Ventilating Giant Railway Tunnels

High-speed trains in Spain cross more than just the plain.

Image courtesy Eurorail Group.

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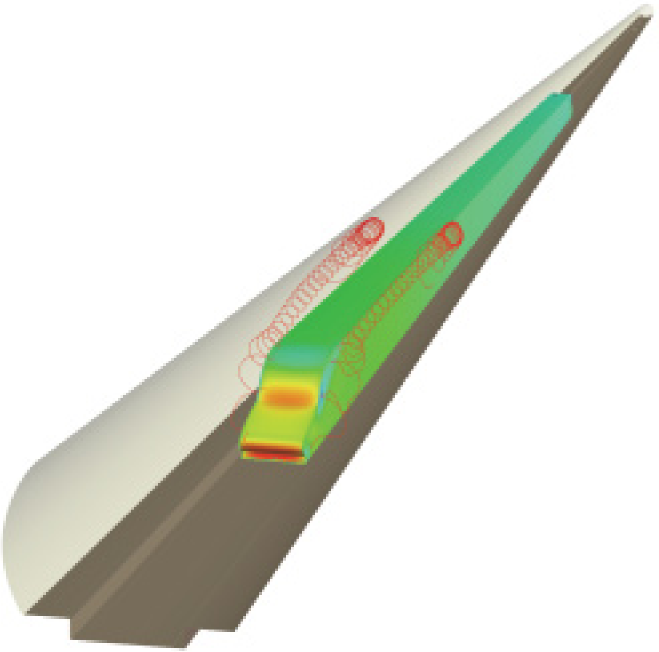
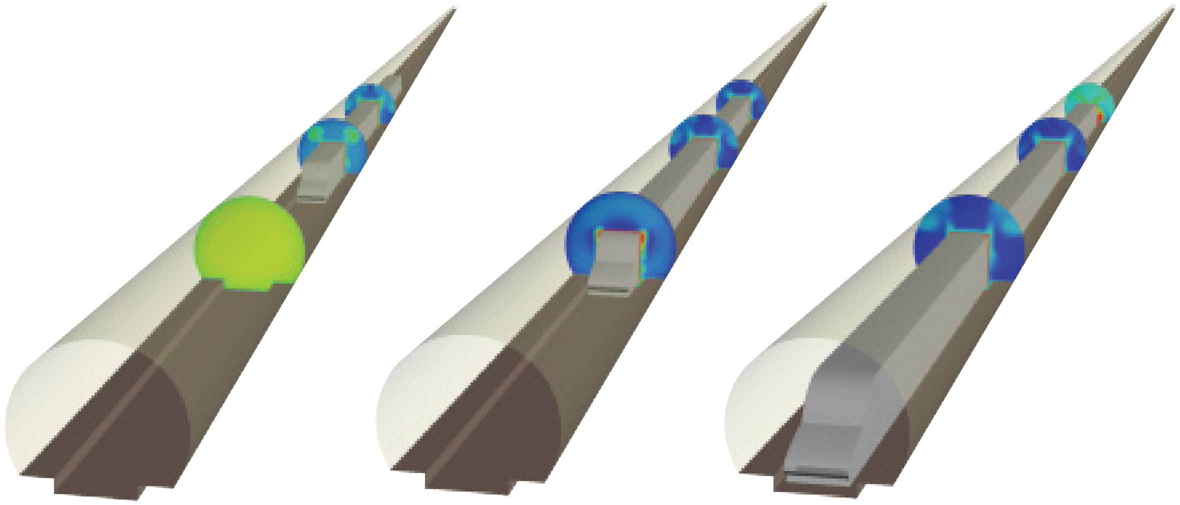


Pressure contours on a train with vortices shown by streamlines in a tunnel

Sunny beaches filled with sunbathers may be the first thing that comes to mind when imagining Spain. However, the reality of its geography is a lot more variable. In fact, the Iberian Peninsula sports many mountain ranges that largely hinder the development of complicated infrastructure, such as the high-speed rail network that is planned to connect Spanish urban areas. This project has led the Spanish railway industry to bore some of the world's longest high-speed transit railway tunnels, such as the 28-km Guadarrama tunnel and the 24.5-km Pajares tunnel. INECO-TIFSA, a transport and telecommunication company located in Madrid, Spain, has contributed to the ongoing expansion of high-speed railways throughout the country by participating in the design of superstructures, such as these giant tunnels.

When designing a railroad tunnel, the ventilation system is a critical component. The ventilation units themselves consist of longitudinal jet fans that are placed at several positions along the tunnel. Their performance is affected severely by air disturbances that result from the motion of a train traveling in the tunnel at speeds of up to 350 km/h (218 mph). Not only does the train movement quickly force the air toward both tunnel exits, it also creates a complex system of pressure waves that propagate throughout the space. A positive-amplitude pressure wave is created when the train enters the tunnel. When the train's rear end passes into the tunnel, another wave, of negative amplitude, originates at the tunnel entrance. Both waves propagate toward the tunnel exit where they are primarily reflected.

Traditionally, 1-D or 2-D simulations have been satisfactory to predict the average pressure correctly inside the



Computational fluid dynamics (CFD) contours at three locations within a tunnel show how the longitudinal velocity changes in the tunnel as a train passes through it. The plane cuts represent the position of jet fans where fluctuating velocities have been monitored.

tunnel. Only by means of a complete 3-D simulation, though, is it possible to obtain an accurate estimate of the velocity components, magnitude and their distribution in the tunnel sections in order to allow for accurate fan sizing.

To design the ventilation system for a long (>5 km) tunnel, INECO-TIFSA chose FLUENT software to perform a full 3-D unsteady simulation of a train passing through such a tunnel. The movement of the train was simulated using the FLUENT sliding mesh capability, in which the train and the domain that it encompasses slide along a non-conformal interface. The interface was placed at the tunnel wall, and the mesh was extruded accordingly. Due to the speed of the train, the ideal gas model was used to account for the effects of compressibility. The computations were performed using the pressure-based solver, which was chosen because the flow is only slightly compressible — that is, there is only a weak coupling between density and velocity, and, thus, the computation does not require the density-based solver. This unsteady simulation was performed using non-iterative time-advancement (NITA) in order to reduce the computational time required. This approach was validated by a series of 2-D computations. Special consideration was given to the determination of the appropriate time step, since it needed to be small enough to predict the wave's propagation correctly.

The velocity components and the static pressure were monitored in seven different locations along the tunnel length corresponding to the ventilators' positions. The flow patterns also were analyzed using velocity contours in various sections of the tunnel. The results showed the amplitude of the flow created by the train's passage. When a train enters a tunnel, air first escapes at the tunnel entrance at the side of the train, both because it is the closest exit and because the mass of air between the front of the train and the tunnel exit has yet to be put in motion. When the train has passed, the flow then changes direction. At that moment the air is pushed by the train and travels backward in the narrow gap between the train and the tunnel. Speeds of up to 35 m/s were observed at the fan positions. Furthermore, some sudden changes of slightly higher amplitude could be seen when the front of the train reached the jet fans, showing how carefully this equipment needs to be selected.

As expected, the pressure waves created by the train's motion do have a discernible effect on flow patterns within the tunnel. Seconds after the train has passed the jet fans at the entrance of the tunnel, the wave patterns form such that they accelerate the air flow by up to 25 m/s. When the air is compressed by a positive-amplitude wave, the air velocity diminishes according to conservation of mass, while the inverse (acceleration) occurs if the wave is of negative amplitude. The train creates both of these types of waves as it passes through the tunnel, thus inducing both accelerations and decelerations in the surrounding tunnel airflow. This complex and decaying phenomenon then continues long after the train has exited the tunnel. Even though the highest velocities observed are longitudinally oriented, the transversal velocity profiles revealed the benefits of a 3-D study, since velocities of the same order of magnitude were observed. Overall, this modeling approach has shown interesting results and proven beneficial for INECO-TIFSA by the level of detail achieved. ■