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quick study

What causes road noise?

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Scientists understand the individual characteristics of roads and tires that contribute to tire–pavement noise. Nonetheless, engineering a quiet ride remains a challenge.

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It is said that perception is reality, and thus it makes sense that as you drive, what you hear will in part define the quality of the road on which you are driving. Sure, you must have a road that is smooth and safe, but the quieter a road is, the more enjoyable the experience—both for you and for those who live and work along that same road. But what makes some roads quiet and others so loud that you must turn up the volume on the radio? The answer is not as simple as you might imagine. In fact, the road is not the only factor; tires are important too.

Measuring the noise

It is a common misconception that vehicle noise is largely the result of engine noise or even the "wind" noise of passing cars and trucks. In most instances, the dominant source—termed tire–pavement noise—is actually located where the rubber meets the road. Many countries have regulations in place that limit the overall noise from vehicles, and noise from tires in particular. However, it was not until recently that international government agencies have thought about the influence of roads. Although institutional inertia was arguably to blame, one legitimate obstacle was the lack of a relevant, accurate, and reproducible method to measure tire–pavement noise.

That technical limitation has been overcome with the adoption of techniques such as on-board sound intensity, a method developed at General Motors in the 1980s, refined under sponsorship of the California Department of Transportation, and standardized by the American Association of State Highway and Transportation Officials. Although the standard continues to evolve, nowadays the most common variant of OBSI employs two probes consisting of two microphones each, as illustrated in figure 1. Each probe is positioned mere inches from the rolling tire and is capable of measuring the sound intensity—that is, the product of pressure and the acoustic velocity, which is the velocity of a small bit of air relative to the air as a whole. Because sound intensity is a vector quantity, intensity measurements provide useful information not derivable from scalar pressure values. The OBSI technique uses two measurement probes because the sounds emanating from the front of the tire–pavement contact patch are usually different from those emanating from the rear.

Thousands of tire–pavement combinations have been evaluated with the OBSI method. To simplify the interpretation of the data, pavement engineers have adopted a standard reference test tire that allows different pavements to be more readily compared. That SRTT is standardized by ASTM International. Although not ideal for a number of reasons, the SRTT has a significant advantage in that it will be available for purchase for the foreseeable future. In contrast, most commercially available tires are subject to being discontinued as a result of market forces.

Sources of the noise

The challenge of developing a measurement technique for tire–pavement noise has now been met. The nature of the sound generation, though, remains an enigma. For both tire and pavement, three principal characteristics govern sound generation: texture, porosity, and stiffness (see figure 2). The complications lie in the specific relationships between those characteristics and the sounds that result when they change.

The most significant characteristic is texture. When driving a vehicle, you may experience roads that are both rough and loud. Texture with a significant amplitude is to blame for the bad all-around experience. But the texture wavelengths responsible for a rough or a noisy ride are different. Long-wavelength, low-frequency texture causes a rough ride. Noise is mostly caused by short-wavelength, high-frequency texture.

Figure 1. On-board sound intensity is a standardized method for evaluating the intensity of noise due to the interaction of tire and pavement. Tests are typically conducted at 60 mph. Visible here are OBSI's two probes; each has a pair of microphones surrounded by a windscreen. The two probes allow engineers to measure noise emanating from both the front and the back of the contact patch where the tire meets the road.

Figure 2. Tires and pavements both contribute to road noise. Tires without tread can be very quiet. Those with simple geometries can be modestly louder, but those with large, blocky tread patterns are among the loudest. The quietest pavements include those with fine texture and significant porosity. Those without porosity but with fine texture can be somewhat louder. Pavements with large or worn textures are among the loudest. All three pavement photos show a sample that is a few centimeters across.

Noise heard outside the vehicle is largely governed by different texture wavelengths than those responsible for the noise heard inside the vehicle. At highway speeds, texture with significant amplitudes and wavelengths of about 10–50 mm is largely to blame for noise that is readily radiated away from the vehicle; texture with wavelengths of 20–200 mm is responsible for in-vehicle noise. In both cases, the dominant noise-producing mechanism is termed impact. As the tire rolls over the pavement, displacements in the road surface or tire-tread pattern create vibrations in the tire structure. Those vibrations, in turn, lead to acoustical energy being radiated from the tire-tread elements and sidewall. The impact mechanism is most evident in the characteristic roar of "knobby" tires found on some off-road or heavy commercial vehicles.

Is the key to making a perfect road, then, to build one that is perfectly flat? Unfortunately, no. In fact, a flat road is a bad idea for many reasons. For one thing, the road would not be safe; absent texture, friction would be low and braking distance could be compromised. Even in terms of noise, engineers have learned that a perfectly flat road is not a quiet road. The reasons lie in the mechanics of the tire–pavement interaction. The realization that texture can reduce tire–pavement noise illustrates the complexity of the relationship between texture and noise.

The quest for a quieter pavement is often complicated by another broad category of texture–noise mechanisms termed aerodynamic. Those mechanisms are both numerous and complex, and their manifestation depends on the particular interaction of tire and pavement. As tire and pavement come into contact, so-called void geometries form in both the tire-tread blocks and the grooves and cavities in the pavement surface. Those geometries can have inherent resonant frequencies that are easily excited by the deformation and vibration of the tire itself. As the tire rolls, air trapped in the voids can be rapidly ejected—and that produces noise.

Numerous other sources of noise exist in addition to the impact and aerodynamic mechanisms. Various sources of vibration will generate sound, including those related to friction between the tire rubber and the finest texture. The characteristic squealing sound you hear when you corner in a smoothly paved parking garage illustrates how a frictional mechanism can sometimes dominate overall tire–pavement noise.

Beneficial holes in the road

Texture is by far the most significant contributor to tire–pavement noise, but porosity has an effect too. Examples of highly porous materials deployed to reduce sound are all around, quite possibly right above your head! In pavement, the geometry of the void spaces and the thickness of the porous surface layer can be tuned to attenuate at the acoustical frequencies at which most of the energy is generated. The acoustical absorption of the pavement not only reduces the noise at the tire–pavement interface but also provides attenuation of the sound as it propagates out to the community. An additional benefit of porous pavements is that they provide drainage or escape paths for air that would otherwise be ejected from cavities between the rolling tire and the pavement. The result can be less noise.

Tire stiffness is another significant factor influencing the overall level of road noise. All else being equal, softer tires will result in a quieter ride. That said, noise is but one property of the tire that must be optimized; others include durability, fuel economy, and handling. Pavements, too, have different stiffnesses depending on how they are constructed. Concrete is typically stiffer than asphalt, but both materials are much stiffer than a tire. In neither case is the material's stiffness conducive to noise reduction: Pavement stiffness appears to be significant for noise attenuation only when it approaches that of a tire. In that case, however, the pavement's durability will be compromised. Still, innovative pavements termed poroelastic road surfaces (PERSs), constructed of epoxy-bound rubber particles, are currently under evaluation. Their acoustical performance appears quite good, due in part to their very low stiffness.

Concepts such as the PERS illustrate how engineers are seeking innovative, quieter pavements. Tire companies are similarly looking for novel, quieter tire designs that will be attractive to consumers—in particular to car companies, by far the biggest purchasers of tires. The challenge for both pavement and tire designers is to ensure a product that is not only quiet but also safe, durable, and affordable.

Additional resources

▶ R. O. Rasmussen et al., *The Little Book of Quieter Pavements*, rep. no. FHWA-IF-08-004, Federal Highway Administration, Washington, DC (July 2007), available at http://www.tcpsc.com/LittleBookQuieterPavements.pdf.

▶ P. R. Donavan, D. M. Lodico, *Measuring Tire Pavement Noise at the Source*, NCHRP rep. 630, National Cooperative Highway Research Program, Washington, DC (2009), available at http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_630.pdf. ■