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5aNS6. Evaluation of Discrete Vehicle Accident Sounds for use in Accident Reconstruction

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Vehicle accidents are complicated events and the resulting sound sequence created by that event is equally complex. Understanding how accident sounds are created is important for two main reasons. One reason is to better understand the events in an accident sequence that have not left visible physical evidence. There are often witnesses to vehicle accidents, and their observations include what they saw as well as what they heard. This information is useful when reconstructing the accident. Another reason is to be able to create more accurate simulated sound composites of an accident for use in forensic visualization, a visual/auditory tool that helps one understand a dynamic accident sequence that they were not able to see in person. While the composite accident sound is complicated when analyzed as an entire sound sequence it is still derived from discreet parts, and by analyzing the discreet parts individually one is able to better understand the contribution each individual sound makes to the entire accident sound sequence. This paper looks at some of the discreet sounds in a vehicle accident, and evaluates how changes in the parameters of the accident sequence affect the resulting sounds.

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INTRODUCTION

A vehicle accident involves a complex series of events that result in a unique and specific accident scenario. Even small differences in the details of the accident can have dramatic changes in overall accident sequence. The speed, weight, and orientation of the vehicles at impact, for instance, affect where the impact occurs, the impact duration and severity, and the final rest positions of the vehicles. Likewise, the sound that results from a vehicle accident is affected by similar parameters such as the dynamics, position and orientation of the vehicles. The unique circumstances of the accident determine the sound pressure level, the duration of the sound, the directivity of the sound, and the sound's frequency spectra. Some vehicle accidents involve tire skidding, glass breaking, engine noise, and tearing metal while other vehicle accidents include only some of these sound sources. These sounds depend on many variables and parameters such as the vehicle's characteristics, the vehicle's dynamic, and their surrounding environment. The experience of the sound is further complicated by the observers themselves. The position and orientation of the observer relative to the accident, and the hearing capabilities of the individual observer can affect the experience of sound.

Understanding the way this sound is created and affected through the unique circumstances of the accident is relevant for two main reasons. One reason is that forensic engineers rely on evidence to understand how an accident occurred. Witnesses often provide important information to forensic investigators by recalling the events they experience[1]. This recollection may be of events they saw as well as events they heard. So while much of the evidence in an accident may be visual some evidence is not. For instance, the revving of an engine due to rapid acceleration may be an important issue in an accident, though not visually observed. The locking of wheels may also be only auditory, as some surfaces and tires may not leave visible tire marks. Sound, then, can be an important piece of evidence used in accident reconstruction to gain a better understanding of the accident sequence.

The second reason it is important to understand how accident sound sequences are created and affected through the unique circumstance of the accident is that visualization tools, such as animations with sound, are effective tools at communicating what would otherwise be a dynamic and confusing event[2]. The ability to see an animation of an accident provides the viewer with both specific circumstance of the accident as well as an overall comprehension of the accident in terms of its duration, speed, and severity. Sound becomes an important component of the viewer's understanding of the accident since it adds more realism, but the sound in an animation also needs to accurately reflect the unique conditions of the accident. Understanding sound in an accident helps to create sound compositions in an animation that are more realistic, and more accurately represent the events of an accident.

The sound heard in a vehicle accident depends on many variables that can be analyzed by isolating these variables and evaluating the sound produced at a more discrete or individual level. Specific sounds like tire skidding, engine revving, yawing, braking, and impact sounds like tearing metal and glass breaking can be analyzed as individual events rather in the context an entire accident sequence. Recreating an entire accident is costly and impractical and makes understanding the discrete sounds rather difficult. Isolating variables that occur in an accident sequence make it possible to look at specific accident sounds, without having to remove this sound from other sounds. This paper looks at some of the discrete sounds commonly heard in an accident sequence, and evaluates how small changes in the parameters that created this discrete sound might affect the over composite sound of an entire accident sequence.

BACKGROUND

The sound that is heard in a vehicle accident is a composite of several sounds created by specific events. These events vary from accident to accident, and the presence of specific sounds resulting from these events can be determined by analyzing how the accident occurred, what physical evidence was deposited during the accident, and by analyzing the photos or documentation of the accident site. Some of the specific events that produce sound in an accident are listed in the table below:

Specific Accident Events	
1	Vehicle Accelerating
2	Vehicle Passing
3	Vehicle Skidding
4	Vehicle Yawing
5	Air underneath the vehicle
6	Sirens
7	Shattered Glass and Debris
8	Tearing of metal and components
9	Running motors
10	Equivalent Noise
11	Fluid
12	Fires

TABLE 1. List of Various Specific Accident Events

Even in an actual accident, when many of these sounds happen simultaneously, the specific sound sources can often be identified, because they have a unique frequency spectrum, sound level, harmonic relationship, tonal range, or other sound characteristic the makes them distinguishable to the human ear. However, understanding how the unique parameters or conditions of the accident sequence may affect a specific sound is not easy to determine in the context of an actual accident since there are so many variables affecting those sounds. The sound occurs in such a short period of time that evaluating the difference a change in the parameter of an accident has on the resulting sequence is very difficult[3]. In order to understand the effect different conditions or parameters of the accident sequence have on the resulting accident sounds, the individual sounds can be analyzed and evaluated independently. A specific accident event can be isolated for testing and factors affecting that sound such as the vehicle speed or road surface can be varied, and the changes in sound can be measured and recorded. The factors in an accident sequence that would change the resulting sound source are listed in Table 2.

Factors Affecting Sound in an Accident	
A	Characteristics of Environment
B	Vehicle Characteristics (size, weight, etc)
C	Vehicle Speeds
D	Impact Velocities
E	Impact details (orientation e.g.)
F	Characteristics of the observer
G	Observers orientation to the accident
H	Ambient and Surrounding sounds

TABLE 2. List of Factors Affecting Sound

The classifications listed in Table 2 demonstrate the enormity in variables that might affect the sound resulting in an accident. Simply within the characteristics of the environment (factor A), for instance, there are differences between the absorption properties of the surfaces, and the geometrical configuration of those surfaces in which an accident occurs. The accident may occur in an environment surrounded by buildings or in an open field, and the difference in reverberation, sound level, and directivity would be very different in each case[4]. Despite this fact, it is possible to generalize the effect these factors have can testing individual factors, and measuring their effect on sound. Combined with existing knowledge about the physics of sound, and research about how sound behaves in different environments can provide the basis for both understanding witness testimony about an accident and creating realistic sound in an animation of that accident.

TESTING PROCEDURES

The effect of the factors listed in Table 2 can be individually analyzed by changing the variable in the test sequence. For instance, the effect that the speed of the vehicle has on the sound of tire skidding can be independently analyzed, by testing various speeds in a skid to stop sequence. The testing sequences reported in this paper looked at the first three factors listed in Table 2 above. These factors included:

A) Characteristics of the Environment
B) Vehicle Characteristics
C) Vehicle Speeds

The specific accident events that were isolated for testing, and chosen to demonstrate how the resulting sound changes when the factors affecting the sound are altered, are listed below and include the first three events listed in Table 1:

1) Vehicle Accelerating
2) Vehicle Passing
3) Vehicle Skidding

In short, the accident events of acceleration, pass-by, and skidding are isolated and tested, with three variables being changed and the resulting differences measured, recorded and analyzed. The variables are the road surface (asphalt and gravel), the vehicle class (passenger, truck, or SUV) and the vehicle speeds (15, 30, and 45 mph). Table 3 demonstrates the variables and combinations tested in this study.

Specific Accident Event	**Variables**
Accelerating	Vehicle Class, Vehicle Speed
Pass-by	Road Surface, Vehicle Class, Vehicle Speed
Skidding	Road Surface, Vehicle Class, Vehicle Speed

TABLE 3. List of Tested Events and Variables Modified in the Testing

Setup

The Society of Automotive Engineers testing standard for vehicle noise was used to create the basic setup for the sound testing in this study[5]. This standard sets requirements for testing sound levels for acceleration and pass-by noise. Since the goal of this study was to understand the sound itself, rather than evaluating sound levels for design criteria, our testing setup varied slightly from the SAE testing standard. Below is a diagram showing the layout of our testing site and the three testing zones setup to measure and record the testing sequences.

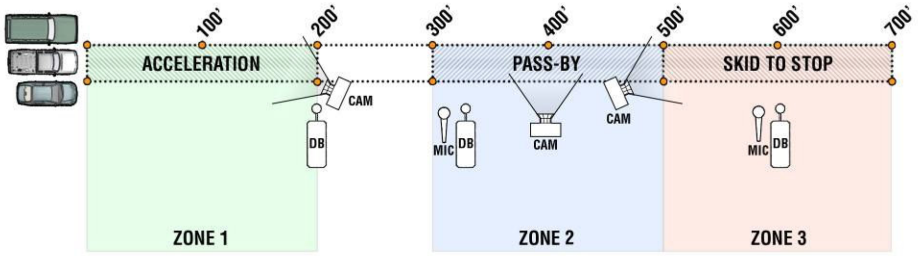
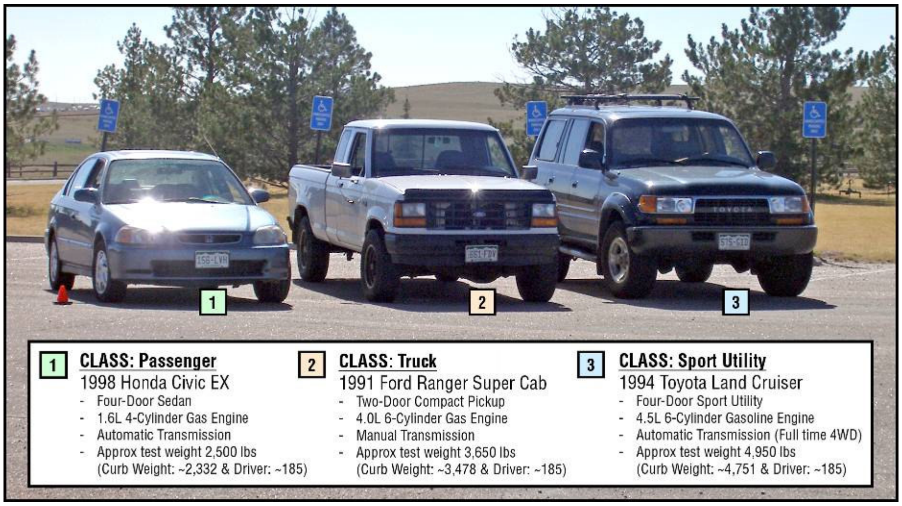


FIGURE 1. Layout of the Testing Site

As shown in this diagram, there are three main testing zones that correspond to three common sounds heard in an accident. These zones include acceleration, pass-by and skidding, noted as zone 1, zone 2, and zone 3 respectively. Equipment is setup at each zone to videotape and measure the sound pressure level over time. For the testing sequences in each of the zones, three different vehicles were used. The vehicles differed in their characteristics, primarily their geometrical size, engine size and vehicle weight. Other testing variables included the speed of the vehicle at the time it performed the test. Three speeds were chosen for testing in zones 2 and 3. These speeds were 15, 30 and 45mph. For the acceleration zone, the vehicles were accelerated at light, moderate and heavy pedal positions. Last, there were two surfaces on which this test setup was configured. Testing was done on asphalt and on gravel, to examine the difference that this surface material had on the sounds created in each zone.

Acquiring sound samples

Three different vehicles were used in this testing. These vehicles included a 1998 Honda Civic, a 1991 Ford Ranger, and a 1994 Toyota Land cruiser. The engine sizes and weights are shown in Figure 2.



1 **CLASS: Passenger**
1998 Honda Civic EX
- Four-Door Sedan
- 1.6L 4-Cylinder Gas Engine
- Automatic Transmission
- Approx test weight 2,500 lbs (Curb Weight: ~2,332 & Driver: ~185)

2 **CLASS: Truck**
1991 Ford Ranger Super Cab
- Two-Door Compact Pickup
- 4.0L 6-Cylinder Gas Engine
- Manual Transmission
- Approx test weight 3,650 lbs (Curb Weight: ~3,478 & Driver: ~185)

3 **CLASS: Sport Utility**
1994 Toyota Land Cruiser
- Four-Door Sport Utility
- 4.5L 6-Cylinder Gasoline Engine
- Automatic Transmission (Full time 4WD)
- Approx test weight 4,950 lbs (Curb Weight: ~4,751 & Driver: ~185)

FIGURE 2. Vehicles involved in Testing

These three vehicles were used to demonstrate a progressive geometrical size increase as well as engine size increase. These are variables that will have an impact on the sound created, since size will affect the flow of air and air pressure as the vehicle travels and the engine noise is dependent on the size and type of engine. The test consisted of two main surface types, gravel and asphalt. As depicted in Figure 1, each surface type had three zones, one for accelerating, one for passing and one for skidding to stop. Each of the vehicles was tested through these zones at 15 mph, 30 mph, and 45 mph. Speeds during the test sequence were monitored by the drivers through the vehicle's speedometer. At each of the zones, video recorded what was happening visually, and the sound meter recorded sound pressure levels as the vehicle traveled through the zones. The acceleration testing sequence was only performed on asphalt due to limitations in the size of the gravel area. The video equipment consisted of digital Sony video camcorders; the sound meters were American Recorder, set to A weighting, fast response time, and high dB range. In addition, the sound sources for skidding to stop were recorded using a Fostex FR-2LE 24 bit field recorder, set to a sample rate of 96 kHz. These sound clips were digitized and synced to the video for use in the analysis.

ANALYSIS AND RESULTS

In order to analyze how the different variables affected the resulting sounds, three sound characteristics were evaluated. These included the change in sound pressure level, the change in the duration of the resulting sound, and the difference in frequency spectra. To assist in this analysis, the recorded video, the recorded audio and the measured sound pressure levels were all digitally synced. When these are synced, it is possible to see both the measured effect of the sound differences, and also the time when that sound is occurring in the video. Figure 3 and Figure 4 graphically represent the digital sync of the pass-by and skid to stop testing results. The sound is shown as a wave form, representing changes in dB level over time.

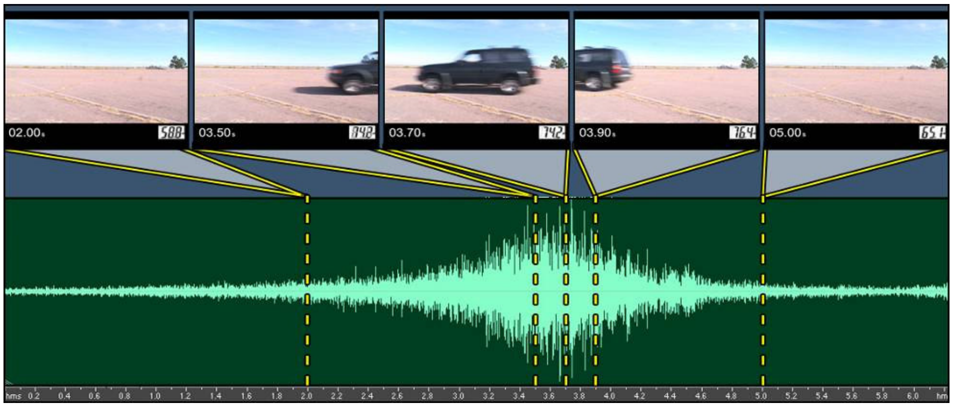


FIGURE 3. Composite of Video and Sound - Passby

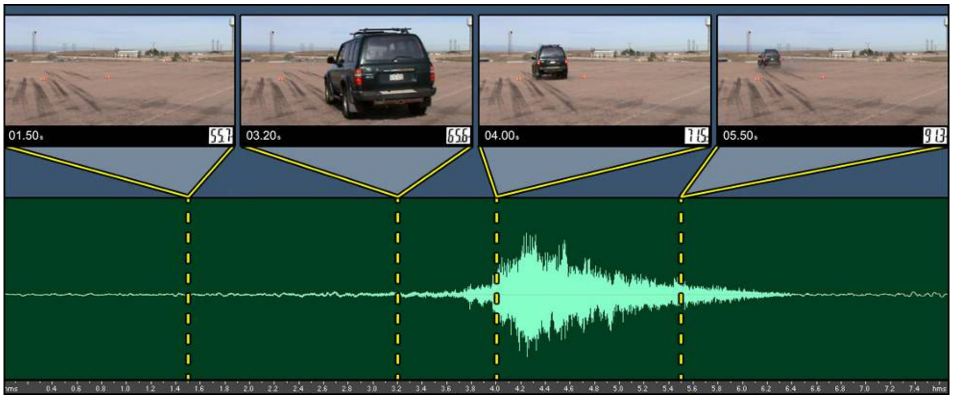


FIGURE 4. Composite of Video and Sound – Skid to Stop

The sound pressure levels were measured at 3 Hz and the video was NTSC standard recording at 29.97 frames per second (fps). This results in sound pressure levels being measured at every 10 frames. The sound samples were compared and evaluated according to how changes in the parameters of the test affected the sound pressure level, duration and frequency spectra. These results are represented in two sections below.

Sound Pressure Levels and Duration

The results of the analysis for how the sound pressure levels changed based on changed in the variable creating the sound are shown in Figures 5-13. In short, the comparative criteria for change in sound pressure and duration included the vehicle type, speed and road surface[6]. Vehicle speed affects engine noise and vibration noise, and also affects air noise resulting from aerodynamics of the vehicle shape, and air turbulence underneath the vehicle. The road surface is relevant since the tire to roadway surface interaction is the main source of noise, especially from vehicles at higher speeds[7]. Vehicle speeds and vehicle types were measured against recorded sound levels to form a picture of how these common accident sounds might differ from asphalt to gravel, from slow to high speeds, and between vehicles of different sizes.

When evaluating the effect of roadway surface on the sounds of skidding and the sounds from pass-by, several patterns emerged. The skid to stop sequence on asphalt was clearly louder than the skid to stop sequence on gravel. This was true regardless of the vehicle type, and was true at each speed interval tested. The data in Figures 5-7 demonstrates this, showing gravel in dotted lines, and asphalt in solid.

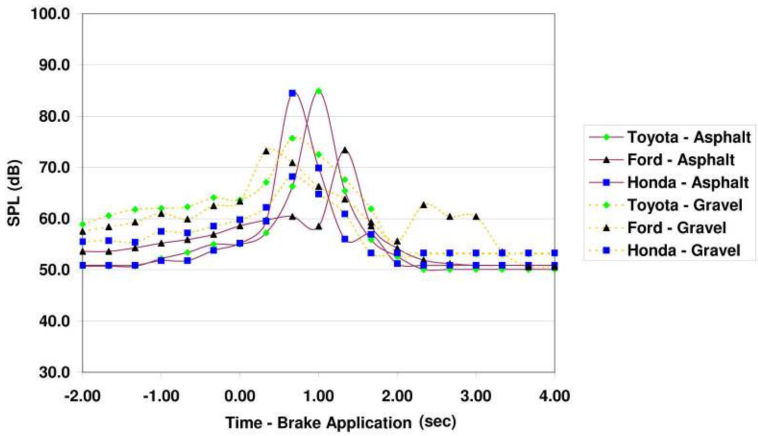


FIGURE 5. Skid to Stop – 15 mph

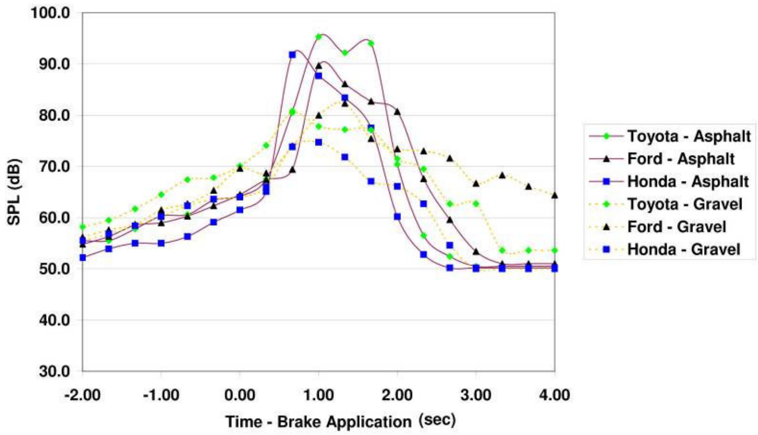


FIGURE 6. Skid to Stop – 30 mph

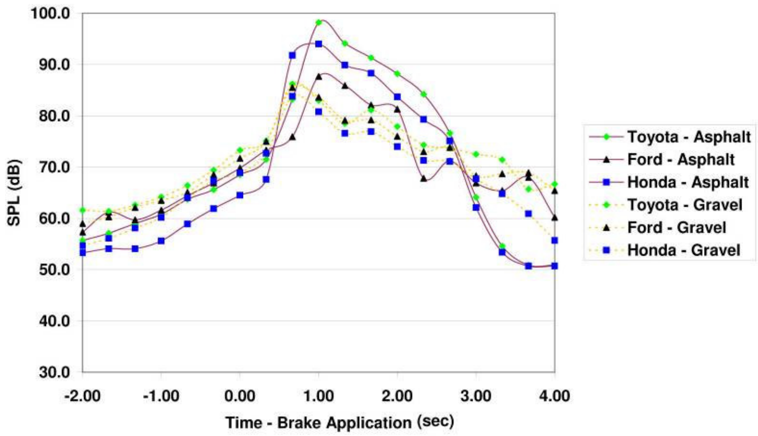


FIGURE 7. Skid to Stop – 45 mph

In the area where the tires have locked up and are actually skidding on the road surface, the sound pressure levels on the asphalt are always higher than those on gravel. This conclusion is consistent with the fact that asphalt has a much higher coefficient of friction than gravel. The tire/road-surface interaction on asphalt creates higher pressure since the friction between the tire and the road surface on asphalt is higher. However, while the skid to stop sound from the gravel was not as loud, its duration tended to be longer. This is also consistent with asphalts higher coefficient of friction, since the vehicle would take a longer time to stop on gravel than on asphalt, and hence the duration of the sound resulting from the skid to stop would be longer on the gravel surface than the asphalt.

Another pattern emerging when comparing the effect of asphalt and gravel on the sounds produced in the testing, is that for the passing sequences, the average sound pressure levels for each vehicle on asphalt was about the same as that for gravel. In fact, for all the speeds tested, the average sound pressure level showed little difference between asphalt and gravel beyond what would be expected due to the increase in vehicle speed. The data in Figures 8-10 shows the similarity in pass-by sounds at the three speeds tested. Again, the gravel is shown dotted, and the asphalt in solid line.

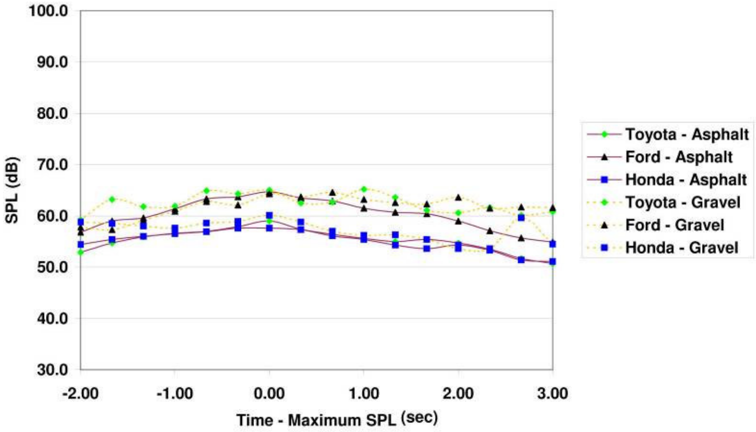


FIGURE 8. Passby – 15 mph

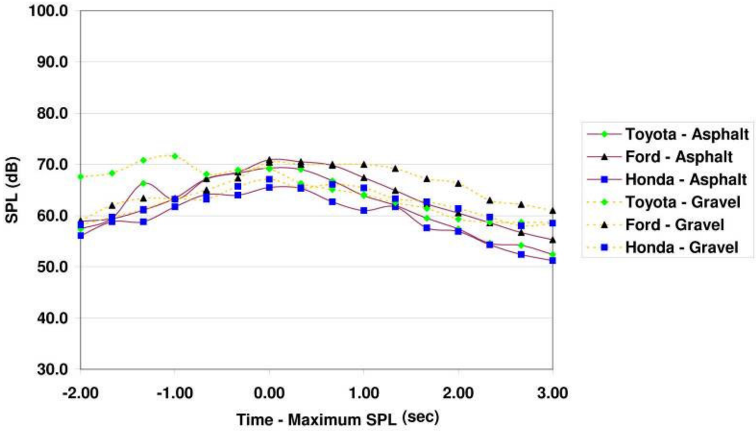


FIGURE 9. Passby – 30 mph

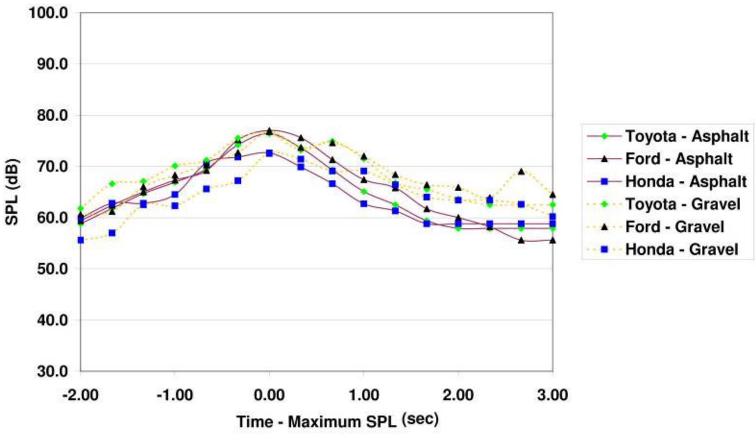


FIGURE 10. Passby – 45 mph

Any differences in the average sound pressure level tended to be more dependent on the vehicle class, than the surface type. For instance, the Honda typically had lower sound pressure levels than the Ford or Toyota vehicles. This could be due to the fact that the Honda is small geometrically, has a smaller engine, or simply weighs less. It could also be a function of the tire type, since the tires on the Honda are very different than on the other two vehicles. Since the topic of why and how tire/surface interaction creates noise is widely researched it is beyond the paper to draw conclusion about the source of this noise in the small sample size used in this testing.

When comparing the average sound pressure levels of all three testing sequences, a clear pattern emerges. Simply, the skid to stop sequence is louder than the acceleration sequence which is louder than pass-by sequence. This pattern is true at all the speeds tested, and is true for both surface types. Empirically this makes since, as most can tell the difference between the sounds of passing and the sounds of skidding. This difference is more pronounced at higher speeds. Figures 11-13 below demonstrates this pattern.

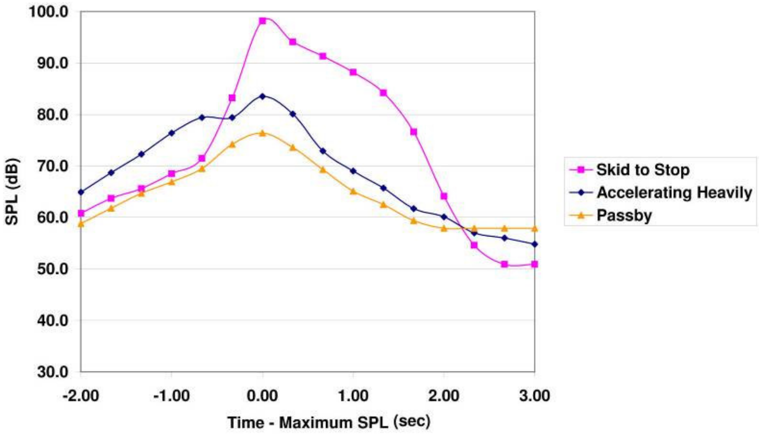


FIGURE 11. Toyota on Asphalt

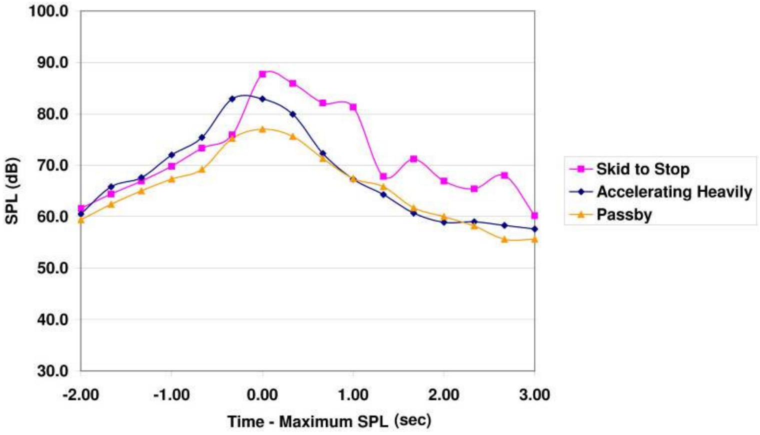


FIGURE 12. Ford on Asphalt

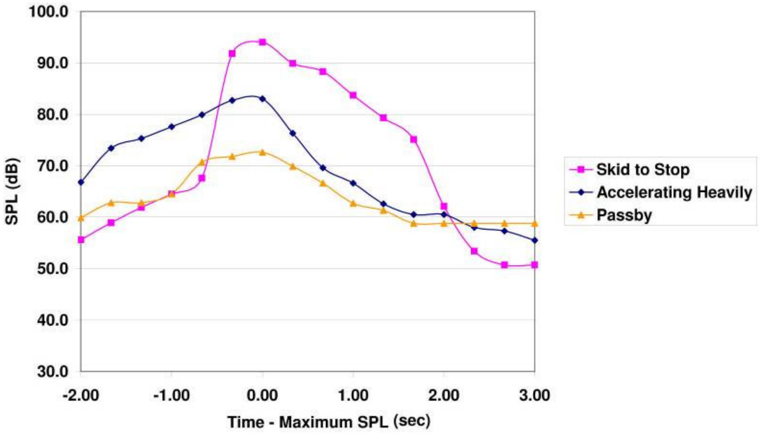


FIGURE 13. Honda on Asphalt

It is interesting to note the effect of transient braking on the results. Transient braking is the time elapsed during the engagement of the brakes, beginning with the first movement of the brake peddle and ending when the brakes are fully applied. It can be seen in the video and the sound recordings that transient braking affects the time when the wheel actually locks relative to when the brake pedal is depressed as indicated by a brake light in the video. It is clear, then, that the individual braking mechanism of the vehicles, along with the driver input directly influence the transient braking time, and subsequently the time when one hears the sound resulting from the locked wheels[8].

Frequency Distribution

In addition to analyzing the differences in sound pressure level and duration in the resulting sounds from the testing sequences, the difference in frequency spectra was also analyzed. The analysis looked at the difference in frequency distribution in the low, middle and upper frequency ranges. In Figure 14, the frequency distributions for acceleration, passing and skid to stop sequences are shown together. In short, the skid to stop sequence had higher sound pressure levels in the upper frequency ranges while the passing and acceleration sounds had higher sound pressure levels in the lower frequency ranges. Empirically this is true too, as the sound of tire skidding is often associated with a higher pitch. The passing sounds having more sound in the lower frequencies also makes empirical sense due to relatively large air space underneath the vehicle that would produced longer wave lengths.

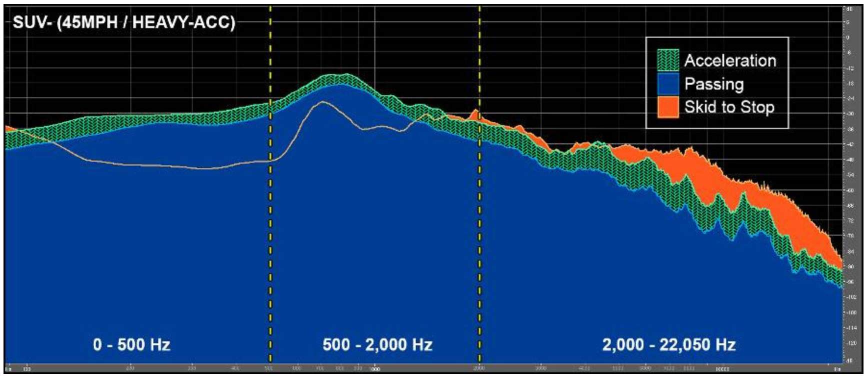


FIGURE 14. Frequency Distribution Comparison – Vehicle Maneuver

When analyzing the impact that surface material (asphalt or gravel) has on the frequency ranges of the sounds created in the skid to stop sequence, the differences tend to be in the lower frequencies, where gravel contains a higher sound level of low range frequencies than the asphalt. Figure 15 below demonstrates this difference. In the upper half of higher frequencies the gravel also has higher sound levels than asphalt. This may be due to the actual gravel material that creates popping sounds during the tire/surface interaction as the tire is locked while it grinds over the gravel surface. The debris in the gravel is not present in the asphalt surface, and hence not represented in these upper frequencies.

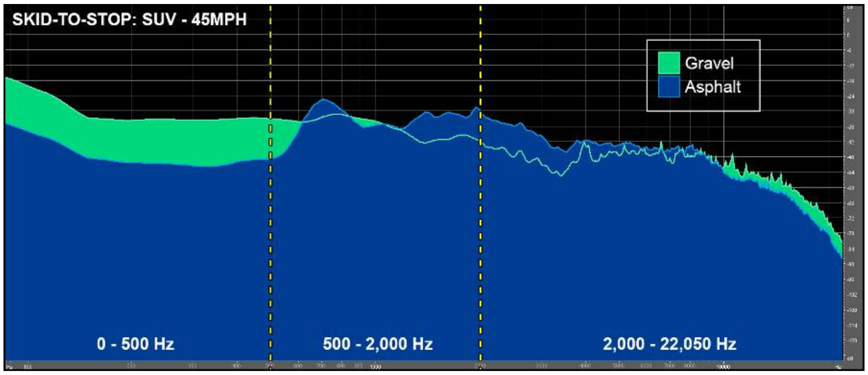


FIGURE 15. Frequency Distribution Comparison – Surface Type

CONCLUSION

Many variables create and affect the experience of sound in an accident and it is beyond the scope of this paper to address them all. Rather, this paper simply tackles a few of these variables and evaluates them independent of the overall accident sound sequence. Specifically, this paper looks at how vehicle weight size and speed affect the sound, and also how the sound is affected by different roadway surfaces such as gravel and asphalt. From this testing and analysis, patterns emerge, suggesting that, for instance, sounds of skidding are louder on asphalt than on gravel, and that the sound of a passing vehicle depends more on the vehicle type than the surface on which the tires are interacting. These patterns create a greater understanding overall of accident sound sources, and specifically, how the many variables in any one accident can be better understood leading to better sound simulation, or greater clarity about the events in the accident. It is to this end that the testing in this paper and future research aims to make progress. Clearly the ability to accommodate more variables and to have greater control over the testing samples, specifically the quality of the sound samples, is an important component validating the testing. The procedures will continue to be more accurate, but more importantly, as the body of knowledge continues to grow, and discrete accident sound sources and variables that affect the sound are correlated, a more accurate picture of how the overall sound is affected will emerge.

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