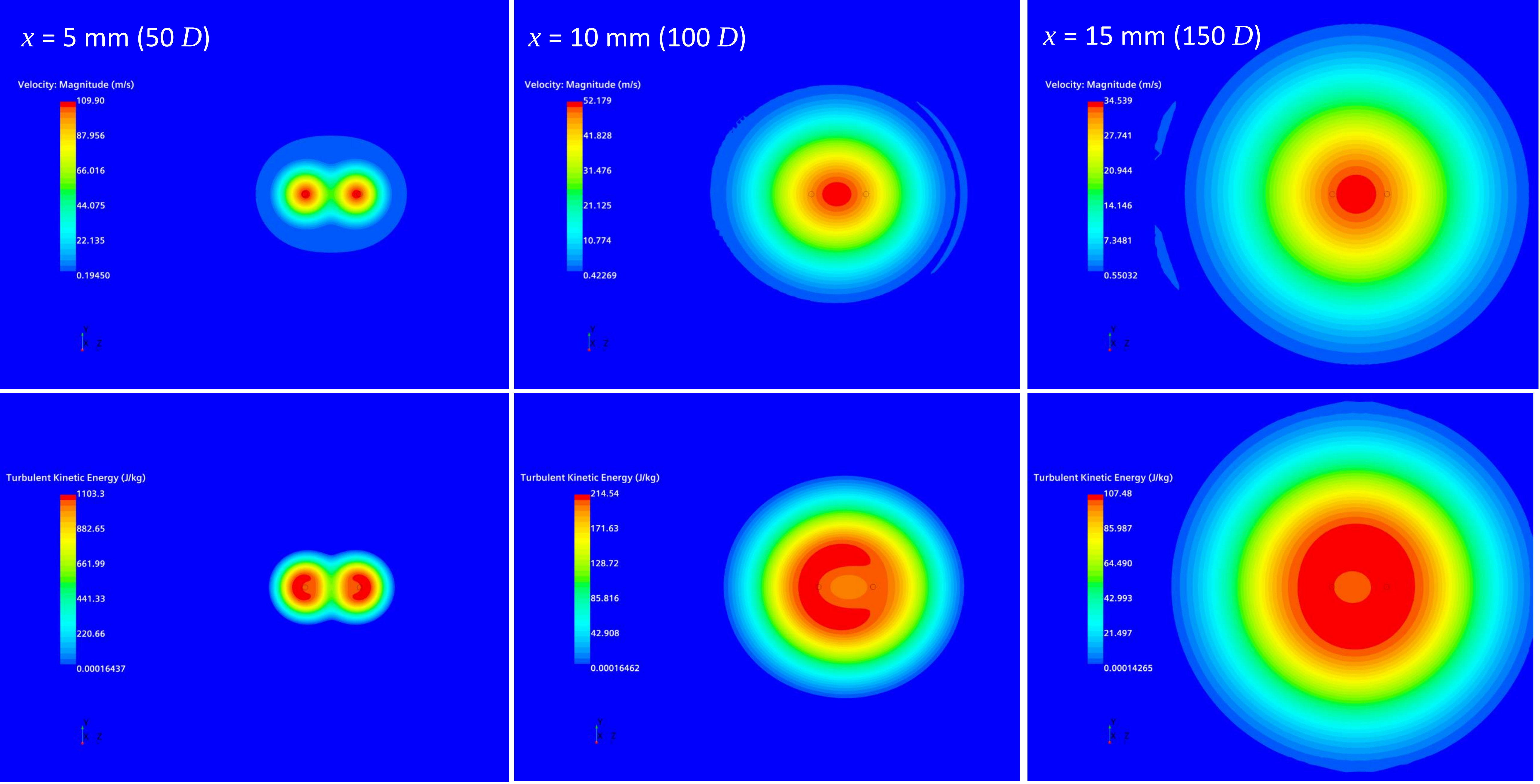
Velocity vectors in a section through jets up to ca. 3.5 mm downstream of holes (solution of Reynolds-averaged Navier-Stokes equations)



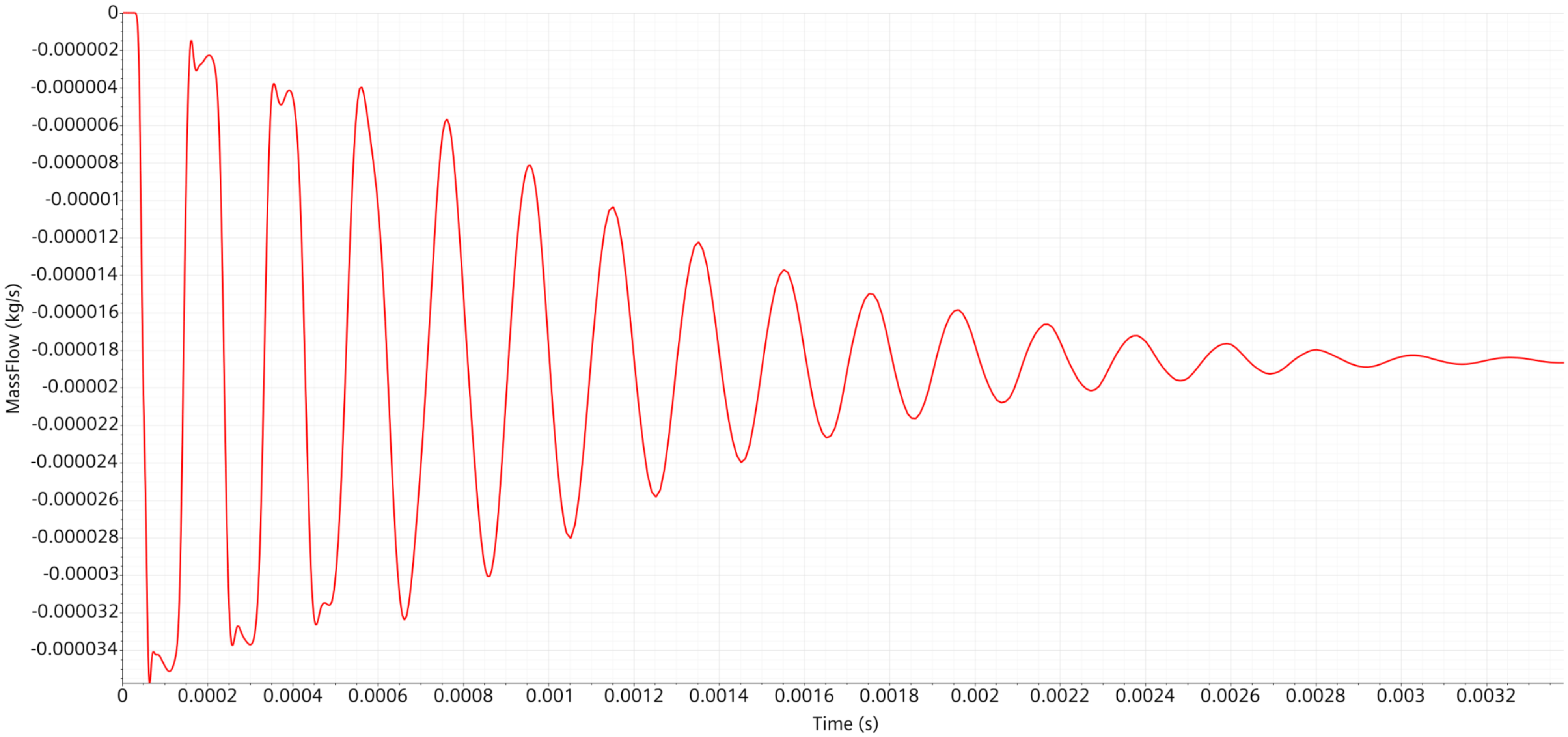
Velocity vectors in a section through jets up to ca. 1.5 mm downstream of hole (solution of Reynolds-averaged Navier-Stokes equations): the contraction of jet at the entry into hole is much less pronounced than in the case of a larger-diameter hole and lower speed shown in the previous presentation.



Pressure filed (solution of Reynolds-averaged Navier-Stokes equations): Pressure reduces rapidly during entry into holes; outside there are several cells with strong pressure variation due to expansion and compression cells in the jet core…
The minimum pressure is 0.85 bar below atmospheric (absolute pressure under 15,000 Pa or 150 mbar).

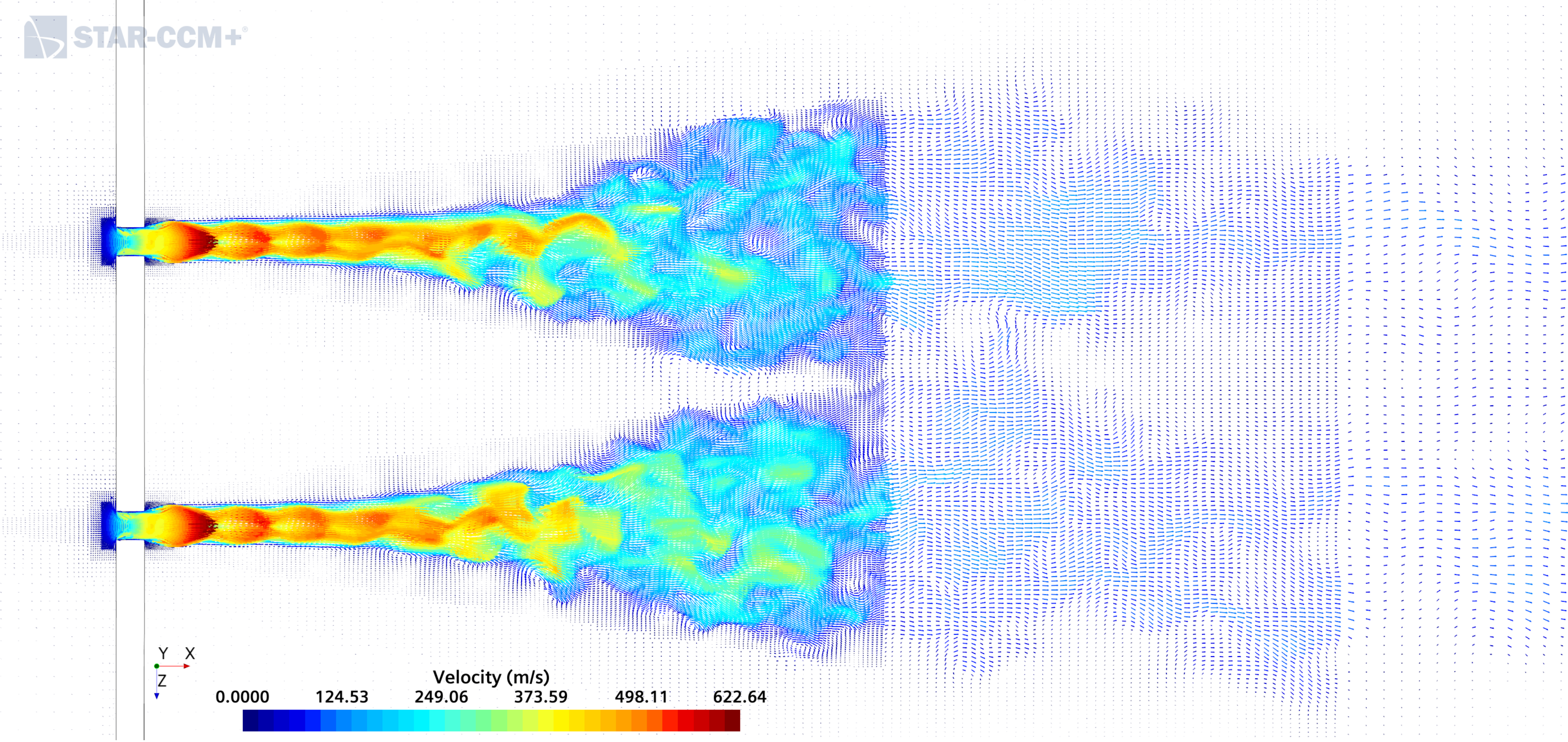


Distribution of axial velocity and turbulent kinetic energy in three cross-sections through jets, showing how the two jets turn into a single round jet.

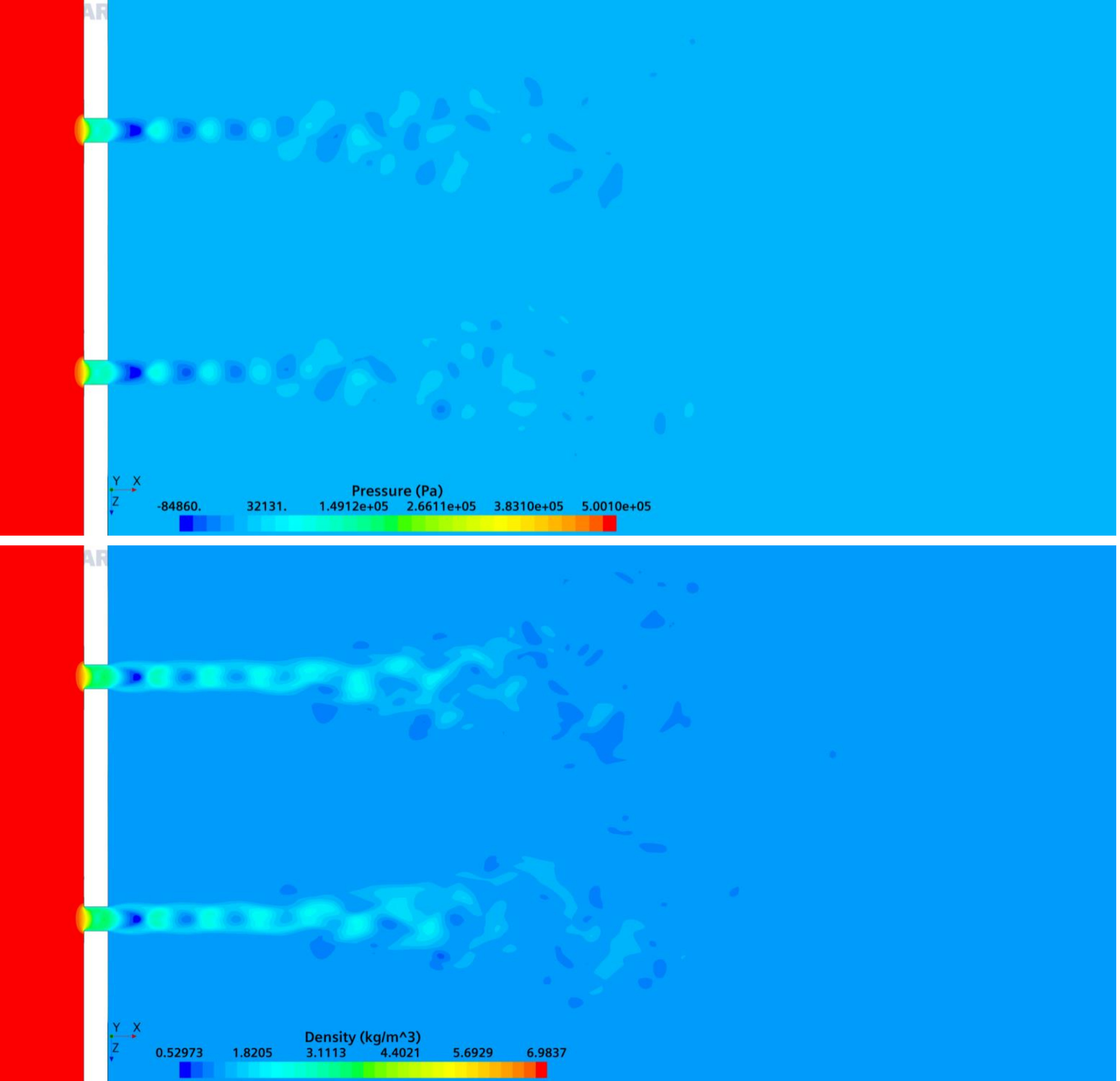


Convergence of mass flow rate as the solution of Reynolds-averaged Navier-Stokes equations approaches steady state. The time step was gradually increased from 0.1 µs to 10 µs, because we are not interested in the development stage. Strong initial oscillations are due to jet interaction. For the two holes, the flow rate settles around 0.0000185 kg/s, which corresponds to 0.0156 liter/s at atmospheric pressure. A pipe with 20 such holes would thus have a discharge of 0.156 l/s for given back pressure.

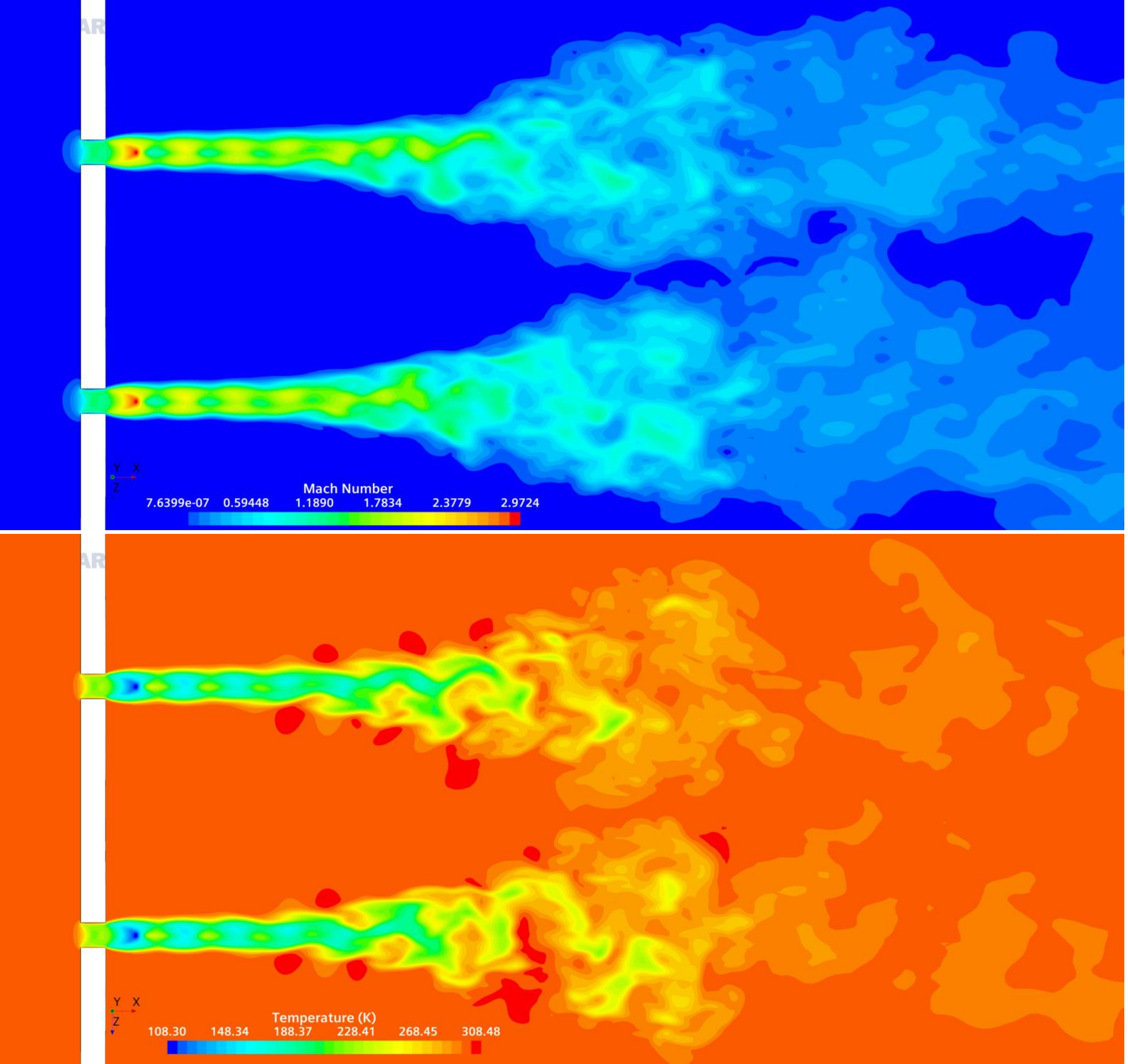
Computation was then continued as large-eddy simulation using time steps of 25 ns (2.5×10^{-8} s) to resolve flow fluctuation…



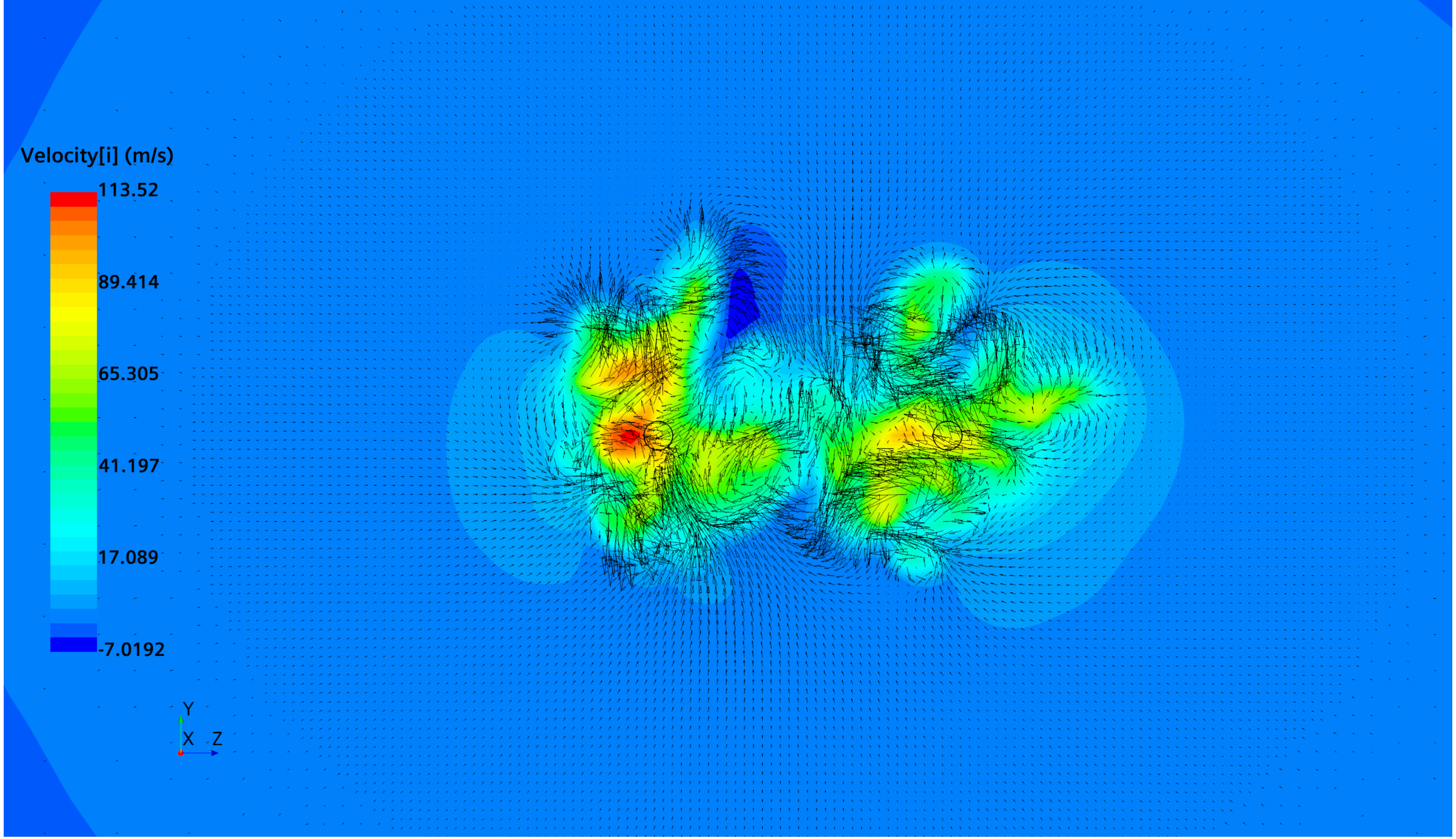
Velocity vectors in a section through the pipe axis and both holes (LES simulation): The supersonic part of jets remains steady, while in subsonic part strong turbulent fluctuations develop. The two jets begin to interact about 2.5 mm downstream of pipe (25 D).



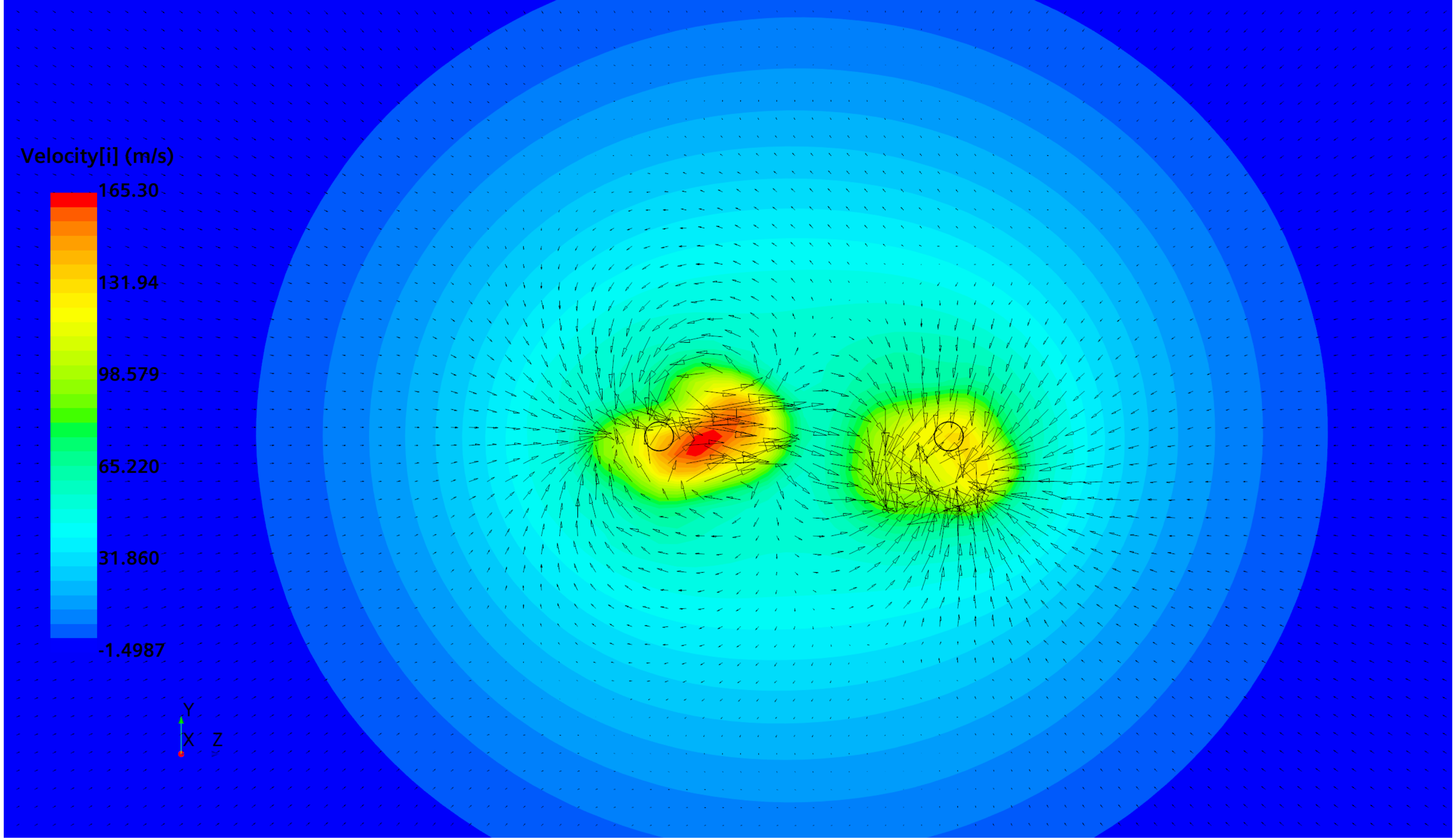
Distribution of instantaneous pressure (upper) and density (lower) in a section through the pipe axis and both holes, LES simulation: The supersonic part of jets remains steady, while in subsonic part strong turbulent fluctuations develop. The maximum air density is about 5.85 times higher than under atmospheric conditions (almost 7 kg/m^3), while the minimum value is less than half of density under atmospheric condition (ca. 0.53 kg/m^3).



Distribution of instantaneous Mach number (upper) and temperature (lower) in a section through the pipe axis and both holes (LES simulation): The supersonic part of jets remains steady, while in subsonic part strong turbulent fluctuations develop. The maximum temperature is 5.48 K (5.48 °C) higher than at inlet, where air enters with 300 K (ca. 27 °C). The minimum temperature is 191.7 K below inlet temperature (which is -164.85 °C). The core of the high-speed jet is very cold!



Distribution of instantaneous axial velocity (contours) and velocity vector projection onto cross-section plane (arrows) in a cross-section through the jet axis 5 mm downstream of hole exit (LES simulation): The turbulent eddies mix the surrounding air sucked into the jet with the air coming out of nozzle.



Distribution of instantaneous axial velocity (contours) and velocity vector projection onto cross-section plane (arrows) in a cross-section through the jet axis 10 mm downstream of hole exit (LES simulation): The turbulent eddies mix the surrounding air sucked into the jet with the air coming out of nozzle. The simulation time in LES-mode was not long enough to propagate turbulent fluctuations across the whole solution domain…