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CFD-SIMULATIONS ON THE GENERATION OF THE PRESSURE WAVE WHEN A HIGH-SPEED TRAIN ENTERS A TUNNEL WITH DIFFERENT PORTAL MODIFICATIONS

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1 INTRODUCTION

When a high-speed train enters a tunnel the bow wave in front of the train is compressed into the tunnel. This compression wave propagates with the speed of sound through the tunnel and steepens depending on the tunnel interior. When the steepened pressure wave reaches the opposite exit portal it is partly reflected back into the tunnel and partly emitted into the environment. The amplitude and the sound pressure level of the emitted so called micro-pressure wave strongly depend on the maximum pressure gradient of the wave approaching the exit. With the new high speed line Nuremberg-Ingolstadt going in operation in the mid of 2006 the sonic boom phenomena has received renewed interest within Deutsche Bahn since in two tunnels on the line micro-pressure wave emission at the exit portals became an issue [1].

With the goal to reduce the acoustic emissions to a minimum in future high speed tunnels it is necessary to keep the pressure gradients in the tunnel as low as possible. This can be done by different countermeasures. A suitable countermeasure to decrease the entry pressure wave gradient is a modification of the entry portal. It is a very effective method because the steepening process proceeds at a lower rate with smaller entry pressure gradients. Portal modifications can be applied very cheap and easy during the construction phase. Portal modifications are also an option as re-install for existing tunnels.

In this paper the effects of different portal modifications on the generation of the entry pressure wave are studied using CFD simulations. The results are compared to TRAIR model experiments at DeltaRail (UK) and to the results from BUHOOD [2], a portal hood dimensioning tool. In addition, practical boundary conditions and simulation parameters are presented.

2 GENERATION OF THE ENTRY PRESSURE WAVE

The sonic boom phenomenon can be clearly divided into three separate phases: the generation of the pressure wave, the propagation of it and the emission of the micro-pressure wave.

This work focuses on the first part, the generation of the entry pressure wave. The results from this work can be used later to calculate the propagation of the compression wave and after that to calculate the pressure signals of the emitted micro-pressure wave. Because of the non-linearities of the propagation the emitted micro-pressure wave can not be calculated directly from the entry pressure wave. It is an iterative way to optimize the shape of the entry pressure wave to minimize the acoustic emissions.

Two approaches are shown to describe the generation of the entry pressure wave. The first one focuses on maximum values of amplitude and gradient whereas the second one considers the entire pressure signal in the time domain. Maximum values of the pressure amplitude and gradient are determined from the CFD-solution to assess the efficiency of each modification. The pressure amplitude is obtained according to

$$\Delta p = \frac{\rho}{2} \cdot v_{Train}^2 \cdot f(M,\Phi) \quad \text{with} \quad f(M,\Phi) = \frac{1-\Phi^2}{\left(1-\frac{v_{Train}}{c_0}\right)\left(\frac{v_{Train}}{c_0}+\Phi^2\right)} . \tag{1}$$

Here, air density is denoted by ρ, the velocity of sound by c_0, train speed by v_{Train} and the blockage ratio between tunnel and train cross-section by Φ. The maximum pressure gradient is calculated according to

$$\frac{dp}{dt} = \eta \cdot \frac{\rho}{2} \cdot v_{Train}^3 \cdot f(M,\Phi) \cdot \frac{1}{D_{h,Tun}} \quad \text{with} \quad D_{h,Tun} = 4 \cdot \frac{A_{Tun}}{C_{Tun}} , \tag{2}$$

with the hydraulic diameter of the tunnel $D_{h,Tun}$ and with a factor η to describe the influence of the shape of train nose in combination with a portal modification. The lower η is, the lower the maximum pressure gradient will be for a given train velocity and the more effective the portal modification will be.

In a second detailed analysis the full time dependent pressure signal resulting from the train entry into the portal is extracted from the simulations. This pressure signal will be used later in the calculations of the wave propagation.

3 BOUNDARY CONDITIONS AND SETUP

Because of the focus on the tunnel entry problem the computational domain consists of the entry portal with a free surrounding area in front of the portal and a short section of the tunnel behind it. It turns out that the generation of the entry pressure wave is independent from the tunnel length. The tunnel has to be long enough to prevent reflections from the outlet to disturb the pressure signals close to the portal. It also turns out that the pressure wave changes to a 1-dimensional wave just a few meters behind the portal.

The computational domain, as shown in Fig. (1), consists of three parts: a moving part including the train, a stationary part including the vicinity of the portal and another stationary part containing 370 m of the environment and the 300 m long tunnel. The mesh interfaces are node-matching interfaces except those around the moving train mesh. Since all interfaces are at fixed positions, the train mesh and the portal mesh can be exchanged easily.

All simulations are made with ANSYS-CFX11 using the SST-turbulence model with a second order backward euler scheme for time discretization. For simplification and speed up the simulations use a symmetric boundary condition with respect to the lateral coordinate and a train model centered to the tunnel entry.

Initially the train nose is located more than 300 m away from the tunnel portal. It is accelerated from rest to the final speed within 20 m. Then it moves with constant speed through the environment, the portal and the tunnel. This procedure is required to ensure that a steady boundary condition has developed around the train before the nose enters the portal. The entry pressure wave is measured in the tunnel 100 m behind the tunnel entrance.

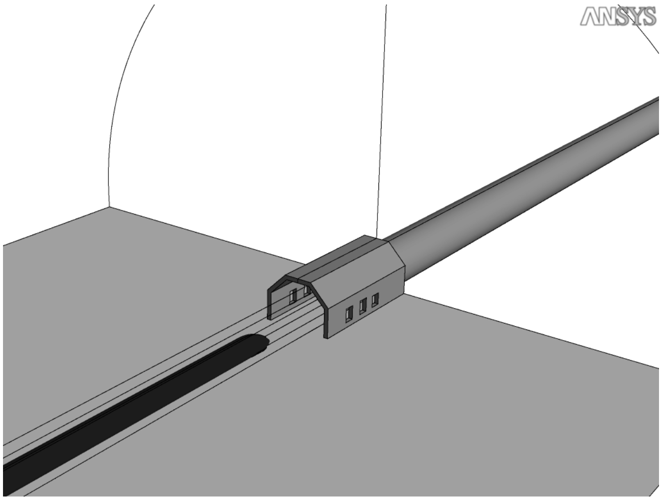

Figure 1: Simulation domain with train, environment, 25m hood and tunnel

4 RESULTS

When the train nose approaches the tunnel portal, the entry pressure wave starts to form. The pressure increases very fast while the train nose travels through the tunnel portal and increases slowly during the time the constant cross section enters the tunnel.

Different portal modifications are simulated. Some are shown in Fig. (2). The associated entry pressure waves are shown in Fig. (3). A vertical portal with zero wall thickness represents the worst case with the highest entry pressure gradient. In this case the rise time is the shortest at all because on one hand the bow wave in front of the train can not interact with the portal wall before the train nose approaches the portal. On the other hand the train nose enters the full tunnel cross section abruptly. Every variation from this scenario lengthens the entry process and decreases the entry pressure gradients. A sloped portal increases the time the nose enters the tunnel. A hood increases the entering time also, but additionally the shape of the entry pressure wave can be changed by openings in the hood. The size and position of the openings in a hood can be varied to create user-defined entry pressure waves to optimize the steepening process.

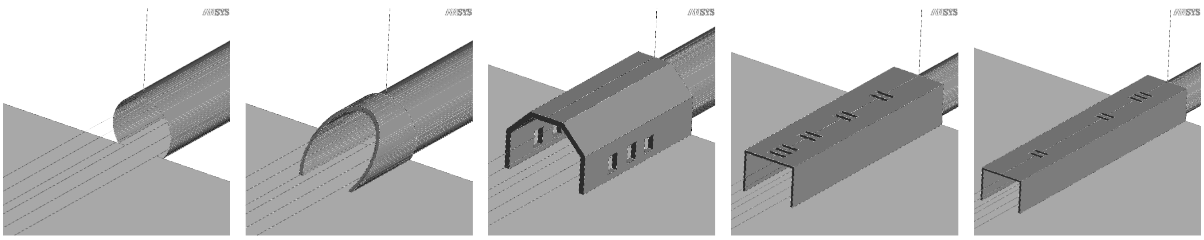

Figure 2: Portal modifications - from left: vertical portal ($\eta = 1.08$), sloped portal ($\eta = 0.75$), 25m hood ($\eta = 0.47$), 50m hood ($\eta = 0.26$), 70m hood ($\eta = 0.34$)

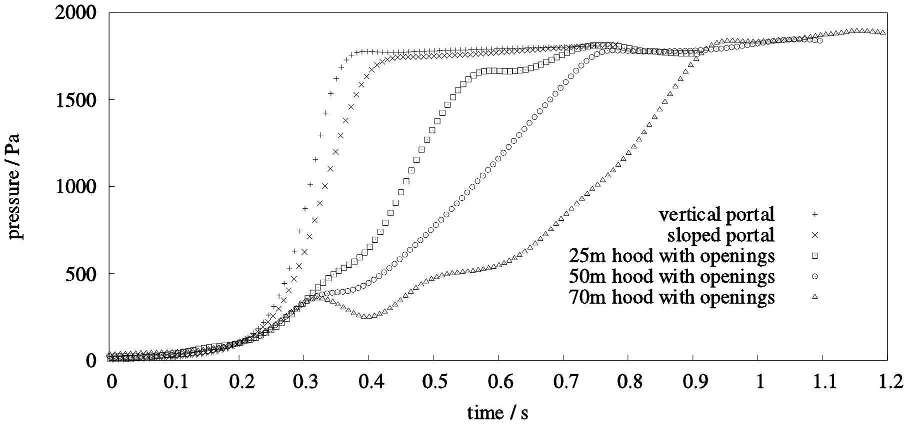

Figure 3: Entry pressure waves from different portal modifications

In Fig. (4) the results for the 50m hood are compared to model measurements from TRAIR and to a calculation with BUHOOD. A very good agreement is found between the calculating methods.

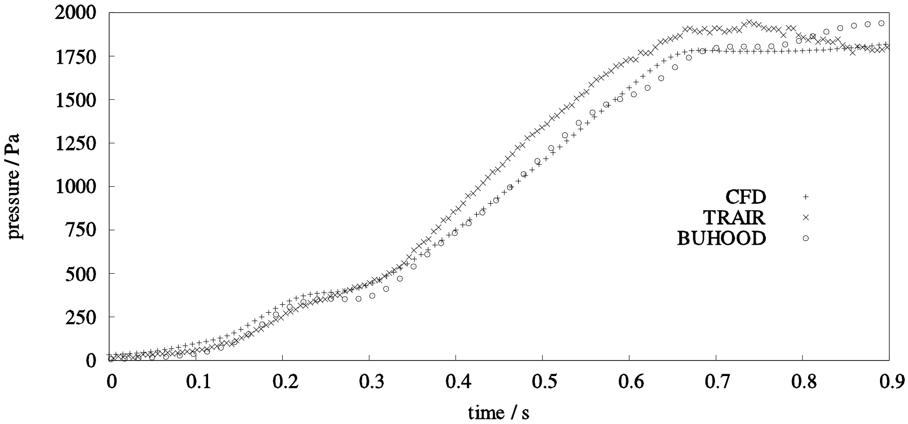

Figure 4: Comparison of calculating methods with model experiment

5 CONCLUSIONS

The generation of the entry pressure wave can be examined in detail by CFD simulations. The results are in good agreement to other calculation methods or measurement results. The process of the wave generation can be studied in detail and different tunnel portal modification can be compared by their effectiveness.

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