# Tunnel Vision

## Zitron trusts engineering simulation to meet evolving needs in tunnel ventilation system design.

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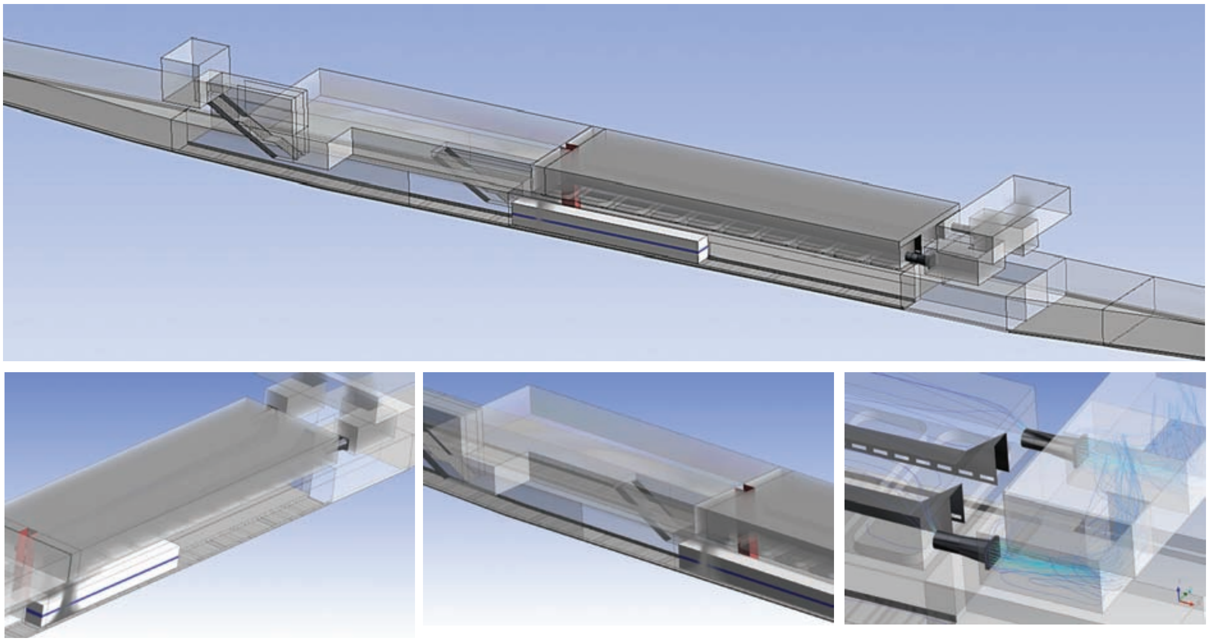
Since tunnels are integral to worldwide transportation networks, it is critical to ensure their proper ventilation and safety. A tunnel ventilation system must provide acceptable air quality for people who are traveling through or working in the tunnel; it also must enable safe evacuation in an emergency. Simulation of tunnel ventilation systems is challenging due to the complex physics involved as well as the large domain sizes required for tunnels that may run several kilometers in length.

Comparison with physical testing results shows that computational fluid dynamics (CFD) can accurately simulate flow patterns and pressure drop in tunnels of any length. Zitron in Spain — a leader in designing and building tunnel ventilation systems that ensure fire safety and air quality for both travelers and crew — has comprehensive experience with CFD. This expertise provides a differentiating factor in winning new tunnel ventilation contracts and in developing designs that perform better than those from similar organizations. Zitron has more than 45 years of experience in the tunnel ventilation industry and has successfully delivered hundreds of systems, including high-profile tunnel projects such as the Guadarrama in Spain, the San Gottardo in Switzerland and the Rennsteig in Germany. Zitron also has supplied more than 100 Madrid metro stations with emergency ventilation systems.

Because of the complexity of these systems, it is difficult and expensive to build and test scale models to evaluate potential ventilation system designs. The ventilation system can impact the tunnel's cross section, shape, alignment, number and size of ventilation devices, and overall civil engineering works required for construction. Simulation makes it possible to evaluate the performance of alternative configurations and to determine how the system should be operated under normal and emergency conditions — all in less time and at a lower cost than with physical testing.

Calle-30 bypass tunnel (Madrid) exhaust vertical fans:
diameter 2,800 mm   power per unit 630 KW



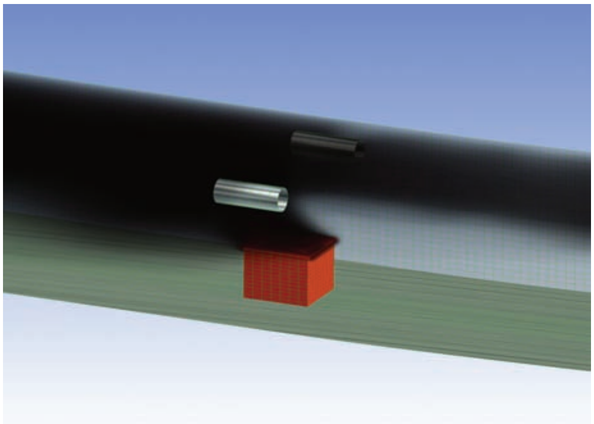
Smoke concentration using volume rendering, Metro of Málaga tunnel in southern Spain

Zitron uses ANSYS Fluent CFD software because the tool provides the exceptionally wide range of physical models needed to accurately predict tunnel ventilation system performance. Furthermore, the technology scales with increasing processor nodes to reduce time to solution by several orders of magnitude. The company's first application, a decade ago, involved estimating pressure drop across a ventilation circuit. After that, Zitron quickly advanced to full-scale tunnel simulations up to several hundred meters in length. Researchers validated these full-scale studies with velocity measurements for many roads, metros and railway tunnels. These early simulation results were in such good agreement with field measurements that Zitron now uses fluid dynamics software as its primary design tool to provide insight into the performance of proposed ventilation systems. Extensive validation of the software results has secured Zitron's position as a leader in tunnel simulation.

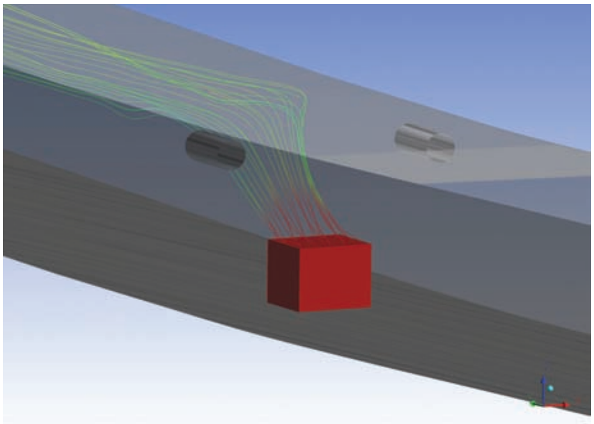
Zitron uses fire simulations to assess the quality of longitudinal ventilation. Engineers define a fire growth model within the tunnel in a location strategically chosen to account for worst-case conditions. A number of longitudinal fans, located in series along the tunnel, are activated with a delay of 60 seconds from fire ignition. The simulation predicts the fans' ability to drive smoke toward one of the exits. The tunnel should be smoke-free within a target time period, usually about 600 seconds. Other key simulation outcomes are velocity distribution and temperature maps along the tunnel.

Tunnel geometries are usually fairly standard with a constant cross-sectional area. The primary design variables are the position and capacity of the fans and the location and size of the possible fire. Because Zitron's CAD software is integrated with the Workbench platform, any change to the design model is automatically updated in the simulation model. Workbench makes it easy for Zitron engineers to perform parametric simulations consisting of a series of runs with varying values of one or more design parameters, such as the number of fans, distance between them and fire location.

Because of the length of the tunnels, meshing is critical. In vital areas, such as the fire location and upstream/downstream of the fans, the mesh must be quite fine to accurately capture the physics. In other areas, cells can be larger to reduce the total cell count. Zitron has performed several sensitivity analyses to understand the effects of cell size and cell type on the solution. Researchers concluded that structured meshes should be used to align cell orientation with flow direction to avoid numerical diffusion. A cell size of 0.25 meters in the proximity of the fire location has been shown to provide accurate velocity and temperature gradients. Cells are stretched to a maximum of 5 meters in length between fire locations and fans, since flow is aligned with the mesh in those areas. The sweep and MultiZone meshing methods available within Workbench permit structured hexahedral meshing with minor user input, and both cell size and cell growth can be enforced through local meshing.



Smoke concentration for Dubai Metro



Flow pathlines of hot smoke gases

Accurate simulation of a tunnel ventilation system today typically requires about 1 million cells per kilometer of tunnel. High-performance computing and recent advances in parallel algorithms have enabled quasi-linear scalability of fluid dynamics calculations. Continual development in both hardware and Fluent software have contributed — and will continue to contribute — to solving more-complex and higher-fidelity tunnel safety applications. High-performing hardware allows the clustering of processing units in a cost-effective manner, while more-efficient computational methods permit prediction of more-complex physical phenomena in larger and longer tunnels. The end result is accurate simulation of larger problems in less computational time.

Zitron engineers set boundary conditions to define domain limits, fan velocity and fire characteristics. They assign tunnel walls an adiabatic behavior and set pressure levels for tunnel exits based on their altitudes. The fan velocity can be defined in different ways, such as a combination of positive and negative inlets, a volume with fixed velocity, a source term, or via the fan boundary condition available within Fluent software. Any way of defining fan velocity provides the same outcome, but fixed velocity and source terms usually are preferred because they ensure both mass and heat transfer.

One of the key boundary condition inputs is fire power and smoke sources or contaminants. The Zitron team has compared several approaches, from the simpler heat and mass source terms to the more sophisticated reaction mechanism. Results from both strategies have proved to be in very good agreement, provided the fire volume obeys the ratio of 1 Megawatt per cubic meter. For convenience, a heat source and combustion product source generally are used for the simulations.

Turbulence modeling is important. Zitron has assessed several Reynolds-averaged Navier–Stokes models but has observed that the k-ε realizable model more accurately describes flow patterns and heat transfer in tunnel ventilation applications.

Smoke propagation is calculated with a time-marching scheme. The standard approach for transient simulations is an iterative time-advancement scheme (ITA). For a given time step, all equations are solved iteratively until convergence criteria are met. Advancing the solutions by one time step normally requires a number of outer iterations and, consequently, a considerable amount of computational effort. Fluent 6.2 included a noniterative time advancement (NITA) scheme, which has been improved in subsequent releases. Only a single outer iteration per time step is needed, which speeds up transient simulations by a factor of between two times and five times.

Although the total fire power can be adjusted to artificially compensate for the impact of radiation, the accurate calculation of wall temperature in the vicinity of the fire should incorporate radiation modeling. Radiation from fire-localized heat sources is not simple to characterize, since wall surfaces and fluid components, such as smoke, are part of the radiation. The discrete ordinates model is the preferred choice as it can describe localized heat sources while considering participating media with multiband properties. Historically, this model was available with only ITA schemes slowing the overall computational time. With the latest Fluent version, the discrete ordinates model application has been extended to NITA schemes, making it possible to increase the speed of the single iteration per time step method.

Zitron obtains reliable insight into the performance of ventilation systems with ANSYS CFD, and the software has kept pace with the company's evolving simulation needs. Zitron's comprehensive experience with CFD has provided the company with a major competitive advantage in tunnel fire-safety engineering. ■