German Aerospace Center

A gentle pop instead of a loud bang

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By Elisabeth Mittelbach

As they enter and exit tunnels, trains generate pressure waves of varying strengths, depending on their speed. Physicist Daniela Heine, from the DLR Institute of Aerodynamics and Flow Technology, is investigating how these pressure waves can be mitigated. The 25-year-old PhD student works with the only tunnel simulation facility of its type in the world, in a gigantic hall at the DLR site in Göttingen. DLR transport editor Elisabeth Mittelbach introduces us to the young researcher and her project.

Daniela Heine remembers her first day as a PhD student at the DLR site in Göttingen like it was yesterday: "It was 16 May 2011," she says instantly. As a physicist, it is not surprising that the 25-year-old has a memory for numbers. On that day, she became acquainted with her workplace – the only tunnel simulation facility of its type in the world. "I was very impressed by the size of the facility. Although I had already heard about it, I had imagined it to be smaller," explains Heine excitedly. Since then, the trainee researcher has been making her way to Bunsenstrasse in Göttingen every day of the week. When she does not have to attend any events or appointments at Göttingen University in the afternoon, she often stays at the Institute a bit longer. "The good thing is that I can really focus on my research when I am here at DLR," she says excitedly. Her office is located directly above the tunnel simulation facility, so the PhD student is always very close to the core of her research project.

The young researcher is investigating the propagation of pressure waves in railway tunnels. She is looking into how they are created and wants to find out how the strength of the waves can be reduced. Though somewhat reserved at first, her commitment to her work and expertise in this research area becomes obvious during our conversation. During her PhD course, which will last three years in total, Daniela Heine will focus intently on the aerodynamics of high-speed trains such as the Inter-City-Express (ICE) and on the shape of tunnel entrances. "Smaller pressure waves on entering and exiting tunnels would make trains safer and more pleasant for the passengers – particularly at high speeds," Heine explains. As the pressure waves reach the tunnel exit, passengers can feel a sensation of blockage in their ears or, more rarely, varying degrees of popping.

The faster the train travels and the narrower the tunnel, the stronger the pressure waves. "Most passengers on the ICE have noticed the change in pressure upon entering a tunnel," says Daniela Heine. When the pressure waves reach the tunnel exit, the compression wave is partially reflected back into the tunnel. The successive reflections of the pressure waves inside the tunnel produce a complex wave interaction, causing aerodynamic loads on the train and tunnel structures, and affecting the passenger's comfort. To attenuate the transmission of pressure waves into the vehicle and protect passengers, the design of the ICE 3 is almost completely airtight and includes extra-thick walls. This means, for example, that the windows cannot be opened. "Ideally, all the windows in an inter-city train would have to be closed before entering a tunnel," the train researcher concludes.

Since this is nearly impossible, conventional inter-city trains must travel through tunnels at lower speeds than the ICE. But the trains of the future will travel even faster, and increasingly be double-deckers. An even stronger pressure seal would make the carriages heavier. "The costs would rise and the energy consumption would be greater," explains Heine. This has to be taken into consideration if modern high-speed trains are to partially replace aircraft in the future – such as for short-haul routes within Europe.

It is for this reason that Daniela Heine began to consider not the train, but the tunnel. Pressure waves are caused by a sudden difference in pressure, which then propagates as a wave. Heine's solution is a portal equipped with vertical ventilation slots in front of the tunnel entrance to reduce the strength of the pressure waves. "With this design, the pressure should build up more smoothly, so the negative side effects of entering and exiting tunnels are minimised," she explains. To achieve the most effective solution, she has conducted trials with different designs during the course of her research. "There must ultimately be an optimal configuration, and I will find it," she states with conviction.

She shows us the portal for the tunnel entrance, which is made from Plexiglas at a scale of 1:30, as is the 10-metre long tunnel itself. The two-metre long ICE 3, a 1:25 scale model, is made of carbon-fibre reinforced composite. "The train was built to a larger scale than the tunnel so it is a 'tighter fit'. This enables the pressure changes to be measured more accurately," the researcher explains.

Elementary work with room for experimentation

Daniela Heine has already 'catapulted' the model train along the 60-metre long railway track and through the tunnel around 200 times. "Sometimes I work with a longer train, and other times I change the number, size and position of the ventilation slits in the entrance portal," the DLR scientist reports. It is elementary work, but with plenty of room for experimentation. "The level of realism achieved is of course much higher with actual tests than with purely numerical work. That is important to me," says the physicist from Celle.

At first, her work was directed towards studying the generation and propagation of pressure waves inside the tunnel. "I knew very little about pressure waves, so I had to 'get to know' them first," says Heine with a grin. Twenty small measurement probes installed in fixed positions in the tunnel record the pressure data during a test. Three pressure probes, an acceleration sensor and a light sensor are fitted on the train. Special software is used to record the measurements taken by the probes in the tunnel and a light-operated timing gate in front of the tunnel, and display them directly on a computer screen. "The data recorded in the train is stored on the train and then read out by the computer," Heine explains. She adds with a hint of pride: "This was specially constructed by Klaus Ehrenfried, my supervisor here at DLR."

The PhD student can use the recorded measurement data to determine the change in pressure and the pressure build-up caused by the compression wave – the wave generated by the train when it enters the tunnel. "I then compare my results with the theory and experiments described in the literature," says the researcher, describing the next stage in the process. The critical factor here is time: "How much time elapses between the formation of the pressure wave and it reaching peak amplitude? This is the quantity I want to work out." The longer it takes for the pressure wave to build up, the better – the passengers can adjust to it and the disruptive effects become less severe. "The wave must build up more slowly, so that in extreme cases the loud bang becomes a gentle pop - like opening a swingtop bottle," she says using a visual comparison. Of course, it would be much better if the acoustic shock disappeared altogether. "Not every tunnel journey involves an acoustic shock; it only happens in exceptional circumstances," the researcher clarifies.

Time, speed and configuration

The pressure rise time and the configuration of the model train and the tunnel portal are important, but so is the speed at which Heine sends the train on its journey. In her tests to date, she has accelerated the model to a maximum 160 kilometres per hour on the 60-metre test track. "At some point, I want to reach 400 kilometres per hour, which is the highest speed that the catapult can accelerate a model train to," she explains. The current model train is too heavy for this, but there are plans for a lighter train. It will happen – Daniela Heine is just starting her research.

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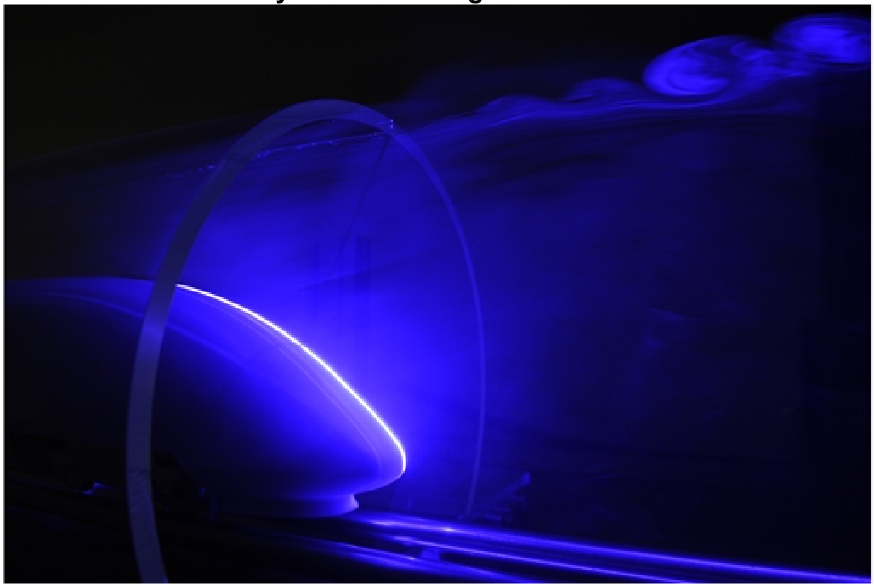
Daniela Heine

Physicist Daniela Heine works at the DLR Institute of Aerodynamics and Flow Technology in Göttingen. There, she conducts research on high-speed train models in the tunnel simulation facility. The aim of her research is to regulate the pressure waves at the tunnel entrance and exit, in the hope of contributing to reducing, among other things, the popping on the ears of passengers.

The tunnel simulation facility at DLR Göttingen



The tunnel simulation facility at DLR Göttingen is the only one of its kind in the world. Before they enter the experimental Plexiglas tunnel, a 'catapult' can accelerate the model trains to speeds of up to 400 kilometres per hour on the 60-metre-long test track.

Smaller pressure waves in tunnels

In order to make trains faster and more economical, design is essential. Using the latest measurement technology, research is being carried out in the tunnel simulation facility at DLR Göttingen into the aerodynamics of high-speed trains inside tunnels. The tunnel entrance is regarded as particularly critical: as the train enters the tunnel, a pressure wave is created that can cause pops as.
