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NOISE SOURCES ON AMTRAK'S HIGH SPEED TRAIN

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ABSTRACT
Noise was identified as one of the key community concerns during the environmental assessment process conducted prior to the introduction of Amtrak's new high speed train, the Acela, in Northeast USA. Although the Canadian-French trainsets are similar to the TGV, there are significant differences for operation on American tracks. Noise sources were measured and identified during tests conducted at the Transportation Technology Center (TTC) near Pueblo, Colorado. Measurements were made using a microphone array system. Line arrays and X-arrays were used to locate and quantify the noise sources. Roughness of the wheel treads and rail surfaces were measured to enable the array-measured rolling noise to be assigned to a particular level of roughness.

1 - INTRODUCTION
Noise measurements of the new AMTRAK Acela Trainset are a requirement of the Environmental Impact Statement (EIS) for the Northeast Corridor North End Electrification Project. The purpose of the measurements is to confirm that the trainsets will meet the projected noise levels used to identify noise impacts in the EIS. A secondary purpose is to identify the location of various noise sources on the train. This information would be used to determine the effectiveness of any noise mitigation measures that may be required as a result of high speed train operations.

2 - MEASUREMENT PROGRAM
Overall noise from a passby of Acela is measured by a single microphone placed at wayside in conformance with procedures promulgated by the U.S. Environmental Protection Agency (EPA) in their Railroad Noise Emission Standards, 40 CFR 201, and in the Federal Railroad Administration (FRA) Railroad Noise Emission Compliance Regulations, 49 CFR 210. These standards call for a microphone to be placed 1.2 meters (4 feet) above ground level at a distance of 30 meters (100 feet) from the center of the track during a moving train passby. Figure 1 shows this microphone.
Noise source locations are measured by microphone arrays placed beside the tracks at a distance of 5 meters (15 feet) in various configurations and at various heights. These microphone systems and their associated software are capable of being steered to follow a given spot on a passing train to determine the amount of noise emanating from that location. By scanning the entire train during a passby, the level and frequency characteristics of noise sources can be determined. One of the microphone arrays used in the tests at TTC is shown in Figure 2.

3 - SOURCES OF HIGH SPEED RAIL NOISE
Wayside noise generated by a high-speed train consists of several individual noise-generating mechanisms, each with its own characteristics of source location, strength, frequency content, directivity, and speed dependence. These noise sources can be generalized into three major types:

- propulsion or machinery noise,

Figure 1: Single point microphone for emission compliance.

Figure 2: Example microphone array for Acela diagnostic tests at TTC.

- mechanical noise resulting from wheel/rail interactions and/or guideway vibrations, and
- aerodynamic noise resulting from airflow moving past the train.

For lower speeds of up to about 125 mph, propulsion and mechanical noise are sufficient to describe the total wayside noise. The aerodynamic noise component becomes an important factor when the train speed exceeds about 150 mph.

The various noise sources for a steel-wheeled high-speed tracked are illustrated for a TGV trainset in Figure 3. These sources differ in where they originate on the train and in what frequency range they dominate.

Type I: Propulsion Sources

At low speeds, propulsion mechanisms, or machinery and auxiliary equipment that provide power to the train are the predominant sound sources. Most high-speed trains are electrically powered; the propulsion noise sources are, depending on the technology, associated with electric traction motors, control units, and associated cooling fans. Fans can be a major source of noise; on conventional steel-wheeled trains fans are usually located near the top of the power units, about 3 m (10 feet) above the rails. Fan noise tends to be fairly broad band and dominates the noise spectrum in the frequency bands near 1000 Hz. External cooling fan noise tends to be independent of train speed, which makes it the dominant noise at low speed or when a train is stopped in a station.

Type II: Mechanical/Structural Sources

Steel-Wheeled Trains. The effects of wheel-rail interaction of high-speed trains, guideway structural vibrations, and vehicle-body vibrations fall into the category of mechanical noise sources. These sources tend to dominate the total noise level at intermediate speeds, and cover the widest of the three speed

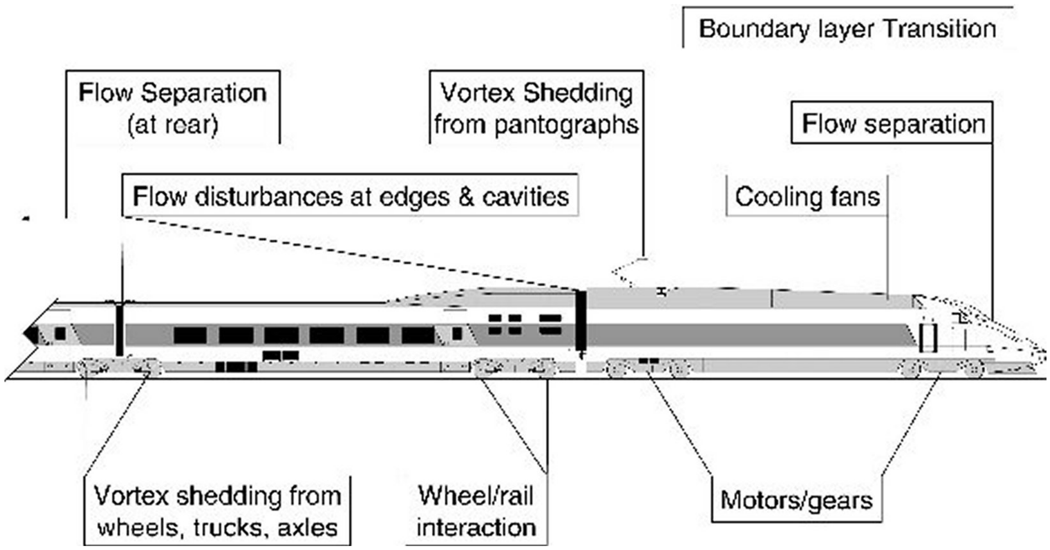

Figure 3: Location of noise sources on high speed train.

regimes. For steel-wheeled trains, wheel-rail interaction the is source of the rolling noise radiated by steel wheels and rails caused by small roughness elements in the running surfaces. This noise source is close to the trackbed with an effective height of about 0.3 m (2 feet) above the rails. The spectrum for rolling noise peaks in the 1 kHz to 3 kHz frequency range, and it increases more rapidly with speed than does propulsion noise. We measured a relationship of 38 times the logarithm of train speed. Wheel-rail noise typically dominates the A-weighted sound level at speeds up to about 150 mph.
Type III: Aerodynamic Sources
Propulsion and rolling noise are generally sufficient to describe the total noise up to speeds of about 150 mph. Above this speed, however, aerodynamic noise sources tend to dominate the radiated noise levels. These sources begin to generate significant noise at speeds of about 180 mph, depending on the magnitude of the mechanical/structural noise.
Aerodynamic sources generally radiate sound in the frequency bands below 500 Hz, generally described as a rumbling sound. Aerodynamic noise level increases with train speed much more rapidly than does propulsion or rolling noise. We measured pantograph noise increasing at 50 to 60 times the logarithm of speed.

4 - RESULTS
Overall Noise
Overall noise from Acela determined by the single microphone method is shown in Figure 4 together with noise data from the Swedish X2000 and the German ICE taken during demonstration tests on the Northeast Corridor in 1993. Although the Acela appears to be noisier than the European trains at low speeds, this may be an artifact of the testing program. All noise measurements for these tests were conducted with all fans running at full load conditions to create a maximum condition. This resulted in higher than normal noise in the speed regime where mechanical systems dominate the noise generation.
Individual Sources
By use of the microphone array system, individual noise sources were determined and rank ordered according to their intensities and frequency ranges. The full analyses include determination of the speed exponents of each important sound source. This information is included in the FRA's full report on the noise measurement program of Acela, as well as the final version of FRA's manual viewable on their website http://www.fra.dot.gov entitled "High Speed Ground Transportation Noise and Vibration Impact Assessment."
The results of the noise source diagnostics are shown in Table 1.

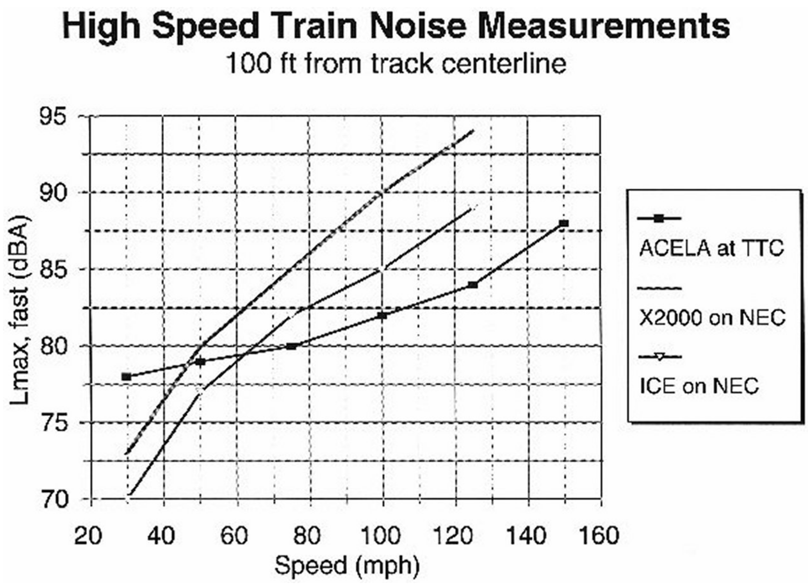

Figure 4: Noise level vs. speed for Acela and two European trains.

Component	Percent of total sound energy
Total noise	100%
Rolling noise	72%
Traction motors	17%
Pantograph	8%
Fans	2%

Table 1: Ranking of Noise Sources at 150 mph.

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