



SAE
**COOPERATIVE
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PROGRAM

400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096-0001 U.S.A.

SAE and ISO Noise Test Site Variability

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SAE and ISO Noise Test Site Variability

AUTHORS

Richard F. Schumacher,

Noise and Vibration Center
North American Operations
General Motors Corporation

Kenneth G. Phaneuf,

Grass Lake Engineering Center
Walker Manufacturing
Division of Tenneco Automotive

William J. Haley,

Core and Advanced Vehicle Systems Engineering
Advanced Vehicle Technology
Ford Motor Company

ABSTRACT

A Society of Automotive Engineers (SAE) Cooperative Research Project has established good correlation between pass-by noise data measured on U.S. test tracks conforming to SAE Sealed (sealed asphalt) and International Standards Organization (ISO) surface specifications. Although the ISO surface has a very specific track composition, it does not reduce the variability of the measurements over an SAE Sealed surface. The project established that the SAE Sealed surface generally produces slightly louder noise levels than a comparable ISO surface when used for pass-by testing, but the SAE Sealed surface does not represent a consistent upper boundary for the ISO test data. The data supports the use of either track surface for pass-by procedures and also suggests that road texture can influence the tire component of vehicle noise.

INTRODUCTION

Recent actions by the European Community (EC) to incorporate a test track surface specification into their ISO pass-by noise procedure R362, "Acoustics - Measurement of noise emitted from accelerating road vehicles - Engineering method" would preclude the use of the SAE Sealed and SAE Unsealed (unsealed asphalt or concrete) test tracks used throughout the United States for certifying vehicles for export to Europe.

In countries with pass-by noise regulations, the vehicle manufacturer must demonstrate compliance to the regulations as part of the legal certification of the vehicle prior to sale. The U.S. automotive manufacturers and many of their component suppliers have test tracks which comply with the SAE [1][2][3] and Environmental Protection Agency (EPA) [4] site specifications. Certification testing for the EC markets would require construction of new test tracks conforming to the ISO-10844 surface specification [5].

The objective of this project was to compare the site-to-site variability of test tracks which comply with the SAE requirements to test tracks which meet the ISO test surface specifications [5] and to quantify any mean measured sound level differences which may exist. The data is intended to provide the rationale to either justify the expenditure to install new ISO test surfaces or identify a correlation factor to use in reporting "ISO" results run on an SAE test site.

This paper describes the controlled experiments performed using five vehicles on 14 test tracks (five SAE Sealed, six SAE Unsealed and three ISO) located in the United States. Three distinct procedures were performed at each site. Cruise-by and coast-by procedures were performed at 56 km/h and pass-by accelerations were performed in accordance with SAE J1470. The tests were conducted according to a statistical sampling plan under controlled conditions to reduce data variability resulting from environmental and procedural factors.

The measurement equipment was provided and operated by Bruel & Kjaer and was transported with the test vehicles, tires and technicians. The test vehicles were driven by the same driver for each test throughout the program and test tires were fitted to each vehicle prior to the testing. Each vehicle was driven on a prescribed warm-up prior to testing to ensure that the vehicle and tires were at normal operating temperature.

FACILITIES

The program included 14 test sites from nine participating companies (Appendix A). The sites represented by a letter code in Table 1 are classified into three groups. One group designated SAE Sealed, conforms to the SAE specifications with a bituminous asphalt sealer. The sealer is required for asphalt sites to conform to the US Federal EPA heavy truck test site requirements. The group designated SAE Unsealed, meet the SAE specifications without sealant. The group designated ISO, conform to the ISO 10844 material and surface specifications.

Table 1 also identifies the characteristics of the top wear course (uppermost 20-25 mm) for all test surfaces. The SAE requirement for non-porous asphalt or concrete implies that the wear course influences the generation, absorption and propagation of sound for a test site. The characteristics of the subsurface were considered to have no influence on the results. This project included one concrete wear surface (Site Code K).

Table 1 Site Identification and Surface Characteristics

Site Code	Surface Type	Surface Material
A	SAE Sealed	Asphalt Consisting of Soft Lime Rock and Sand with 32% Passing Sieve #30 and 80% Passing Sieve #4; Sealed with Jennite 16 Sand Filled Asphalt Sealer
B	SAE Unsealed	Asphalt
C	SAE Sealed	Sheet Asphalt with Torpedo Sand Aggregate; Sealed with Jennite Asphalt Sealer & Sand
D	ISO	Asphalt mixed to ISO/DIS 10844 with 28% Passing Sieve #30 and 77% Passing Sieve #4
E	ISO	Asphalt mixed to ISO/DIS 10844 with 28% Passing Sieve #30 and 77% Passing Sieve #4
F	SAE Unsealed	Sand Asphalt per Indiana Spec. #403.04 with 100% Passing Sieve #4 and 20% crushed stone sand
G	ISO	Asphalt mixed to ISO/DIS 10844 with 28% Passing Sieve #30 and 77% Passing Sieve #4
H	SAE Sealed	Asphalt Aggregate with 30% Passing Sieve #30 and 80% Passing Sieve #4; Sealed with Jennite 16 Sand Filled Asphalt Sealer
I	SAE Unsealed	Vehicle Lane is Asphalt Aggregate with 30% Passing Sieve #30 and 80% Passing Sieve #4; Measurement Pad is Stone and Sand with 30% Passing Sieve #30 and 70% Passing Sieve #4
J	SAE Sealed	Asphalt Aggregate with 20% Passing Sieve #30, 70% Passing Sieve #8 and 90% Passing Sieve #4. Sealed with Jennite 16 Asphalt Sealer with sand
K	SAE Unsealed	Burlap Dragged Concrete
L	SAE Unsealed	Asphalt mixture 1100Taa Series Michigan State Mix
M	SAE Sealed	Fine Grain Asphalt with 50% Passing Sieve #30 and 99% Passing Sieve #4; Sealed with Jennite 16 Asphalt Sealer and 3 pounds of sand per mix
N	SAE Unsealed	Asphalt Consisting of Soft Lime Rock and Sand with 32% Passing Sieve #30 and 80% Passing Sieve #4

VEHICLE / TIRE SELECTION

The program was designed to evaluate the site-to-site variability of sound measurements acquired during vehicle pass-by testing. Recognizing that a portion of the variability could be attributed to vehicle/tire surface interaction, this program included a cross-section of vehicle models, with components representing a mixture of product characteristics (See Appendix B). The program included five vehicles equipped with a 4 or 6 cylinder engine. Two vehicles had manual transmissions and three had automatic transmissions. The vehicles represented build combinations available for international markets.

The vehicles were equipped with standard production tires ranging from performance to touring styles. This offered a range of tire constructions that were expected to respond differently to various driving cycles and test track surfaces [6][7].

EQUIPMENT

The Research Program Committee eliminated the influence of individual site measurement equipment by using the same set of instrumentation at all test locations. The individual test sites provided the environmental instrumentation.

The instrumentation was calibrated before each measurement series and when necessary, to verify ongoing performance. The instrumentation package included a personal computer that controlled the sound data acquisition system. The resulting data set included right and left sound pressure levels, engine speed and vehicle speed digitized by position on the course. Third octave spectra were also acquired for each side of the vehicle at quarter meter intervals along the test course from 15 meters (-15) before the microphone line to 15 meters (+15) after the microphone line. Photo cells located 15 meters before and after the microphone centerline were used to start and stop the data acquisition system.

DATA ACQUISITION

Two important sources of vehicle noise are the powertrain and the tire/road interaction. The data available [7] indicated that among other factors, the acoustic behavior of the tire/road interface is influenced by the level of torque being transmitted to the surface. The test program therefore included three distinct operating conditions. The free rolling coast-by procedure at 56 km/h did not include a torque load. The cruise-by procedure produced a minor torque load on the tires. A high torque loading condition was applied through the use of the wide open throttle acceleration procedure. The torque loading varied with each vehicle due to vehicle differences. Although the loading was not measured in this project, similar tests by Donovan [6] resulted in acceleration rates in the range of 1.5 to 2.3 m/sec² that translated to high torque at the tire road interface.

A full factorial Design of Experiments (DOE) process was used to develop the sampling plan. The plan provided adequate replication and randomization in identifying and measuring the effect of test site variation on pass-by noise measurements. Site and vehicle selections were blocked (grouped) to minimize the transportation costs and time delays. The plan indicated that the test site order was not crucial to maintaining a random sample, therefore, the plan specified a random order for test vehicles and test procedures only (See Table 2). All three test procedures were completed for a given vehicle before proceeding to the next vehicle.

The environmental conditions under which the testing was performed met the SAE J1470 specifications except for the ambient temperature, which was restricted to 15°C ± 5°C. Wind speed was restricted to <19 km/h. Historically, humidity and barometric pressure have not correlated with sound level measurements, therefore no attempt was made to restrict these variables. Since data from SAE and ISO standards committees have indicated that pad temperature can influence sound measurements, pad temperatures were measured when available but no limitations were imposed.

A tabulation of the raw data is shown in Appendix C. A summary of all the data for each vehicle sorted by site type is shown in Appendix D.

Table 2 Sampling Arrangement of the Vehicles Sites and Procedures

Vehicle Site	I			II			III			IV			V		
	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
A	51	53	52	13	12	11	33	31	32	42	43	41	23	22	21
B	11	12	13	33	32	31	21	23	22	53	51	52	43	41	42
C	11	12	13	42	42	41	51	53	52	22	23	23	31	33	32
D	23	21	23	11	13	12	41	42	43	32	31	33	#	#	#
E	31	32	33	22	21	23	11	13	12	51	52	53	41	43	42
F	52	51	53	41	42	43	12	11	13	31	33	32	23	21	22
G	13	12	11	23	22	21	32	33	31	52	51	53	43	41	42
H	13	12	11	31	32	33	41	42	43	51	53	52	21	22	23
I	52	51	53	42	41	43	23	22	21	13	12	11	33	32	31
J	12	11	13	53	51	52	22	23	21	31	32	33	43	41	42
K	52	51	53	42	41	43	23	22	21	13	12	11	33	32	31
L	33	31	32	11	12	13	22	21	23	52	53	51	43	42	41
M	11	13	12	23	22	21	42	43	41	32	31	33	53	51	52
N	11	12	13	33	31	32	21	23	22	#	#	#	#	#	#

NOTE: The following key should be applied to Table 2:

x - SAE J1470 Acceleration test, y - Coast-by test with transmission in neutral, z - Cruise-by test with transmission in appropriate gear range

11 through 53 - the first digit indicates the order in which the vehicle was tested at that site. The second digit indicates the order in which the specific procedure was run at that site. For example a 11 is the first car and the first test procedure, 53 is the fifth vehicle run and the third procedure on that vehicle.

- indicates that this vehicle was not tested at this site

The instrumentation was set up in a location at each site to minimize the interference on the sound measurements. All data was scrutinized during the data acquisition process to ensure that no systematic or ambient influences affected the results. All sites met the clear area requirements for free field radiation conditions as specified in SAE J1470. The committee determined that the tests would be qualified based on the vehicle speed and location criteria developed in the proposed revision of SAE J1470. The acceleration test was accepted if the vehicle approach speed was 50 ± 1.2 km/h at the 10 ± 1.5 m position before the microphone line (Figure 1). The coast-by and cruise-by tests were accepted if the vehicle speed was 56 ± 1.2 km/h at the microphone line ± 1.5 m (See Figure 2). The data was rejected if any of these criteria were not met or when ambient conditions were outside the specified limits. Testing on each vehicle continued for each procedure until four measurements on each side of the vehicle were obtained that met the requirements above.

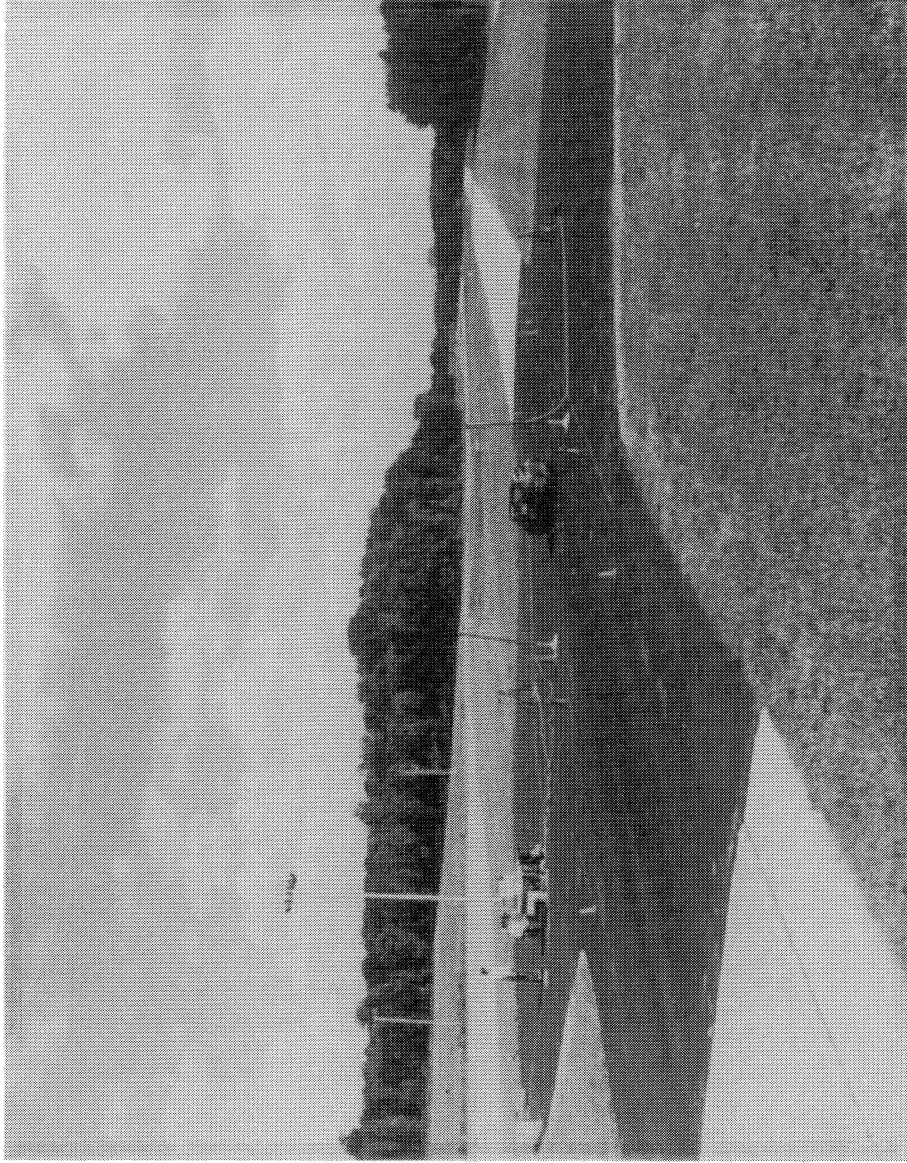


Figure 1 Typical Test Site

This is an example of the typical test facility used in the project. At all sites the measurement area is located at least 50 feet from the support building or trailer. The portable system was positioned off to the side of the microphone to minimize influence on the measurement. The site shown has the SAE Sealed surface.

Figure 2 SAE J1470 Test Controls

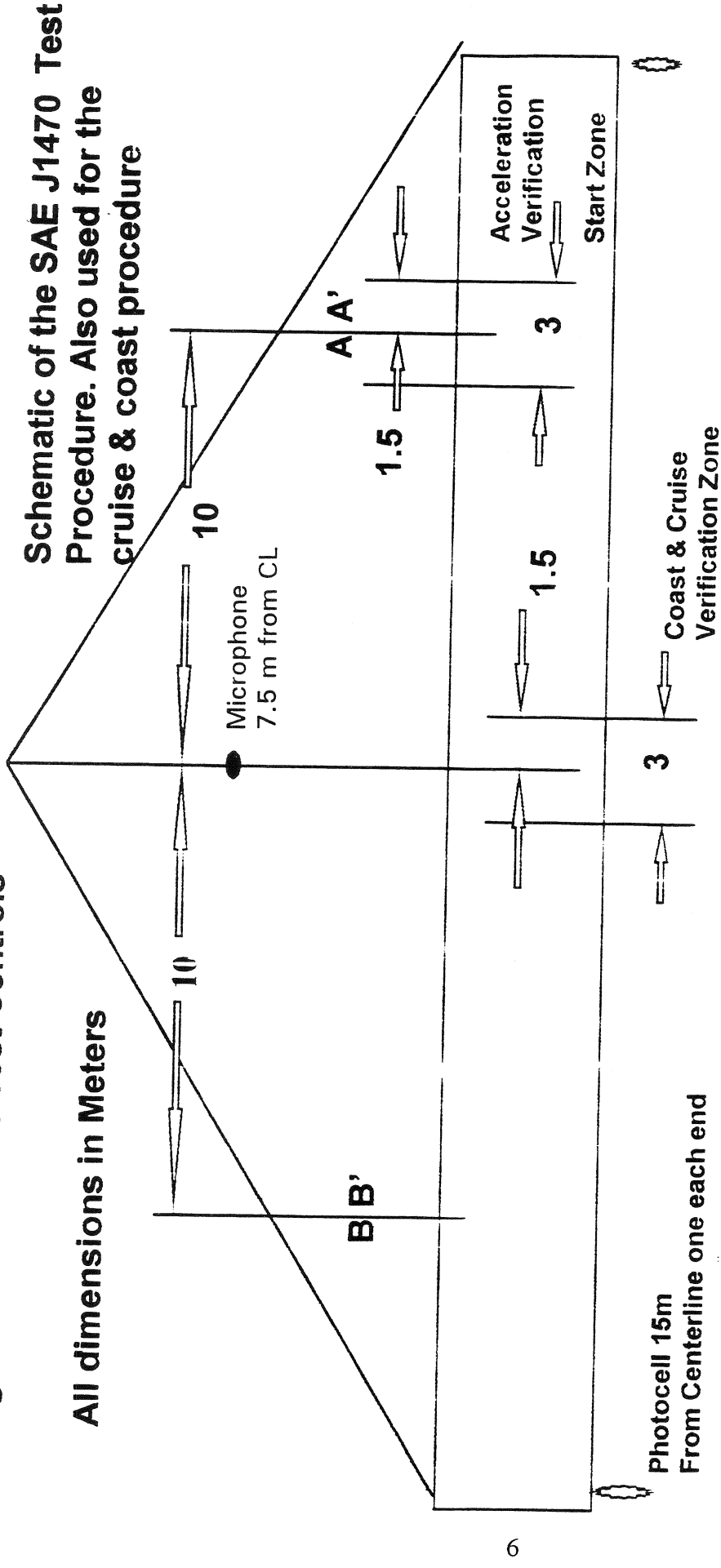


Figure 2 SAE J1470 Test Controls

Transmission gear selection for the acceleration tests were based on SAE J1470 specifications. Second gear was used for the manual transmissions¹ and Drive or Overdrive for the automatics. The cruise-by tests were run in third gear for manual transmissions and Drive or Overdrive was selected for the automatics. All coast-by tests were conducted with the transmission in neutral and the engine at idle. Preliminary testing at project inception established that coast-by results at 56 km/hr were not affected by the idling engine.

A test site strategy was developed and used at all sites to minimize the vehicle/tire variations. A unique tire/wheel assembly for each vehicle/wheel position was installed prior to testing. An 80 km tire conditioning break-in was run at highway speeds at the beginning of the project. Subsequently, tires were warmed up by operating at highway speeds for 32 km immediately prior to the testing sequence being performed. In addition, there was a one minute wait between each pass to maintain powertrain temperature stability. The test tire/wheel assemblies were removed for vehicle transportation and storage immediately after testing.

RESULTS

Statistically significant differences in decibel readings were found between tests, surfaces, and vehicles. Significant differences were also found for the two-way interactions of these variables (Vehicle x Surface, Test x Surface and Test x Vehicle). These are summarized as follows:

- A statistically significant difference was found among surfaces for all three tests. The average decibels for test X were significantly higher on the Sealed surface than on the ISO and Unsealed surfaces. The ISO and Unsealed surfaces were not significantly different from one another. For tests Y and Z, all three surfaces were found to be significantly different with the Sealed surface having the highest mean decibels and the ISO having the lowest mean decibels.
- The Vehicle x Surface interaction was significant for all three tests. The difference between noise levels for the different surfaces was a function of the vehicle tested.
- The Test x Surface interaction was significant for all vehicles. The difference between noise levels for the different surfaces was a function of the test procedure.
- A statistically significant difference was also found for vehicles, tests and their interaction, however these effects were not of primary interest to this study.
- A comparison of the site-to-site variation within each surface found that the Sealed surface had significantly lower site-to-site variation than the Unsealed surface. The site-to-site variation for the ISO surface was not significantly different than the other two. However, the power of the tests for the ISO surface to detect differences was limited by the small sample size (only three ISO sites measured).

¹ The purpose of this project was to evaluate the variations of test sites rather than determine the absolute level of the product being used as a typical noise source, therefore, the 5 speed manuals were not tested in third gear per SAE J1470.

Although there are statistically significant differences present, they may not be acoustically meaningful. The magnitudes in decibels of the differences for the Surface fixed main effects are summarized in table 3. The values are ordered from highest to lowest average values. The column labeled "Difference" shows the difference between the ordered averages with statistically significant differences shaded. For example, Table 3 shows that a difference in average decibels of 0.52 between the Sealed and Unsealed surfaces was statistically significant, while a difference of 0.22 between Unsealed and ISO was not.

Table 3 Surface Comparison

DIFFERENCES BETWEEN SURFACES Statistically Significant Differences are Shaded						
SURFACE	TEST PROCEDURE					
	X		Y		Z	
	AVERAGE	DIFFERENCE	AVERAGE	DIFFERENCE	AVERAGE	DIFFERENCE
SEALED	76.15		69.42		70.03	
UNSEALED	75.63	0.52	68.69	0.73	69.44	0.59
ISO	75.41	0.22	67.66	1.04	68.43	1.01

A difference between vehicle sides was known to be caused by specific vehicle components and therefore, was not included in this analysis. It is important to note the analysis assumptions listed in the following section.

ANALYSIS ASSUMPTIONS

Randomization of this experiment was limited for the following reasons:

- Cost and time constraints allowed only one visit to each site.
- Time constraints dictated that once a given vehicle was instrumented all three test procedures (Coast-by, Cruise-by and Accel) would be completed for that vehicle.
- The time involved in setting up a test (Coast-by, Cruise-by or Accel) dictated that a given site/vehicle/test configuration be run four times in a row.

Randomization efforts were therefore limited to 1) the order in which the vehicles were run at each test site, and 2) the order in which the tests were run for each vehicle at each test site. The result of these constraints on the experiment is that in order to estimate the magnitude of the vehicle and test effects, any other effects that could be the result of not randomizing completely must be assumed negligible. In other words it must be assumed that there are no time effects related to noise levels, under the given test conditions.

A danger in this assumption may be illustrated by an example. Suppose ambient temperature was increasing during the testing period, leading to decreased sound levels. Because the data for each vehicle was collected sequentially, we would then be introducing this temperature effect into the vehicle variable. In other words, there would be no way to separate differences due to temperature from differences due to vehicles. Note this particular example is not of concern in this case since the tests were only run when ambient temperature fell within a specified range, chosen to minimize this temperature effect (scatter plots support this choice of ambient temperature range).

ANALYSIS TECHNIQUES

Analysis of Variance was used to determine if the average decibel readings were statistically different among the different tests, surfaces and vehicles, and their interactions. A statistically significant difference was defined at the 95% confidence level. That is, a difference was declared if the effect of a given variable calculated in the experiment would be observed by chance less than 5% of the time given that the variable in fact had no effect.

The variables test and surface were analyzed as "fixed" factors while the vehicle was analyzed as a "random" factor. Fixed factors are those for which levels are specifically chosen in an experiment. The conclusions of the experiment apply only to the specific levels chosen. Random factors are those for which the levels are a random sample from a larger population of levels and it is desirable to extend the conclusions of the experiment to this larger population. Therefore, surface is a fixed factor because we are only interested in the three surfaces selected while vehicle is a random factor because we want to extend our conclusions to the population of possible test vehicles.

For fixed main effect variables found to be significant, Tukey's Studentized Range Test was used to determine which values of the variable were different from one another.

The comparison of variation among sites for each surface was conducted by estimating the variance due to site for each test and surface combination. These values were then compared via an F-test.

SUMMARY

The SAE J1470 acceleration procedure showed a statistically significant difference between the SAE Sealed surfaces and the ISO surfaces. The same is true for the coast-by and the cruise-by procedures. The data also indicates that the mean measured sound level is higher for the SAE Sealed surfaces than the ISO surfaces (See Table 4). For particular combinations of vehicle and test procedure, exceptions to this finding have been encountered.

There is no statistically significant difference in variability between the SAE Sealed surfaces and the ISO surfaces. By contrast, the SAE Unsealed surfaces result in measurements with a significantly greater variability than either the SAE Sealed or ISO sites.

Table 4 Data Summary - Average of All Five Vehicles

SAE Unsealed		SAE Sealed				ISO	
		Left	Right	Left	Right	Left	Right
Accel	Average	75.8	76.5	75.1	75.8	75.3	76.0
	Avg. Max.	77.5	78.0	76.7	77.3	77.8	78.3
	Avg. Min.	74.6	75.4	73.8	74.4	72.9	73.8
	Avg. Spread	2.9	2.7	2.9	2.9	5.0	4.5
	Std. Dev.	0.8	0.8	1.0	1.0	1.4	1.3
Coast-by (56 km/h)	Average	69.4	69.4	67.8	67.6	68.6	68.6
	Avg. Max.	72.1	71.9	69.2	69.1	72.3	71.9
	Avg. Min.	67.8	67.7	66.8	65.9	64.6	64.2
	Avg. Spread	4.3	4.2	2.4	3.2	7.8	7.7
	Std. Dev.	1.3	1.2	0.9	1.2	2.5	2.5
Cruise-by (56 km/h)	Average	70.0	70.1	68.5	68.4	69.5	69.4
	Avg. Max.	72.4	72.4	70.3	69.9	72.9	72.4
	Avg. Min.	68.5	68.7	67.2	66.9	65.4	65.3
	Avg. Spread	3.9	3.8	3.1	3.0	7.4	7.1
	Std. Dev.	1.1	1.1	1.0	1.0	2.3	2.3

CONCLUSIONS

The site to site variability between the SAE Sealed surfaces and the ISO surfaces was not significantly different (Table 4) [8]. This is attributed to the effects of the sealant coat on the macro texture of the SAE Sealed surface and the specification for small grain material in the asphalt mix of the ISO surface which results in a similar macro texture. The analysis of the differences between the Sealed and the ISO surfaces indicates that, at the 98% confidence level, the difference in the mean dB readings for the Sealed surface will be between 0.4 and 1.1 dB higher than from the ISO surface (see Table 5). The same applies to the coast and cruise data from within their respective ranges.

Table 5 Confidence Intervals for the Difference Between Mean Decibel Readings For Sealed and ISO Surfaces

Test	Surface Comparison	Lower 98% Confidence Limit	Difference Between Means	Upper 98% Confidence Limit
X	SAE Sealed - ISO	0.42	0.74	1.07
Y	SAE Sealed - ISO	1.24	1.76	2.28
Z	SAE Sealed - ISO	1.13	1.60	2.08

Confidence Interval Interpretation: If one were to repeat this experiment many times and calculate 98% confidence intervals, one would expect 98% of the intervals constructed to contain the true but unknown value being estimated.

ACKNOWLEDGMENTS

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APPENDIX A **Participating Companies**

Company
AP Parts Mfg. Co.
Arvin Industries
Chrysler
Bridgestone/Firestone Inc.
Ford
General Motors
General Tire
Goodyear
Walker Manufacturing

Product
Automotive Exhausts
Automotive Exhausts
Vehicles & Components
Tire & Rubber Products
Vehicles & Components
Vehicles & Components
Tire Products
Tire & Rubber Products
Automotive Exhausts

Corporate Headquarters
Toledo, Ohio
Columbus, Indiana
Highland Park, Michigan
Nashville, Tennessee
Dearborn, Michigan
Detroit, Michigan
Akron, Ohio
Akron, Ohio
Racine, Wisconsin

APPENDIX B **Vehicle and Tire Description**

<u>Number</u>	<u>Vehicle Description</u>	<u>Tire Description</u>
I	Production Compact 2 Door Hatchback 4 Cylinder Engine with 5 Speed Manual Transmission, Front Wheel Drive	Production Touring Tire Size - P175 / 70 R 13 Test Pressure 221 kPa
II	Production Midsize 4 door Sedan 6 Cylinder Engine with 4 Speed Automatic Transmission, Front wheel Drive	Production Touring Tires Size - P205 / 70 R 14 Test Pressure 241 kPa
III	Near Production Midsize 2 Door Sedan 4 Cylinder Engine with 3 Speed Automatic Transmission	Production Aggressive Sport Tire Size - P215 / 60 R 14 Test Pressure 207 kPa
IV	Prototype Small Passenger Van 4 Cylinder Engine with 5 Speed Manual Transmission, Front wheel Drive	Production European Tread Size - P205 / 65 R15 Test Pressure 241 kPa
V	Near Production Midsize 4 Door Sedan 6 Cylinder Engine with 3 Speed Automatic Transmission, Front Wheel Drive	Production Touring Tire Size - P195 / 70 R14 Test Pressure 221 kPa