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REPORT

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WYLE RESEARCH REPORT

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LIGHT VEHICLE NOISE: VOLUME I — DEVELOPMENT OF A TEST PROCEDURE TO MEASURE THE NOISE EMISSIONS OF LIGHT VEHICLES OPERATING IN URBAN AREAS

For

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control
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1.0 INTRODUCTION

1.1 Background

The noise produced by motor vehicles is a major factor in determining community noise exposure in urban and suburban areas. The largest contribution to this exposure is provided by medium- and heavy-duty trucks due to the individually high sound levels produced by this type of vehicle. Automobiles and light trucks, collectively termed light vehicles, produce much lower levels individually, but their large numbers (automobiles outnumber trucks by the ratio 9 to 1) result in a significant contribution to community noise exposure. Other vehicles, such as buses and motorcycles, are present in much smaller numbers than trucks or automobiles in most urban and suburban situations. However, the individual sound levels are high and hence these vehicles constitute a significant noise problem.

In an attempt to reduce the noise exposure from motor vehicles, EPA has established both new vehicle and in-use noise standards for medium- and heavy-duty trucks, and has proposed new vehicle standards for buses and motorcycles. These actions will result in the introduction of quieter vehicles in future years. Light vehicles, on the other hand, have not yet been addressed with regulations by EPA, and there are indications that recent moves by the U.S. Congress to require reductions in light vehicle gasoline consumption will lead to the introduction of diesel engines in light vehicles and more vehicles with small engines which, in turn, may result in an increase in sound levels, particularly in the acceleration mode.[1] To evaluate the extent of this potential increase, and its effect on community noise exposure, it is necessary to develop a data base of the sound levels produced by light vehicles, projected to form a major part of the fleet in future years, and compare this to levels produced by vehicles in today's fleet. To this end, a suitable method for measuring vehicle sound levels is required.

There are several methods for measuring the noise emissions of light vehicles, but these involve operations that are not representative of the way in which vehicles are typically operated, and hence are considered unsatisfactory as they do not rank vehicles in accordance with their contribution to community noise exposure. The method currently in general use in the United States is defined in the Society of Automotive Engineers (SAE) J986a procedure[2] that specifies the measurement of sound for full-throttle vehicle operation at speeds in excess of 30 mph. From existing vehicle operation surveys, it is known that full-throttle acceleration is not a typical mode of operation for most light vehicles, and hence is responsible for only a part of the urban community noise exposure. Further, vehicles exhibiting similar sound levels as measured by the SAE J986a procedure do not necessarily contribute equally to community noise. It has also been observed that values of noise reduction achieved by many engineering treatments as measured under full-throttle conditions are not exhibited in other less severe but more typical operating conditions. The standard method of measurement used in Europe — namely, the International Standards Organization (ISO) R362 procedure[3] — is very similar to the SAE J986a procedure in terms of vehicle operation and hence is equally unsatisfactory.

Because the existing established full-throttle procedures do not provide a method for reasonably assessing community noise exposure due to light vehicles, a more representative procedure for light vehicle acceleration was developed and validated.

1.2 Description of the Program

In January 1977, a program was initiated to develop and validate a suitable noise test procedure for light vehicles that would rank vehicles according to their contribution to community noise exposure during typical urban acceleration. To achieve this objective, it was decided that the vehicle operation required by the test procedure should simulate that exhibited in typical urban driving conditions. A preliminary review of the published data on light vehicle operations in urban areas indicated a lack of detail in the vehicle parameters that would be required in defining a test operating procedure. Accordingly, a limited series of driving tests were conducted, the results of which defined more precisely the vehicle parameters observed in typical acceleration operations. Using all of the available data, a set of criteria were established against which potential measurement methods could be evaluated.

The motor vehicle manufacturers have recognized the shortcomings of the current full-throttle test procedures, and have proposed a number of alternative approaches. These were evaluated in terms of repeatability and representation of typical vehicle operations by a series of noise tests conducted on 19 automobiles and light trucks. The tests were conducted at a site established at the Marana Air Park, located near Tucson, Arizona, selected for its excellent support facilities, good weather, and proximity to a metropolitan area, providing access to a wide variety of test vehicles. Each vehicle was fully instrumented and subjected to a comprehensive sequence of tests including those proposed by manufacturers and others designed to document the noise and operational characteristics under all modes of operation. The results indicated that the proposed procedures were not entirely suitable as a standard method of light vehicle noise measurement. An alternate procedure was developed in an attempt to satisfy the previously established criteria, and was implemented on ten test vehicles. With a few minor modifications, this procedure was tentatively adopted for use by EPA in measuring the noise emissions of light vehicles operations in urban areas.

1.3 Organization of the Report

The following chapters in this report present detailed information on the program outlined above. Chapter 2.0 considers various approaches that can be taken in the selection of a light vehicle noise measurement procedure, establishes the overall requirements of such a procedure, and identifies the necessary inputs. Chapters 3.0 and 4.0 provide the inputs related to vehicle operation. Specifically, Chapter 3.0 presents an analysis of the published operational data; Chapter 4.0 describes the driving tests performed to supplement these data. The light vehicle noise measurement program designed to provide a data base for evaluating proposed test procedures is described in Chapter 5.0. The comprehensive evaluation, together with the selection, development, and trial implementation of an alternative test procedure, is detailed in Chapter 6.0. This procedure is presented in full in Chapter 7.0. Supporting information on vehicle operation studies and a description of the instrumentation system used in the vehicle noise measurements are included in the appendices at the end of the report.

It should be noted that vehicle parameters and distances were measured and printed out in English units (feet, pounds, seconds) during the test program. Therefore, in accordance with EPA's request to reduce the data reduction and analysis effort, English units are also used throughout this report.

Subsequent to the development of the light vehicle noise test procedure described in this report, a data base was established for the noise emissions of 66 1977 model automobiles and light trucks. The details of this program are contained in a companion report, "Light Vehicle Noise: Volume II – Implementation and Evaluation of a Test Procedure to Measure the Noise Emissions of Light Vehicles Operating in Urban Areas".[4]

2.0 APPROACH TO THE SELECTION OF A LIGHT VEHICLE NOISE TEST PROCEDURE

2.1 Criteria for the Evaluation of Test Procedures

The first step in the selection of an automobile noise test procedure is the definition of criteria with which the various existing and proposed methods can be evaluated and suitable modifications introduced. The fundamental concern underlying the selection of a methodology is the reduction of vehicle noise exposure in communities. A viable measurement method must be related directly to noise exposure so that measured noise reductions will be passed on to the community on a one-to-one basis. The attainment of this objective implies that the relation between the noise produced using the method and the noise experienced by the community is known for all vehicles, or that the measurement method includes the modes of operation that are responsible for the exposure. A measurement methodology must also be constructed in such a way that the sound levels measured using the procedure accurately characterize noise emissions for the specified operating condition. Further, this characterization must be obtained uniformly for all configurations of automobiles. Finally, a viable methodology will keep to a minimum the cost and time required for measurement and will measure noise emissions in a repeatable manner.

These considerations form the criteria which can be used to review and analyze existing and proposed automobile noise test procedures. The criteria are that the test procedure must be:

- Directly related to community noise exposure;
- Accurate in measurement of the desired operating condition;
- Uniformly applicable to all automobile types and configurations;
- Able to provide repeatable results;
- Practical in terms of cost and time.

2.2 Review of Existing Test Procedures

Automobile noise test procedures currently in use and proposed for use are of two types, vehicle pass-by or moving tests, and stationary tests. Most pass-by procedures have historically addressed the measurement of maximum potential sound levels, although noise production under more typical operating conditions has been proposed. Stationary unloaded measurement methods have been developed to assess the noise produced by individual automobile components or groups of components, and to assess overall noise production. There has not, however, been an adequate correlation between either stationary unloaded tests or pass-by tests with community noise exposure.

Of the automobile noise test procedures currently in use, there are three which are designed to measure the maximum noise produced by the vehicle – namely, the Society of Automotive Engineers (SAE) Standard J986a,[2] and the California Vehicle Code 27160[5] in the United States, and the ISO R362 Standard[3] in Europe. Each of these procedures specifies similar vehicle operating conditions in which a full-throttle acceleration is initiated from a low speed, and maintained throughout the test section. The microphone is placed at a height of 4 feet and at a distance of 50 feet from the vehicle path for the SAE J986a and CVC 27160 tests, and at a distance of 7.5m (25 feet) for the ISO R362 test. Other differences among the three procedures include the relation of the microphone to the initiation point of acceleration, the initiation speed, and the length of the test section.

A well-recognized, common fault with these three methods is that the sound level measured does not necessarily correspond to the maximum sound which is associated with maximum rated engine speed. This occurs because vehicles of low power-to-weight ratio do not attain maximum rated engine speed within the test section, whereas higher performance vehicles do attain this condition. Further, by alteration of the final drive ratio on a given automobile configuration, the location at which the maximum rated engine speed is achieved can be influenced significantly, producing a corresponding influence on the measured sound levels since only a single microphone is specified. To eliminate the bias towards low power-to-weight vehicles and the sensitivity to gear ratio, a revised procedure (XJ 1030) has been proposed by the SAE. This proposed method ensures that each vehicle will attain its maximum rated engine speed within the test section and that the relative position with respect to the microphone will be approximately the same in each case. A similar type of revision for ISO R362 is also under consideration.

Aside from the technical aspects of determining maximum sound, a full-throttle measurement method alone is inadequate for assessing community exposure. From existing vehicle operation surveys (see Section 3.0), it is known that full-throttle acceleration is not a typical mode of operation, and hence is responsible for only limited noise exposure. Further, vehicles exhibiting similar sound levels as measured by such procedures do not necessarily contribute equally to community noise. This inequality arises because vehicles of low power-to-weight ratio must be operated closer to their maximum rated engine speed than vehicles with a high power-to-weight ratio in order to maintain equivalent acceleration characteristics under typical driving conditions. It has also been observed that values of noise reduction measured under full-throttle conditions are often not exhibited in other less severe operating conditions.[6] Despite these criticisms of full-throttle measurement methods when considered as a single test, such a test method can be useful for determining the maximum noise potential of light vehicles, particularly if it is modified according to the specifications contained in SAE XJ 1030.

2.3 Alternative Types of Test Procedures

2.3.1 The Driving Cycle Method

One approach to vehicular noise measurement is to develop a noise driving cycle test similar to the EPA urban driving schedule for determining compliance with the Federal Exhaust Emission Standards. The vehicle could be operated on a quieted dynamometer whereby the equivalent continuous sound level, L_{eq}, for the cycle could be determined for each vehicle. However, substantial additional research and development would be required to prove the feasibility of this approach. Further, such an approach to measuring noise emissions is very likely to require a more expensive and complex facility than is now required for measuring exhaust emissions. Accordingly, further consideration of this procedure has not been pursued in anticipation that an alternative, less complex and costly, approach will be found acceptable.

2.3.2 Stationary Test Procedures

Existing stationary light vehicle noise measurement methods are of three types. The first is that of ISO R362[3] which specifies a sound level measurement 7.5m (25 feet) from the vehicle with the engine operated at 75 percent rated engine speed. The second type is that used by the State of California and the City of Grand Rapids, Michigan, as an enforcement test for exhaust systems,[7] and involves a sound level measurement close to the exhaust outlet at a given, stabilized engine speed. A similar near-field exhaust noise measurement is currently being proposed as a recommended practice by the SAE for unloaded engines at 3000 RPM.[8] As a third variation of stationary testing, the Ford Motor Company has adopted a test using a microphone position 5 feet in front of the vehicle in addition to the near-field exhaust measurement. Refinement of this latter method is still in progress at Ford, and correlations are currently being attempted between the stationary sound levels and levels measured in pass-by tests. Stationary testing offers many advantages in terms of reproducibility, site restrictions, and enforcement, which make its development desirable. However, it is not anticipated that a stationary measurement procedure could be related directly to community noise exposure without the development of a representative pass-by measurement procedure as an intermediate step.

2.3.3 The Pass-By Test Procedure

Several of the American automobile manufacturers have introduced the concept of a multi-modal test procedure in an attempt to overcome the limitations of the full-throttle test. The multi-modal test procedure combines the sound levels produced during a number of different operating modes to produce a single level defined by the expression:

$$L = 10 \text{ Log} \left[A_1 \ 10^{L_1/10} + A_2 \ 10^{L_2/10} + \ldots + A_N \ 10^{L_N/10} \right]$$

where $L_1, L_2, \ldots, L_N$ are the levels produced in each mode, and $A_1, A_2, \ldots, A_N$ are the fractional contributions to community exposure from each mode. With the assumption that more than one vehicle operating mode is responsible for community noise exposure, the concept of a multi-modal test fulfills explicitly the requirement of being relatable to community exposure since all the modes contributing to the exposure can be included. However, the development of such a methodology requires a knowledge of the contribution of each mode to the total exposure in order that significant modes can be selected and properly weighted — as shown for a hypothetical example in Figure 2.1. This requires a knowledge of the sound levels for each mode and the occurrence of those modes in the community. To determine appropriate automobile test modes and weighting factors for a multi-modal methodology, the automobile manufacturers have suggested using the results of a vehicle operations survey conducted by General Motors that employed a "chase-car"

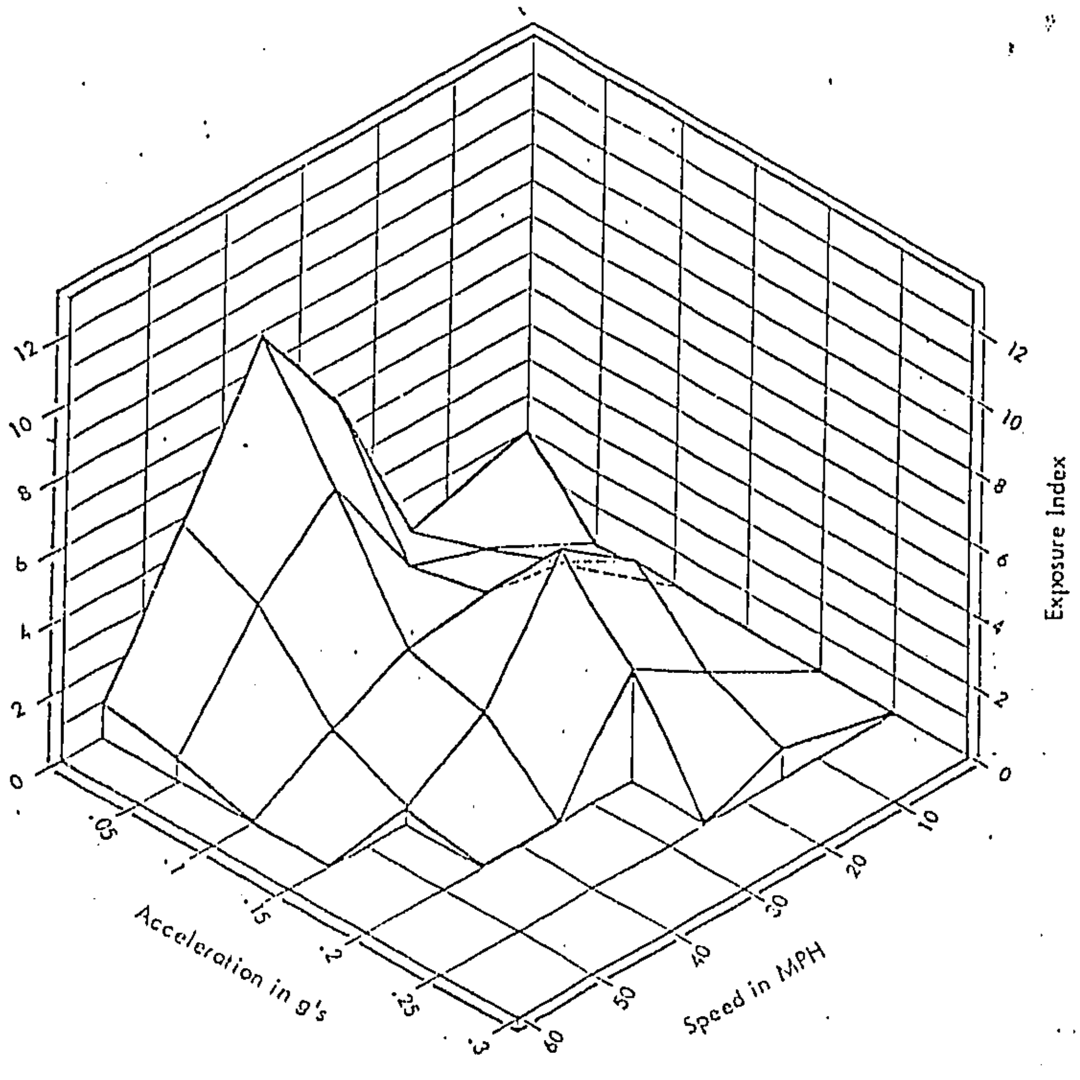

Figure 2.1. Relative Impact From Vehicle Operating Modes (Hypothetical).

technique. This study has been reviewed in detail and has been found to be suspect for reasons which will be mentioned in Section 3.2 and are detailed in Appendix A. Accordingly, a multi-modal test procedure cannot be developed until further investigation of automobile operation is completed.

At this point, however, it is necessary to recapitulate on the primary objective of this program — namely, the development of a test procedure to identify the potential damaging effects on the community caused by the introduction of more fuel-efficient light vehicles. In a previous study of light vehicle noise characteristics,[1] it was shown that automobiles in the subcompact and compact classes, with gasoline engines of size less than about 200 CID, exhibited sound levels that were about 4 dB greater than those produced by automobiles equipped with the larger, less fuel-efficient engines, when operated at a typical urban acceleration rate of 0.15g. However, there was little difference in sound levels between the two automobile categories under cruise conditions, mainly because of the influence of tire noise. Therefore, for the purpose of identifying the relationship between vehicle sound levels and fuel efficiency, it is only necessary to consider the acceleration mode, since the sound levels produced under cruise conditions by vehicles equipped with gasoline engines appear to be much less sensitive to fuel efficiency. The sound levels generated by vehicles with diesel engines are understandably higher under all modes of operation. Accordingly, the acceleration mode is identified as the mode of operation that needs to be simulated by the test procedure. The test procedure to be developed for this mode will be suitable for specifying noise levels for the acceleration mode in any subsequent multi-mode procedure.

2.3.4 Conclusion

As a result of considerations presented in this chapter, it was decided to develop a single mode pass-by test procedure to simulate the sound levels generated by light vehicles during acceleration under typical road conditions. To define the typical acceleration characteristics that must be simulated in the test procedure, it is necessary to review data defining the way in which vehicles are driven under typical road conditions. This is the subject of the next two chapters. Chapter 3.0 presents an analysis of the published light vehicle operation data. Chapter 4.0 describes the results of light vehicle operation measurements which were conducted as part of this study.

3.0 REVIEW AND ANALYSIS OF PUBLISHED LIGHT VEHICLE OPERATIONAL DATA

3.1 Introduction

In order to reduce the impact of automobile noise on a community, it is necessary to identify the specific automobile operations that produce the impact and then reduce the sound levels associated with these operations. The sound levels before and after abatement measures are applied must be measured by subjecting the automobile to a standard test procedure. The levels measured under this procedure should be representative of those to which the community is exposed, which means that the test procedure should include the operations that produce the impact. In this way, the noise exposure can be related directly to the noise emission measurements.

The development of a measurement procedure to satisfy this requirement can be subdivided into three stages, namely:

- Determination of typical vehicle operating modes;
- Determination of the noise produced by automobiles in each of these typical modes;
- Determination of the contribution of each mode to the total noise exposure.

Once the contribution of each operating mode is known, a test procedure can be constructed which represents, or is directly relatable to, those modes which are most significant to the total exposure.

3.2 Review of Light Vehicle Operation Studies

There are four sources of information which provide some indication of typical light vehicle operation in the low-speed, urban acceleration mode. These sources include:

- CAPE-10 Vehicle Operation Survey[9]
- EPA Urban Driving Cycle[10]
- General Motors Chase-Car Study[11]
- Wyle Traffic Motion Measurements

Although several of these studies are quite extensive, all four have sufficient limitations when considered individually that they cannot be used to determine detailed vehicle operation in the acceleration mode.

Of the four sources of information, the results of the General Motors Chase-Car Study of 1974 have been most often cited as an appropriate data base from which vehicle operation can be defined for noise exposure calculations. The "chase-car" technique utilizes an instrumented vehicle in an attempt to follow and simulate visually and thereby monitor the behavior of individual vehicles in a flow of traffic. This technique has several limitations. The first is the ability of the chase-car to simulate accurately the acceleration of the vehicle being chased. The instantaneous value of acceleration is considerably more difficult to duplicate visually than steady or slowly varying speed because of the added derivative of time. In this regard, it should be noted that in low-speed acceleration, large changes in vehicle speed can occur in quite short time intervals, such as 20 to 30 mph in 5 to 6 seconds in duration. The duplication of acceleration is also inexact because the manner in which a vehicle accelerates depends on both the characteristics of the vehicle and the driver. Thus, chase-car acceleration is strongly biased by the chase-car and the operator of the chase-car. In addition to the difficulty of duplicating the acceleration of another vehicle, the acceleration was not measured directly in the GM study, but was derived from the vehicle speed which was sampled at one-second intervals. From these data it is difficult to define the detailed vehicle acceleration characteristics.

Another limitation of the chase-car technique is that it is not suited for either high or low density traffic situations. In high density traffic, contact with the chased vehicle can be lost easily due to lane changes or by vehicles coming in between the two vehicles. In low density traffic, it is difficult for the chase-car to remain undetected so that it does not influence the operator of the chased vehicle. A final limitation is that engine speed, the vehicle parameter most directly related to noise production, cannot be monitored with this method. A more detailed critique of the GM chase-car study is given in Appendix A.

The CAPE-10 Study also has several limitations which make it unacceptable as an information source of vehicle operation in the acceleration mode. It employed the chase-car data collection method and hence suffers from the limitations described above. Further, it was conducted for purposes of determining exhaust emissions and hence contains no information relating to the occurrence of operating mode with local environment, road type, population density, or traffic congestion, all of which may be important for purposes of determining noise exposure. The manner in which the study was conducted limited data collection to a predetermined route which was constructed to represent the typical home-work, work-home round trip. Further, it was conducted in 1971 prior to the increased public awareness of fuel economy.

Several aspects of the EPA Urban Driving Cycle also prohibit its use as a sole source of typical vehicle operation information for purposes of noise impact. Unlike the CAPE-10 and GM studies, the EPA Cycle utilized an instrumented vehicle directly for data collection. The Cycle consists of a velocity profile obtained from an instrumented vehicle as it was driven over a prescribed route in Los Angeles, California. This route was developed to represent the morning home-to-work trip which is believed to be the type of urban trip which most significantly contributes to the air pollution problem in the Los Angeles area. The relationship of this type of trip to vehicular noise exposure is now known, and indeed, the driving cycle for quantifying air pollution may be less sensitive to certain vehicle operating modes than that for noise exposure.

There are several aspects of the EPA Urban Driving Cycle that influence details of the velocity profile which are important for determining typical noise emission. Since only one vehicle was used in developing the Cycle, the derivative of the velocity profile (acceleration) is biased by that particular vehicle. Also, from the CAPE-10 Study, there is evidence that the acceleration rate may vary from one metropolitan area to another. Finally, the Cycle has been modified so that accelerations greater than 4.84 ft/sec^2 (0.15g) do not occur. This is required so that the trip may be duplicated on a dynamometer.

Unlike the other three studies, the Wyle study was not designed to establish general vehicular operational patterns. The intent of the study was to demonstrate a specific data collection technique and to obtain very limited data for purposes of comparison to the other studies. The study was performed by making a high-speed movie at a road intersection for a given period of time, and subsequently replaying the movie, frame by frame, to measure the distance travelled by each vehicle. In this way, vehicle velocity (sampled 24 times per second) and hence acceleration could be determined. Details of the measurement technique and the results obtained are given in Appendix B. Because of the very limited nature of the study, it alone cannot be used to determine vehicle operations for noise exposure purposes. The study was conducted at one site only and hence variables which may influence driving patterns were not assessed.

3.3 Analysis of the Data From Light Vehicle Operation Studies

While none of the vehicle operation studies can be considered definitive of typical low-speed acceleration, they represent the only available data and hence it is useful to compare the results. This can be done in two ways. The first is to consider the frequency of occurrence of various speed and acceleration bands, and weight these occurrences with the acoustic energy associated with each band. In this manner, the energy contribution at each speed and acceleration combination for the acceleration mode of operation can be determined. The second method is to consider typical or average acceleration profiles measured for accelerations initiated from rest. With this information, vehicles can then be operated according to that profile or portions of the profile and resultant sound levels measured. The results determined by both of these approaches are discussed below.

To determine energy-weighted operations contributing to community exposure, it is necessary to know both the frequency of occurrence of various speed-acceleration combinations and the sound level produced at each of these combinations.

The information on the occurrence of various speed-acceleration configurations can be extracted directly from the GM Study. The percent of time spent in individual speed and acceleration bands is given for the acceleration mode in non-highway driving in Table 3.1. To obtain such information from the EPA Driving Cycle, further reduction must be performed on the speed-versus-time data defining the cycle. This reduction has been performed and the result is presented in Table 3.2. Unfortunately, a similar analysis cannot be performed with the CAPE-10 Study due to the manner in which the data are presented. However, the frequency of occurrence of various acceleration bands at speeds of 10, 20, and 30 mph can be obtained. These results are given in Table 3.3.

The necessary sound level data were supplied by General Motors[12] for three of their 1976 automobiles — namely, a Chevrolet Nova (305 CID, V8), a Buick Skyhawk (231 CID, V6), and a Chevrolet Chevette (97.6 CID, L4). In order to eliminate tire noise from the energy-weighting of the operational data, the acoustic energy produced by coast conditions was subtracted from the total energy produced in each operating band.

Using the data in Tables 3.1 and 3.2, together with the GM sound level data, the percent energy contribution of each speed-acceleration band was calculated and is presented in Tables 3.4 to 3.10. It should be noted that the energy-weighted operation

Table 3.1

Percent Time Spent in Various Speed-Acceleration Combinations for Acceleration in Non-Highway Driving — GM Chase-Car Study

Average Vehicle Speed (mph)	Range of Acceleration, g's			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
2.5	6.3	1.9	0.2	0.3
7.5	5.9	3.7	2.0	0.7
12.5	8.5	4.1	2.4	0.5
17.5	10.4	4.5	2.0	0.2
22.5	10.3	4.0	1.4	0.1
27.5	10.1	2.6	0.8	0
32.5	7.0	1.2	0.3	0
37.5	3.9	0.4	0	0
42.5	1.9	0.1	0	0
47.5	0.6	0	0	0
52.5	0.2	0	0	0
57.5	0	0	0	0

Table 3.2

Percent Time Spent in Various
Speed-Acceleration Combinations
for Acceleration in the EPA Urban Driving Cycle

Average Vehicle Speed (mph)	Range of Acceleration, g's		
	0.04-0.10	0.10-0.14	0.14-0.20
2.5	4.8	2.1	3.9
7.5	1.7	1.3	3.7
12.5	3.5	1.6	1.8
17.5	8.5	1.7	1.3
22.5	17.8	2.8	0.5
27.5	22.7	1.4	0
32.5	5.5	1.8	0
37.5	0.4	0	0
42.5	0.1	0	0
47.5	0.2	0	0
52.5	0.4	0	0

Table 3.3

Percent Time Spent in Various
Acceleration Bands for 3 Speeds
From CAPE-10 Study

Accel. Band (g's)	Vehicle Speed (mph)		
	10	20	30
0.05-0.10	30.6	46.3	74.4
0.10-0.15	27.9	36.4	20.0
0.15-0.20	23.7	13.4	5.8
0.20-0.25	12.5	4.0	0
0.25-0.30	4.2	0	0
0.30-0.35	1.1	0	0
Total	100	100	100

Table 3.4

Percent Sound Energy Produced in
Various Speed-Acceleration Combinations —
Chevrolet Nova for EPA Urban Driving Cycle

Average Vehicle Speed (mph)	Range of Acceleration (g's)			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
2.5	0	0	0	---
7.5	0.1	0	0.1	---
12.5	1.3	0.9	0.4	---
17.5	4.8	1.2	1.4	---
22.5	13.8	3.3	0.5	---
27.5	30.1	2.4	-	---
32.5	7.7	2.9	-	---
37.5	2.1	-	-	---
42.5	0.2	-	-	---
47.5	9.2	-	---	---
52.5	16.6	-	---	---
57.5	-	-	---	---

Table 3.5

Percent Sound Energy Produced in
Various Speed-Acceleration Combinations —
Chevrolet Nova for GM Chase-Car Data

Average Vehicle Speed (mph)	Range of Acceleration (g's)			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
2.5	0	0	0	0
7.5	0.6	0.1	0.1	0
12.5	3.9	2.8	0.7	0.1
17.5	6.9	3.9	2.6	0.4
22.5	9.5	5.6	1.7	0.5
27.5	16.0	5.6	1.8	0.1
32.5	11.6	2.4	1.4	---
37.5	7.1	1.4	0.5	---
42.5	5.5	0.8	0.3	---
47.5	2.8	0.4	0.1	---
52.5	0.9	0	---	---
57.5	0.2	---	---	---

Table 3.6

Percent Sound Energy Produced in
Various Speed-Acceleration Combinations —
Chevrolet Chevette for EPA Urban Driving Cycle

Average Vehicle Speed (mph)	Range of Acceleration (g's)			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
2.5	0	0	0	---
7.5	0.2	0.2	0.7	---
12.5	0.6	0.7	1.4	---
17.5	3.0	0.8	2.3	---
22.5	9.1	3.0	1.5	---
27.5	20.9	3.4	---	---
32.5	6.0	4.2	---	---
37.5	9.0	---	---	---
42.5	0.4	---	---	---
47.5	11.8	---	---	---
52.5	19.6	---	---	---
57.5	---	---	---	---

Table 3.7

Percent Sound Energy Produced in
Various Speed-Acceleration Combinations —
Chevrolet Chevette for GM Chase-Car Data

Average Vehicle Speed (mph)	Range of Acceleration (g's)			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
2.5	0	0	0	---
7.5	0.9	0.9	0.4	---
12.5	1.9	2.2	2.1	---
17.5	4.2	2.7	4.0	---
22.5	6.1	5.0	5.1	---
27.5	10.7	7.5	3.9	---
32.5	8.7	3.3	1.4	---
37.5	10.0	3.2	---	---
42.5	10.1	---	---	---
47.5	3.5	---	---	---
52.5	1.1	---	---	---
57.5	---	---	---	---

Table 3.8

Percent Sound Energy Produced in Various Speed-Acceleration Combinations — Buick Skyhawk for EPA Urban Driving Cycle

Average Vehicle Speed (mph)	Range of Acceleration (g's)		
	0.05-0.10	0.10-0.15	0.15-0.20
2.5	---	---	---
7.5	0.4	0.3	0.8
12.5	3.5	1.6	1.8
17.5	6.0	1.2	2.8
22.5	10.0	3.1	1.1
27.5	25.8	1.9	---
32.5	6.4	1.2	---
37.5	4.0	---	---
42.5	0.1	---	---
47.5	5.2	---	---
52.5	22.7	---	---

Table 3.9

Percent Sound Energy Produced in Various Speed-Acceleration Combinations — Buick Skyhawk for GM Chase-Car Data

Average Vehicle Speed (mph)	Range of Acceleration (g's)			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
2.5	---	---	---	---
7.5	1.5	0.9	0.5	0.2
12.5	10.1	4.9	2.9	0.6
17.5	8.6	3.7	5.0	0.6
22.5	6.8	5.3	3.7	0.6
27.5	13.5	4.2	2.5	0.1
32.5	9.6	1.0	1.0	---
37.5	2.2	0.5	0.7	---
42.5	1.6	0.2	0.2	---
47.5	1.3	0.2	0.1	---
52.5	0.4	---	---	---
57.5	0.4	---	---	---

Table 3.10

Percent Sound Energy Produced in
Various Acceleration Bands at 20 mph
for 3 Vehicles Using CAPE-10 Data

Vehicle	Range of Acceleration (g's)			
	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25
Chevrolet Chevette	22.4	37.4	40.1	--
Buick Skyhawk	22.4	36.8	26.1	14.8
Chevrolet Nova	33.5	40.0	12.9	13.7

data are only approximate, because of the approximate nature of the chase-car data, and because vehicle sound levels are much more dependent on engine speed than vehicle speed, and gear data are not available from the chase-car study. Using the data of Table 3.3, the percent contribution of each acceleration band at 20 mph was calculated and is presented in Table 3.10. Comparison of Tables 3.4 through 3.10 indicates that the energy contribution varies from one study to another and from one vehicle to another. Even with this variability, the following general conclusions can be made:

- Most of the energy contribution to the acceleration mode occurs at speeds in the range 10 to 35 mph with the exclusion of the highway portion of the EPA Driving Cycle.

- Almost all of the sound energy contribution to the acceleration mode occurs between nearly cruise conditions (0.05g) and 0.20g.

Thus, based on sound energy contributions, the region of interest for a low-speed urban acceleration test procedure is bracketed by speeds of 10 to 35 mph and by accelerations from nearly cruise (0.05g) to 0.20g.

The other method of using the published vehicle operational data is to construct average acceleration profiles. As part of the results, the CAPE-10 Study provides average speed-versus-time profiles for accelerations from 0 to 30 mph. A profile for each of the five cities of the Study is presented. From these data, average acceleration over an interval of 0.2 second was calculated. The resultant acceleration plotted against vehicle speed for two of the cities included in the Study that showed the highest and lowest acceleration rates is presented in Figure 3.1.

An average acceleration profile was also developed from the speed-versus-time data of the EPA Driving Cycle. In this case, average acceleration was calculated over one-second intervals. The resultant acceleration in each 1 mph speed band was then averaged to construct the profile given in Figure 3.1. It should be noted that the accelerations were all initiated from 0 mph and that the average terminal speed of the acceleration was 23.4 mph with a standard deviation of 5.5 mph.

In its two published forms, the results of the GM Chase-Car Study cannot be used to construct acceleration profiles. Recently, however, General Motors has reanalyzed

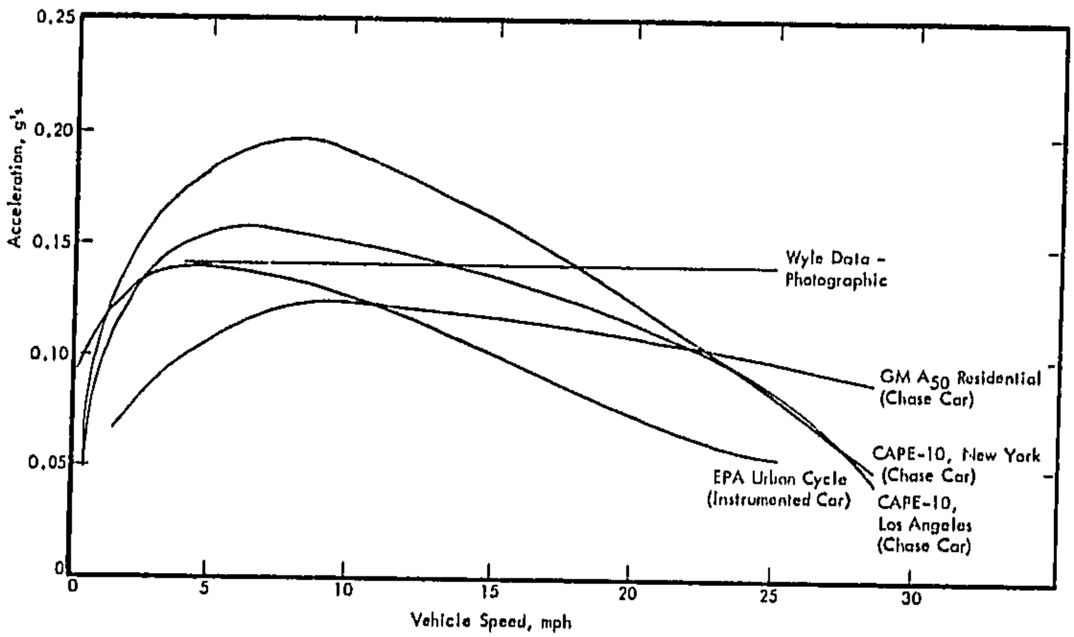

Figure 3.1. Typical Characteristics for Light Vehicle Acceleration in Urban and Suburban Areas.

the original data tapes and has produced some acceleration-versus-speed data. These data correspond to the acceleration exceeded 50 percent of the time as a function of speed for accelerations in residential areas initiated from speeds less than approximately 2.5 mph. The resultant profile is also indicated in Figure 3.1. It should be noted that the acceleration presented in this curve corresponds to the average acceleration calculated from a speed change over a one-second interval. Further, the average terminal speed of the accelerations is not given; however, it is assumed to lie between 25 and 45 mph with a standard deviation similar to that of the EPA Driving Cycle.

The results of the Wyle Photographic Study can be used directly for comparison to the acceleration profiles of the other studies. In this study it was found that vehicles accelerated at an approximate linear rate of 0.14g over the range of 10 to 25 mph. This result is also indicated in Figure 3.1. It should be noted that the terminal speed of the accelerations was not measured in this study. However, the posted speed limit on the roadway was 45 mph. It is, therefore, assumed that the average terminal speed would be close to 45 mph.

Comparison of the profiles given in Figure 3.1 leads to the following conclusions:

- There is no close agreement between the four studies.
- The total envelope defined is approximately 0.07g wide over the complete speed range.
- Within the results of the CAPE-10 Study there is significant difference between vehicle operation in New York and Los Angeles.
- There is an indication that the terminal speed of acceleration significantly influences the acceleration rate at speeds above about 18 mph. As a particular example of this behavior, the acceleration at 25 mph for each of the studies is plotted in Figure 3.2 against average terminal speed of acceleration for the particular data set. The GM data are presented as a range as no specific speed is available. From this figure it appears that the acceleration at 25 mph is a linear function of terminal speed.
- The average acceleration reported in all four studies range from 0.05g to 0.20g over the speed range 0 to 25 mph.

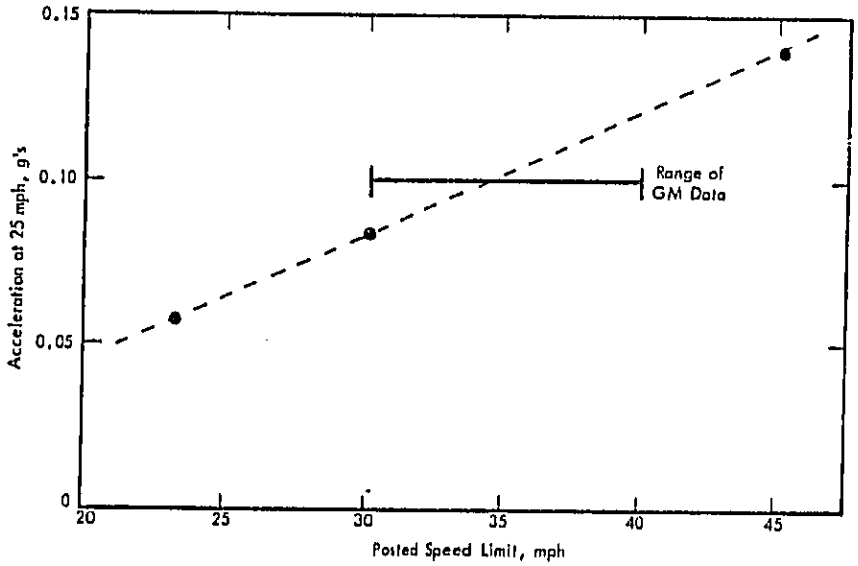

Figure 3.2. Typical Light Vehicle Acceleration at 25 mph as a Function of Posted Speed Limit.

- The average acceleration rate appears to decrease significantly at speeds greater than 20 to 22 mph in situations where the terminal velocity (or posted speed limit) is 35 mph or less.

3.4 Conclusions From Existing Light Vehicle Operation Data

A review of the data describing the operation of light vehicles in urban areas has shown that the specific information required in the development of a test procedure is not available. However, it is possible to draw some general conclusions and to define bounds on some of the operating parameters of interest.

It appears that, for urban areas, the vehicle speed range of interest is from 10 to 35 mph. Since only a small proportion of the integrated sound energy is produced at speeds less than 10 mph (see Tables 3.4 to 3.9), the range of interest can be limited to 10 to 35 mph. As far as the upper limit of 35 mph is concerned, previous data collected by Wyle have shown that tire noise starts to become an important contribution to overall vehicle noise at speeds greater than 25 mph. For example, at 25 mph, the difference between sound levels produced at an acceleration rate of 0.15g and those produced under a coast condition are sometimes less than 5 dB for vehicles equipped with engines of capacity 200 CID and greater. The difference is greater for smaller vehicles. Since the purpose of the test procedure is to measure propulsion system noise, the vehicle speed range of interest can be restricted still further to 10 to 25 mph.

The acceleration range of interest is from near cruise (0.05g) to about 0.20g. The data in Tables 3.4 to 3.9 indicate that a significant amount of the integrated sound energy is produced at acceleration rates in the range 0.05g to 0.10g. However, it should be noted that this generally occurs at speeds greater than 25 mph and not at lower speeds when accelerating from rest. This is somewhat confirmed by the curves shown in Figure 3.1, from which it is reasonable to specify an acceleration range of interest from 0.10g to 0.20g covering most of the speed range 0 to 25 mph.

It must be recognized, however, that for reasons discussed earlier, the conclusions drawn from the existing data are not necessarily completely definitive of light vehicle operations. For example, none of the existing studies include data on the engine speed, which is probably more important than either acceleration or vehicle speed in determining vehicle sound levels. However, the overall ranges in parameters defined above are useful in identifying general bounds of interest.

There is also little information on the time history of vehicle acceleration from rest in the published data. The Wyle photographic study indicated that the acceleration was fairly constant up to speeds of 25 mph where the terminal speed was about 45 mph. This implies that the driver is gradually increasing the throttle setting as the speed increases, and intuitively this seems to be a typical driving action. Others believe, however, the action is more one of constant throttle, where the throttle setting is initiated and held constant. In reality, the typical driver probably operates somewhere in between these two extremes.

In view of lack of definitive data on the acceleration characteristics of light vehicles, it was decided that additional measurements were required before a suitable test procedure could be developed. These measurements are described in the next chapter.

4.0 COLLECTION OF ADDITIONAL LIGHT VEHICLE OPERATIONAL DATA

4.1 Data Requirements

The published data on light vehicle operations, reviewed in Section 3.0, are presented in terms of the fraction of time spent in various bands of speed and acceleration. At the low speeds of interest in this study (less than 25 mph), the noise produced by light vehicles is dependent on the engine speed and rate of acceleration. For vehicles equipped with manual transmissions there is, of course, a direct relationship between engine and vehicle speed determined by the transmission gear ratio. Such a relationship does not exist for vehicles equipped with automatic transmissions, due to the presence of a fluid coupling or torque converter in the transmission chain. The gear selection was not monitored in the published data, so there is some uncertainty in relating the vehicle speed and acceleration data to the noise produced. For example, according to Table 3.1, the relatively low fraction of time spent at low vehicle speeds at 0.10 to 0.15g might well involve high engine speeds and a correspondingly higher sound energy contribution than indicated in Tables 3.4 to 3.9.

In accelerating from rest, the noise produced by a light vehicle increases with engine speed. The maximum engine speed, and hence the maximum noise level, will be achieved immediately prior to the transmission upshift from first to second gear. Assuming a fairly linear increase in engine speed, and hence noise level, with time during the acceleration (Reference 1), there will be a simple relationship between this maximum noise level and the total sound energy produced by the vehicle up to the time of the transmission upshift. For the purpose of simulating vehicle operating conditions, and the corresponding sound energy propagated into the community, it is therefore necessary to define the typical engine speed at which the transmission upshift occurs as well as the vehicle acceleration at this point.

This information by itself is not sufficient, however, since the engine speed at which vehicles equipped with automatic transmission shift is determined not so much by the acceleration <u>at</u> the shift point but the <u>time history</u> of the acceleration. An automatic transmission in the drive mode will shift at an engine speed that varies with the throttle setting, and hence the acceleration. Accordingly, in simulating the noise levels produced during typical operations and evaluating the relative benefits of constant-throttle and constant acceleration operating procedures it is necessary to know the overall shape of the time history of vehicle acceleration.

In order to obtain the required information, a series of vehicle operation tests were conducted at the Marana Air Park where subsequent vehicle noise tests were performed. These tests and the results are presented in the following sections.

4.2 Test Description

The course selected for the vehicle operation measurements was designed to include the type of situations typically encountered by light vehicles while operating in urban and suburban areas, and is shown in Figure 4.1. The total length of the course from start to finish was 0.94 miles, containing six start-stop sections ranging in length from 340 feet to 1,700 feet, two of which involved a right-angle turn without the need to stop. The roadway consisted of two lanes with no traffic other than the vehicle under test.

The vehicles used for the measurements were selected to be representative of those manufactured in 1977 and to include a cross-section of engine and transmission types. The vehicle specifications are given in Table 4.1. Prior to the measurements, each vehicle was tuned according to the manufacturer's specifications.

Each vehicle was equipped with transducers and associated instrumentation required to monitor engine speed and vehicle acceleration. The engine speed was sensed by means of a capacitative pick-up attached to the secondary wire of the ignition coil. The signal was conditioned to provide a single pulse for each ignition firing pulse, and fed to a frequency-to-voltage converter to provide a DC signal proportional to the engine speed. Calibration was achieved by using an electronic function generator to simulate the ignition pulses. With this system, the accuracy of the measured engine speed was within a tolerance of ±20 RPM of the actual engine speed. The vehicle acceleration was measured with a strain-gage accelerometer hard-mounted on a bracket to the floor of the vehicle with the carpet removed. The accuracy of the acceleration measurement was estimated to be within ±0.002g. Both engine speed and vehicle acceleration were monitored continuously on a strip-chart recorder mounted in the vehicle.

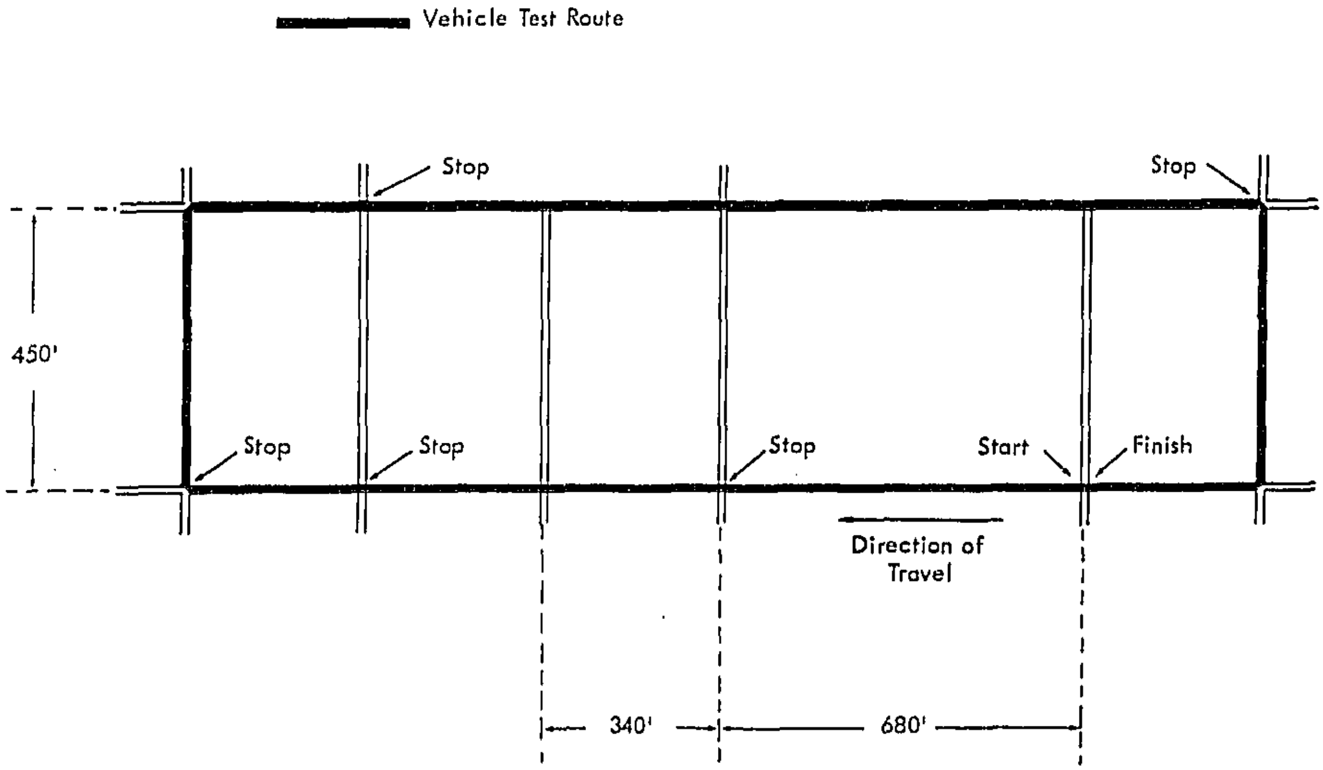

Figure 4.1. Layout of Test Route for Marana Vehicle Operation Measurements

Table 4.1

Specifications of Test Vehicles Used in Vehicle Operation Measurements

Vehicle	Engine Type	CID/Carb.[1]	BHP @ RPM	Trans.[2]	Rear Axle Ratio	BHP/LB[3]
Buick Skylark	V6	231/2	105 @ 3200	3A	2.56	0.028
Toyota Corolla	L4	97/2	75 @ 5800	3A	3.91	0.030
Oldsmobile Cutlass	V8	350/4	170 @ 3800	3A	2.14	0.043
Chevrolet Chevette	L4	85/1	57 @ 5200	3A	3.70	0.025
Dodge Monaco	V8	360/2	155 @ 3600	3A	2.71	0.034
VW Rabbit	L4	97/FI	78 @ 5500	4M	3.76	0.036
Toyota Corolla	L4	97/2	75 @ 5800	5M	3.91	0.029
Chevrolet Chevette	L4	85/1	57 @ 5200	4M	3.70	0.025

1 Number of barrels to carburetor.

2 Number of gears/automatic or manual.

3 Vehicle inertia weight in lbs. (curb weight plus 300 lbs).

The drivers for the eight test vehicles were chosen from employees at the Marana Air Park, and consisted of both sexes engaged in secretarial, administrative, and engineering work. Each driver was informed that the tests were being conducted to monitor the performance of the vehicle and the driving habits of the operator. No obvious subterfuge was used to veil the purpose of the test. Then they were asked to complete a lap of the test track to become acquainted with both the vehicle and the course to be followed. At the completion of this practice lap, the drivers were asked to complete five additional circuits of the course during which vehicle data would be recorded. Data for the first of these five laps were not used in the subsequent analysis. Finally, for comparative purposes, the drivers were asked to complete one lap as if they were out for a Sunday afternoon drive (slowly), and one lap as if they were late for work (quickly).

4.3 Test Results

The strip-chart recordings obtained from the operation study were reviewed and information extracted on the engine speed at the transmission shift from first to second gear together with the vehicle acceleration at this and other points in the time history. Examples of typical traces for engine speed and vehicle acceleration for vehicles equipped with manual and automatic transmissions are shown in Figure 4.2(a) and (b). The following points can be noted:

- Vehicles equipped with manual transmissions exhibit an acceleration time history in both first and second gears that approximates to constant acceleration.
- Vehicles equipped with automatic transmissions exhibit an acceleration-time history in first gear covering a much larger range of acceleration than that for vehicles with manual transmissions. However, the time history does not match that produced by a typical constant-throttle acceleration as shown in Figure 4.2(c).

In extracting the data from the charts, the maximum engine speed prior to the shift from first to second gear was recorded for both manuals and automatics. Acceleration data for automatics was recorded at the maximum value and immediately prior to the shift point – see Figure 4.2(b). Due to the action of the clutches and the fluid coupling in an automatic gearbox, the actual shift point is not well defined in the acceleration-time

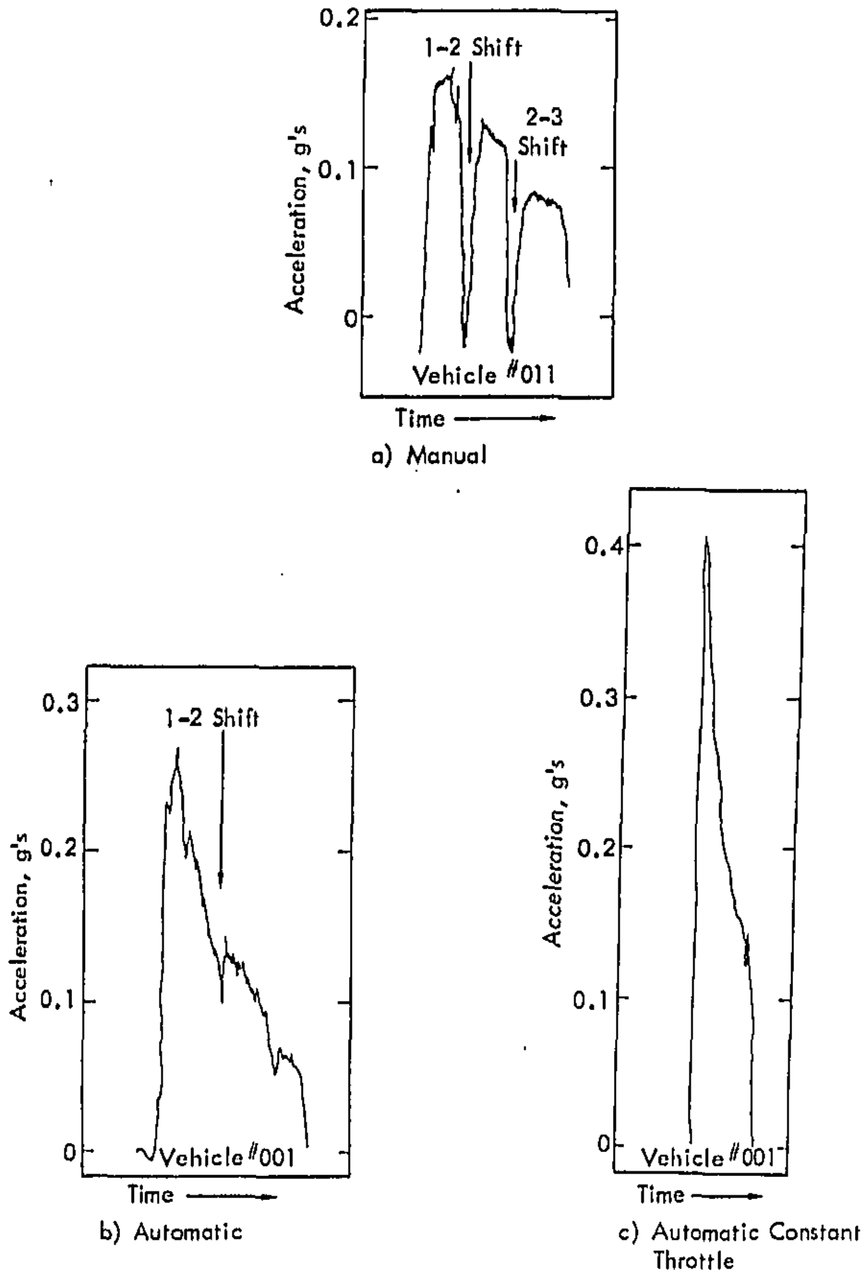

Figure 4.2. Typical Acceleration Profiles for Light Vehicle Operation.

history. It is, however, fairly well defined in the engine speed-time history. The acceleration at the shift point was, therefore, defined as the acceleration at an engine speed 100 RPM less than the maximum engine speed at the shift point. As will be shown later in Section 5.7.2, this definition allows a much greater repeatability to be obtained in measuring engine speed at the shift point for many different types of transmissions. Acceleration data for manuals was recorded for the mean value in first gear (since the time history covers only a small range), the value at the shift point (this being well defined due to the positive clutch depression), and the mean value in second gear. The data measured are shown in Table 4.2.

The results show fairly consistent values for the engine speed at the shift point for manuals, although the data base is small. No such consistency is apparent for automatics, where the engine speed at the shift point is more a function of transmission design. There is no clear relationship between the engine speed and acceleration at the shift points for automatics. However, there does appear to be such a relationship for manuals, as can be seen from the comparison of slow, normal, and fast operational data shown in Figure 4.3 for uninfluenced driving only. The unknown complexities introduced by the presence of other vehicles may render this relationship invalid for typical highway driving, although the general trend towards higher engine speeds at the 1-2 shift for greater acceleration rates is expected to still hold true.

The values of acceleration in first gear indicate the differences between the acceleration-time history for automatics and manuals — the difference between the average maximum value and that at the shift point is 0.07g for automatics, but only 0.02g for manuals (remembering that the acceleration for manuals is fairly constant with time). The mean values of acceleration at the shift point are 0.14g and 0.15g for automatics and manuals, respectively, the overall average being 0.15g to the nearest 0.005g. In second gear, the mean acceleration for the three manuals is 0.12g.

To enlarge the rather limited data base presented above, information on the engine speed at the 1-2 shift point has been obtained from various domestic automobile manufacturers.[12,13,14] These data are presented in Table 4.3 together with that from the study at Marana for vehicles equipped with manual transmissions. It is interesting to note that the manufacturers' data, which were taken on vehicles operating in urban conditions,

Table 4.2

Vehicle Operating Data From Marana Study

AUTOMATICS

Vehicle	No. of Meas.*	% Rated RPM at 1-2 Shift	Max. Accel. in 1st Gear	Accel. Prior to 1-2 Shift
Buick Skylark	120 (6)	70	0.26g	0.17g
Toyota Corolla	200 (10)	38	0.20g	0.14g
Oldsmobile Cutlass	200 (10)	46	0.22g	0.13g
Chevrolet Chevette	200 (10)	55	0.19g	0.12g
Dodge Monaco	120 (6)	46	0.19g	0.13g
Mean	--	--	0.21g	0.14g

MANUALS

Vehicle	No. of Meas.*	% Rated RPM at 1-2 Shift	Mean Accel. in 1st Gear	Accel. at 1-2 Shift	Mean Accel. in 2nd Gear
VW Rabbit	380 (19)	64	0.19g	0.17g	0.13g
Toyota Corolla	400 (20)	57	0.15g	0.12g	0.11g
Chevrolet Chevette	400 (20)	65	0.17g	0.15g	0.12g
Mean	--	62	0.17g	0.15g	0.12g

* Total number of data points (number of drivers).

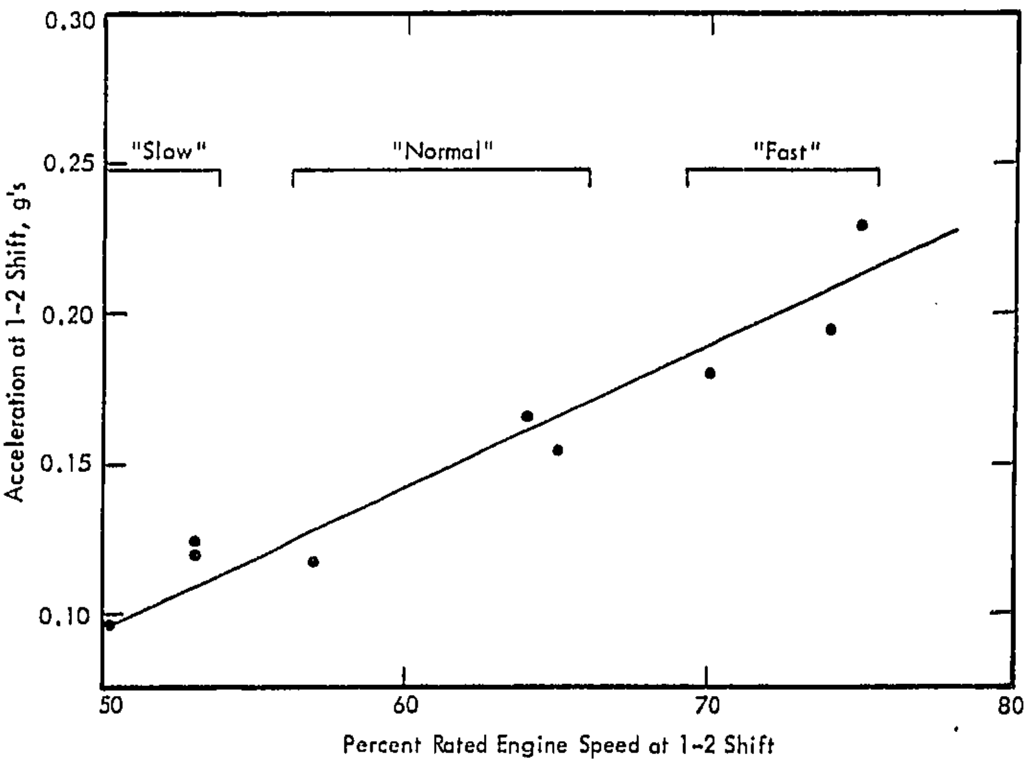

Figure 4.3. Acceleration as a Function of Normalized Engine Speed at 1-2 Shift for Uninfluenced Driving Operations of Manual Transmission Vehicles.

Table 4.3

Summary of Shift Point Data
for Manuals

Vehicle	% Rated RPM at 1-2 Shift	Source
VW Rabbit	64	Wyle Study
Toyota Corolla	57	
Chevrolet Chevette	65	
AMC Gremlin	63	AMC
AMC Pacer	67	
Ford Pinto	79	Ford
Chevrolet Nova	64	GM
Chevrolet Chevette	69	
Chevrolet Monza	70	
VW Rabbit	65	
Chevrolet Camaro	71	
Chevrolet Camaro	63	
Chevrolet C-10	63	
Mean of All Data	66	
Mean of All Data Excluding High Value	65	

show higher values of the normalized engine speed at the shift point — the mean of these data being 65 percent compared to 62 percent for the uninfluenced operational data in the Wyle study (omitting the one high value of 78 percent from the manufacturers' data which appears to be inconsistent with the main body of data). The standard deviation in the measurements of engine speed was typically on the order of 4 percent in rated engine speed.

Data provided by General Motors[12] show that the maximum engine speed at the 1-2 shift for automatics operating in urban conditions is in the range 55 to 59 percent of rated engine speed. Again, this is higher than the general range of 46 to 55 percent measured in the uninfluenced tests conducted at Marana and shown in Table 4.2 (omitting the high and low values of 70 and 38 percent). Thus, although the data are limited, it appears that, under urban conditions, vehicles may shift from first to second gear at a rated engine speed about 5 percent or so higher than under uninfluenced conditions.

4.4 Definition of Typical Vehicle Operating Parameters

The following conclusions can be drawn from the data presented in this section together with that of Section 3.0:

- The acceleration-time history for light vehicles is difficult to define exactly, falling between constant acceleration and constant throttle.
- The mean acceleration exhibited by light vehicles at the 1-2 shift point is about 0.15g. This agrees fairly well with that shown in Figure 3.1 at vehicle speeds less than 22 mph. It also agrees well with the value 0.15g as recommended by GM and Ford for vehicles equipped with manual transmissions — see Section 5.0. Accordingly, a typical rate of acceleration at the 1-2 shift point at speeds less than 22 mph was taken as 0.15g.
- The engine speed at the 1-2 shift point for vehicles equipped with manual transmissions is typically 65 percent of the maximum rated value with a standard deviation of 4 percent. To take some account of worst-case situations, the value can be taken as the mean value plus one standard deviation, i.e., approximately 70 percent. For automatics, the engine speed is largely a function of transmission design.

- A review of the distribution of vehicle speeds at the 1-2 shift for manuals (taken to be at 70 percent rated engine speed) shows that the majority shift at speeds less than 22 mph. At higher speeds, manuals will generally be in second gear, and the data in Figure 3.1 show a decreasing rate of acceleration. The data taken at Marana for manuals in second gear, together with that shown in Figure 3.1, indicate that 0.12g is a fairly typical rate of acceleration at 25 mph.
- In summary, the vehicle operating parameters to be simulated in the test procedure are as shown in Table 4.4.

Table 4.4

Summary of Typical Vehicle Operating Parameters
To Be Simulated in Test Procedure

Transmission	Vehicle Speed	
	22 mph	22 mph
Manual	0.15g at 70% MRES*	0.12g at 25 mph
Automatic	0.15g at 1-2 shift	

* Maximum Rated Engine Speed.

5.0 LIGHT VEHICLE NOISE MEASUREMENTS

5.1 Introduction

In previous chapters it was shown that a test procedure suitable for measuring the noise emission of light vehicles and identifying the range of sound levels associated with vehicles of varying fuel efficiency should address the acceleration mode. Furthermore, a review of light vehicle operation data has led to a definition of end conditions that must be met for the test procedure to be representative of typical driving habits. It now remains to specify the exact operating procedure necessary to achieve these end conditions so that accurate and repeatable measurement of noise emission levels can be obtained.

A number of alternative test procedures have been proposed by the automobile industry. It was therefore decided to conduct a series of light vehicle noise and operation measurements to determine whether any of these methods were suitable for achieving the operating conditions specified in Table 4.4. In addition, to evaluate these proposed procedures, it was also necessary to generate vehicle operation and sound level data under partial-throttle acceleration so that modifications to the proposed procedures could be introduced or totally new methods considered. A summary of proposed test procedures and a description of the noise measurement program designed to evaluate them are given in the remainder of this chapter.

5.2 Test Facilities and Instrumentation

The light vehicle noise measurements were conducted at the Marana Air Park, located approximately 30 miles northwest of Tucson, Arizona. The Air Park was originally a military air base and is now privately operated as an aircraft storage and maintenance facility. Accordingly, many of the facilities required for vehicle testing were readily available. An abandoned runway was used as the test site. A garage space was available which was used for vehicle tuning and instrumenting prior to testing. In addition to these facilities, the Air Park also afforded support by the availability of personnel, shop facilities, and specialized equipment.

In addition to the facilities available at the Marana site, several other aspects of the location were conducive to vehicle noise tests. The prevailing weather conditions were quite favorable for outdoor sound measurement. During the evening hours in the

Spring of 1977, during which the testing was conducted, temperatures were quite moderate, ranging from 16° C to 32° C, and the wind speed was generally below 5 mph. There was also very little precipitation during the testing period. Another favorable aspect of the site was its low ambient noise level. Typically, the ambient sound level was below 40 dBA. Because the Air Park is used primarily for aircraft storage and maintenance, the noise intrusions usually associated with aircraft facilities did not occur. A final aspect of the site was its proximity to metropolitan Tucson. This afforded a good local selection of test vehicles and an availability of auxiliary equipment and supplies required to support the test program.

To provide a surface suitable for light vehicle noise measurements, an asphalt test section was constructed as an overlay to the existing runway. The test pad was 200 x 120 feet, built and sealed to the same specifications as the test pad used for vehicular testing at the EPA Noise Enforcement Facility in Sandusky, Ohio. The area surrounding the test pad and runway was clear for distances over 300 feet of all objects which might act as reflecting surfaces. A trailer was installed in the vicinity of the test pad to house the data collection instrumentation and act as a test control room. The trailer was positioned approximately 300 feet from the center of the test pad, thus assuring that any sound reflections would be typically at least 20 dB less than the direct sound from the vehicle as measured at the microphone positions. Power was supplied to the trailer by two diesel generator sets which were partially enclosed so that the ambient sound level measured on the test pad was approximately 40 to 45 dBA. A photograph showing the test pad and trailer is shown in Figure 5.1.

During the pass-by tests, vehicle parameters were monitored and transmitted to the control room by means of a telemetry system. The parameters measured were vehicle speed and position, measured by a fifth wheel, acceleration measured using a strain-gauge accelerometer hard-mounted to the floor of the vehicle, engine speed, manifold pressure, and A-weighted interior sound level. Each of these parameters were recorded on analog tape and stored in a digital computer simultaneously with the exterior sound level. A complete description of the instrumentation system is presented in Appendix C.

Eight microphones were used to monitor the exterior sound pressure level. The microphones were placed 25 feet apart to form a linear array parallel to and 50 feet distant from the centerline of the path of vehicle travel on the test pad. A diagram and

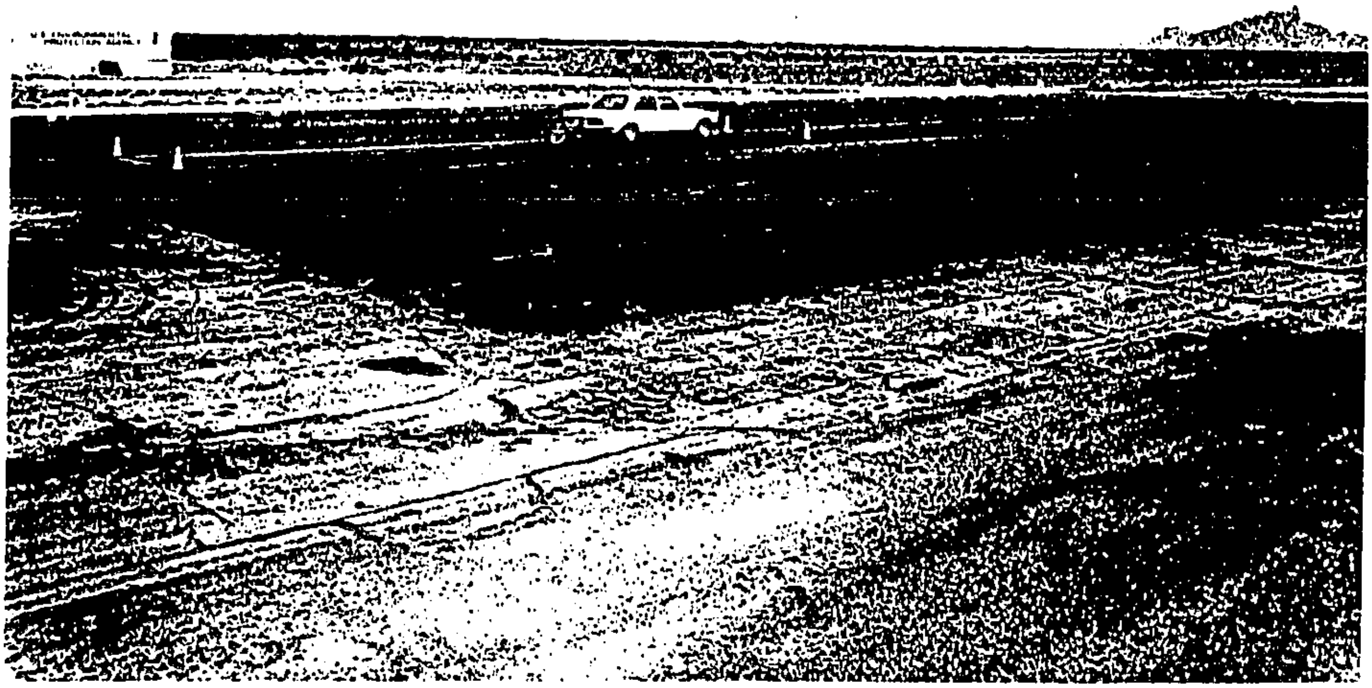

Figure 5.1. General View of Test Track

photograph of the microphone array on the test pad are presented in Figures 5.2 and 5.3, respectively. The signal from each of the eight microphones was monitored continuously during each test using a multi-channel oscillograph. Each signal was also amplified and recorded in analog format on a 14-channel FM magnetic tape recorder. Simultaneously, the signals were converted to A-weighted sound level, fed to an on-site computer, printed, and stored digitally on magnetic tape. The system was programmed to acquire and print instantaneous sound level and vehicle parameter data ten times for every revolution of the fifth wheel. The data were, therefore, provided at equal intervals of distance along the test track of 0.7 feet. With this computerized system it was possible to obtain a complete printout or plot of the test parameters within two minutes of any test run.

5.3 Proposed Test Procedures

The test procedures proposed by the automobile industry have been developed in an attempt to measure light vehicle sound levels that can be related to community noise impact. The various procedures involve a determination of vehicle noise levels by the following different methods:

- constant-throttle operation,
- constant acceleration operation, and
- interpolation from full-throttle and cruise operations.

5.3.1 The General Motors Constant-Throttle Procedure

General Motors has proposed a test procedure for acceleration noise that is based on measurements of vehicles accelerating from a stop on an urban road. Motion pictures were taken of accelerating vehicles on a four-lane road and typical acceleration profiles were obtained. It was found that the average time for the vehicles to travel the first 100 feet was 5.4 seconds. Under the assumption that the vehicles were operated at a constant throttle, a test procedure was developed for automatics requiring the throttle to be set such that the vehicle travels 100 feet in 5 seconds. The maximum sound level produced during the acceleration is measured by a microphone placed 50 feet from the centerline of the vehicle path and 50 feet from the initiation point.

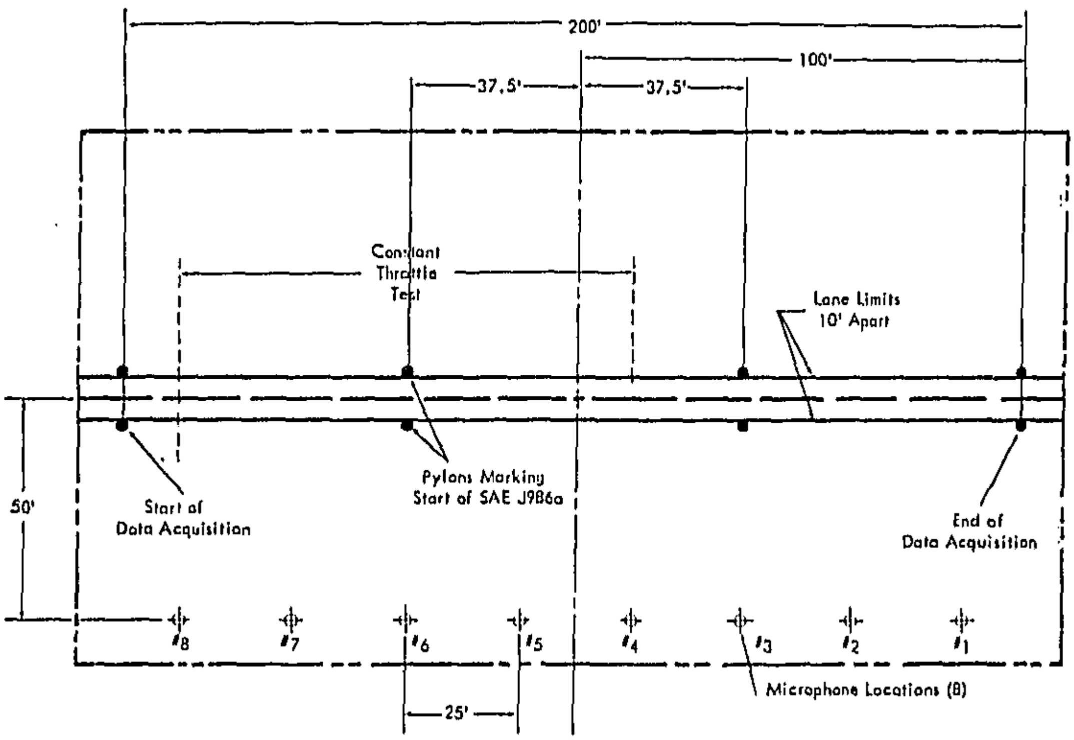

Figure 5.2. Test Section Layout for Noise Tests.

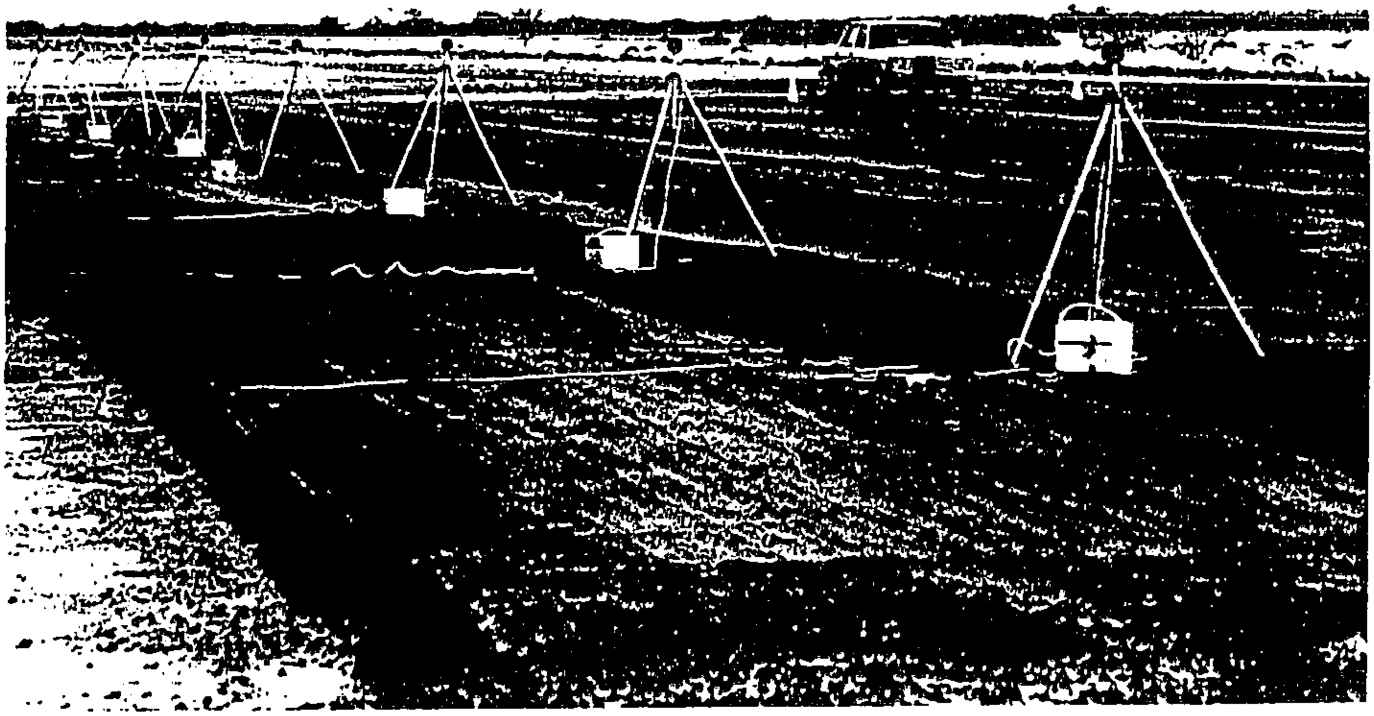

Figure 5.3. Microphone Layout at Test Track

Since it is not practical to achieve a constant-throttle operation from rest for vehicles equipped with manual transmissions, an alternative procedure has been proposed by GM for this type of vehicle. It involves an acceleration at constant throttle from an initial engine speed equal to 25 percent of the maximum rated engine speed to achieve an acceleration of 0.15g at 22 mph or maximum rated engine speed, whichever occurs first.

5.3.2 The Ford Procedure

The Ford Motor Company has proposed an alternative test procedure for acceleration noise that has the advantage of being identical for vehicles equipped with both manual and automatic transmissions. This procedure involves constant acceleration at 0.15g, initiated from a vehicle speed of 5 mph, up to a speed of 20 mph. The test section is 109 feet in length and a single measurement microphone is located 60 feet from the initiation point.

5.3.3 The CCMC Procedure

An alternative test procedure to determine vehicle noise emissions under partial-throttle operation has been proposed by the Comité des Constructeurs D'Automobile du Marché Commun (Committee of Common Market Automobile Constructors — CCMC).[15] The method takes advantage of the relative simplicity and repeatability of the full-throttle test procedure, and involves the interpolation of sound levels measured during full-throttle and cruise operations according to a formula developed from urban driving studies. As proposed, the method applies only to vehicles equipped with manual transmissions — further development of an equivalent test method suitable for automatics is currently under study by the CCMC.

5.4 Test Conditions and Vehicle Selection

To evaluate the proposed light vehicle noise test procedures for applicability and repeatability, it was necessary to define a test program that included all the variations of vehicle operation contained in these procedures as well as additional operations that might prove to be more suitable. Separate test programs were required for vehicles equipped with manual and automatic transmissions to take account of their differing operating characteristics. The test conditions for the two types of vehicles are given in Tables 5.1 and 5.2 and are described below. It should be noted that, unless stated otherwise, the sound levels quoted in this report are the maximum values measured by any of the 8 microphones.

Table 5.1

Test Conditions for Automatic Transmission Vehicles

Cond. No.	Vehicle Operation	Trans-mission	No. of Runs
0.0	30 mph cruise.	1st Gear	1
1.0	Constant 0.15g acceleration from standing start	Drive	4 in each direction
2.0	Constant 0.15g acceleration from initial speed of 10 mph. Hold to rated engine speed.	1st Gear	4
3.0	Constant 0.15g acceleration from initial speed of 15 mph.	2nd Gear	4
4.0	Full-throttle acceleration from standing start.	Drive	
5.0	Not included for automatic transmission vehicles.		
6.1	Coast at 15 mph, engine off.	Neutral	1
6.2	Coast at 20 mph, engine off.	Neutral	1
6.3	Coast at 25 mph, engine off.	Neutral	1
6.4	Coast at 30 mph, engine off.	Neutral	1
7.0	SAE J986a Procedure — full-throttle acceleration from initial speed of 30 mph.	*	4 in each direction
8.0	Constant-throttle acceleration from standing start to achieve 100 feet in 5 seconds. Hold to end of test section or rated engine speed.	Drive	4
9.0	Constant-throttle acceleration from standing start to achieve 0.15g at 100 RPM prior to the maximum engine speed at the 1-2 transmission shift. Hold to end of test section.	Drive	4
10.0	Constant-throttle acceleration from standing start to achieve 0.15g at 22 mph. Hold to end of test section.	Drive	4
0.0	30 mph cruise	1st Gear	1

* The lowest gear such that the front of the vehicle will have reached or passed a line 25 feet beyond the microphone line when the rated engine speed is reached.

Table 5.2

Test Conditions for Manual Transmission Vehicles

Cond. No.	Vehicle Operation	Trans-mission*	No. of Runs
0.0	30 mph cruise.	2nd Gear	1
1.0	Constant 0.15g acceleration from standing start. Hold to rated engine speed, then decelerate.	1st Gear	4 in each direction
2.0	Constant 0.15g acceleration from initial speed of 10 mph. Hold to 50 feet beyond test section or to rated engine speed.	1st Gear	4
3.0	Constant 0.15g acceleration from initial speed of 15 mph. Hold to 50 feet beyond test section or to rated engine speed.	2nd Gear	4
4.1	Full-throttle acceleration from standing start. Hold to rated engine speed, then decelerate slowly.	1st Gear	2
4.2	Full-throttle acceleration from initial speed of 15 mph. Hold to rated engine speed, then decelerate.	2nd Gear	2
5.1	Cruise at 60 percent rated engine speed.	1st Gear	2
5.2	Cruise at 80 percent rated engine speed.	1st Gear	2
5.3	Cruise at 25 mph.	2nd Gear	2
6.1	Coast at 15 mph, engine off.	Neutral	1
6.2	Coast at 20 mph, engine off.	Neutral	1
6.3	Coast at 25 mph, engine shut off.	Neutral	1
6.4	Coast at 30 mph, engine off.	Neutral	1
7.0	SAE J986a Procedure — full-throttle acceleration from initial speed of 30 mph.	**	4 in each direction
8.0	Constant-throttle acceleration to achieve 0.15g ±0.01g at either 22 mph or rated engine speed, whichever occurs first, from a moving start at 25 percent rated engine speed. Upon reaching this condition, gradually reduce the vehicle speed throuth the remainder of the test section.	1st Gear	4

* For transmissions where 1st gear is unusually low, and used for off-highway conditions.

** The lowest gear such that the front of the vehicle will have reached or passed a line 25 feet beyond the microphone line when the rated engine speed is reached.

The first and last tests, Condition 0.0 in Tables 5.1 and 5.2, were performed at the beginning and end of the testing of each vehicle. This condition was used in conjunction with system calibration solely as a verification that system transducers and data acquisition instrumentation were operating properly. The lowest selectable gear was used for this condition in order that the fullest possible range of sound level would be produced at each microphone position.

Conditions 1.0, 2.0, and 3.0 of Table 5.1 for automatics were all performed to assess different methods of measurement under 0.15g constant acceleration operation. Condition 1.0 corresponds to vehicle operation as prescribed in the preliminary EPA procedure — that is, 0.15g constant acceleration initiated from rest with the transmission in Drive. There were several specific issues to be resolved by this condition. The first was whether a 0.15g constant acceleration can be achieved readily and quickly from a standing start. The second was whether constant acceleration could be maintained near a shift point and how quickly it could be resumed after the shift. A third issue was how much variability in shift point RPM (and hence sound level) was introduced due to the small throttle position movements required to maintain a constant acceleration rate. It was clear that given sufficient time, any driver in any vehicle could eventually complete a given number of runs that would satisfy the operational criteria for the test. The question to be resolved was — can this be achieved with a limited number of runs, and if so, how many runs are required?

The second constant acceleration condition, Condition 2.0, specifies a moving start. In order to control the gear range at the initiation of this particular procedure, it was necessary to constrain the transmission to its low (high numerical gear ratio) range. The purpose of this condition was to compare constant acceleration operation for moving versus standing starts. Specifically, it was desired to compare which method enabled the quickest attainment of the constant 0.15g rate and which produced the least amount of run-to-run variation.

The third constant acceleration condition, Condition 3.0, specifies 0.15g acceleration with the transmission constrained to its second lowest (second highest numerical gear ratio) range. A moving start from a constant speed of 15 mph is required so that the transmission will have shifted from first to second gear (automatic transmissions initially engage first gear when second gear is selected). A procedure of this type would be necessary if it was determined that automatic transmission vehicles could not be operated in Drive for a constant acceleration procedure. In such a case, sound data might be required in both the first and second gear ranges in order to characterize the noise emission of a complete "typical" acceleration. The results from this condition were to be used to determine how quickly and how well constant acceleration could be achieved and maintained in this gear. A second aspect to be considered was the occurrence of transmission downshifts to the low gear range.

Conditions 4.0 through 7.0 were not directly applicable to a partial-throttle acceleration test, but were included for reasons related to development of such a test. Condition 4.0 was a full-throttle, standing-start acceleration. For automatic transmission vehicles, this type of pass-by was performed primarily to establish the maximum performance capability of the vehicle in order that it might be compared to performance under the proposed procedures. Also, the condition generally afforded an upper bound for low-speed acceleration sound levels.

Coast pass-bys were conducted at speeds of 15, 20, 25, and 30 mph with the engine off and the transmission in neutral as specified in Conditions 6.1 through 6.4. The purpose of these pass-by measurements was to determine the noise floor attributable to tire and aerodynamic noise at speeds at which partial-throttle acceleration noise was measured. With this information, the contribution of tire noise to total vehicular noise under low-speed acceleration could be determined.

The SAE J986a standard test procedure for passenger cars and light trucks was conducted on each of the vehicles as stated in Condition 7.0 so that there would be a link between the data taken at Marana and the data which are most widely referred to by automobile manufacturers.

The eighth test condition corresponded to the constant-throttle procedure as it was originally proposed by General Motors. This condition requires that the vehicle cover 100 feet in 5.0 seconds from a standing start with the throttle opened rapidly to a fixed position. Conditions 9.0 and 10.0 involved a constant-throttle operation to achieve an acceleration of 0.15g at the 1-2 transmission shift and 22 mph, respectively. These vehicle operations were included as a result of information developed in the previous test conditions.

The test conditions used for manual transmission vehicles are reproduced in Table 5.2 and correspond directly to those used for the automatic transmission vehicles. As for the automatics, Condition 0.0 was performed at the beginning and end of the testing for each vehicle.

The purpose for conducting each of the three constant acceleration conditions, Conditions 1.0, 2.0, and 3.0, were similar to those discussed for the corresponding conditions for automatic transmission vehicles. Conditions 1.0 and 2.0 were performed to assess how well constant acceleration could be maintained in first gear and whether a standing or moving start allowed for quicker and more repeatable attainment of the acceleration rate. As for automatics, the constant acceleration pass-bys of Condition 3.0 were required to characterize the complete low-speed acceleration. It will be noted that it was decided not to change gears for manuals during the constant acceleration conditions. Prior to the initiation of the testing program, it was decided that shifting of manual transmission vehicles could not be achieved repeatably from run to run or from driver to driver.

Conditions 4.1 and 4.2 were used to establish maximum vehicle performance and noise emission levels in first and second gears. In addition, full-throttle acceleration noise data were also required to evaluate the proposed CCMC interpolation technique. The cruise conditions, Conditions 5.1, 5.2, and 5.3, were performed for the same purpose.

The remainder of the test conditions, namely the coast pass-bys of Conditions 6.1 to 6.4 and the SAE J986a procedure of Condition 7.0, were analogous to those for automatic transmission vehicles.

Condition 8.0 of Table 5.2 corresponds to the constant-throttle procedure for manual transmission vehicles as proposed by General Motors. This procedure specifies that the throttle-stop position be determined such that 0.15g is achieved at 22 mph or rated engine speed, whichever occurs first. The measurement condition is then either 22 mph or 75 percent rated engine speed, whichever occurs first.

Recalling that the purpose of the noise and operation measurements was to evaluate the applicability and repeatability of various operating procedures, it was necessary to select a suitable sample of light vehicles representing the majority and the range of those projected to be sold in the 1977 model year. To aid in the selection, criteria were established to ensure that the following factors were included:

- Projected sales for the 1977 model year.
- The range of vehicle types and sizes.
- The range of available engine types and drivetrain combinations.
- Performance characteristics, such as engine size, engine power, power-to-weight ratio (HP/LB), engine size-to-weight ratio (CID/LB), etc.

Applying these criteria to all available 1977 light vehicles resulted in the selection of 18 to be included in the test program. The specifications of these vehicles are given in Table 5.3.

Prior to testing, each vehicle was fully documented, photographed, and subjected to a complete check of engine performance according to standard inspection procedures. Vehicles were tuned according to manufacturer's specifications, the procedure including measurement of hydrocarbon and carbon monoxide emission levels. The vehicles were then instrumented and brought to normal operating temperature. During the tests, all auxiliary equipment was turned off and the windows closed.

It should be noted that all the tests were conducted with the same driver who gained familiarity with each vehicle during pretest checks of the instrumentation and vehicle warm-up.

5.5 Test Results For Constant Acceleration Operation

5.5.1 Automatic Transmission Vehicles

The results of test Conditions 1.0, 2.0, and 3.0 for vehicles equipped with automatic transmissions showed that it was generally possible to achieve and maintain constant acceleration of 0.15g within a fairly narrow acceleration range. However, meaningful quantification of the ability of a vehicle to be operated at constant acceleration was found to be difficult. One method used was computing the mean acceleration and its standard deviation over a velocity range of 20 to 26 mph for each run. This speed range was selected for examination because it was considered most important for maximum sound levels. The percentage of distance over which the acceleration exceeded the range from 0.14g to 0.16g was also determined. This method of quantification was adequate for all conditions except Condition 1.0. For this particular case, with the transmission in Drive, the 1-2 shift of the vehicle sometimes occurred in the velocity range of interest, 20 to 26 mph, with corresponding irregularities in the acceleration. For this reason, comparison of

Table 5.3

Specifications For Light Vehicles Included in Noise Measurement Program

Vehicle No.	Make	Model	Curb Weight (lbs)	Engine Type	CID	Rated Power (BHP @ RPM)	Transmission Type
001	Oldsmobile	Cutlass	3696	V8	350	170 @ 3800	3-Speed Auto.
002	Dodge	Royal Monaco	4265	V8	360	155 @ 3600	3-Speed Auto.
003	Lincoln	Continental	5077	V8	460	208 @ 4000	3-Speed Auto.
004	Toyota	Corolla	2225	L4	97	75 @ 5800	3-Speed Auto.
005	Toyota	Corolla	2325	L4	97	75 @ 5800	5-Speed Man.
006	Volkswagen	Rabbit	1860	L4	97	78 @ 5500	4-Speed Man.
007	Mazda	RX-4	2780	Rotary	80	110 @ 6000	5-Speed Man.
008	Datsun	280 Z	2765	L6	168	170 @ 5600	5-Speed Man.
009	Mercedes Benz	240 D	3210	L4 (Diesel)	147	62 @ 4000	4-Speed Auto.
010	Ford	Granada	3410	L6	250	98 @ 3400	4-Speed Man.
011	Chevrolet	Chevette	1958	L4	85	57 @ 5200	4-Speed Man.
012	Volvo	244	2938	L4	130	105 @ 5500	4-Speed Man.
013	Pontiac	Firebird	3459	V8	301	135 @ 4000	4-Speed Man.
014	Ford	E-350 Van	4486	V8	351	168 @ 3800	3-Speed Auto.
015	Ford	F-150 Pickup	4590	V8	351	168 @ 3800	4-Speed Man.
016	Chevrolet	C-10 Pickup	3313	V8	350	165 @ 3800	3-Speed Auto.
017*	Buick	Skylark	3394	V6	231	105 @ 3200	3-Speed Auto.
018	Buick	Skylark	3394	V6	231	105 @ 3200	3-Speed Auto.
019	Chevrolet	Chevette	1958	L4	97.6	63 @ 4800	3-Speed Auto.

* Vehicle #017 was subsequently found to exhibit a noticeable transmission resonance and was replaced by #018.

Condition 1.0 to other conditions and comparison of Condition 1.0 for different vehicles requires knowledge of vehicle operation in more detail. A second method of assessing the ability to achieve and maintain constant acceleration is inspecting, visually, plots of acceleration versus other parameters.

The averages over four runs of the mean acceleration, standard deviation and percentage of distance where the acceleration was outside the range 0.15g ±0.01g are given for Conditions 1.0, 2.0, and 3.0 for each of six automatic transmission vehicles in Table 5.4. The first point to be noted is that the mean acceleration for all conditions and vehicles lies within a range of ±0.005g about the required value of 0.15g. Further, the average standard deviation for all cases is 0.01g or less, and in most cases 0.005g or less. The average percentage of distance over which a range of ±0.01g is exceeded is, for most cases, less than 15 percent. Two exceptions to this are vehicles #014 and #016 for which the 1-2 shift occurred in the 20 to 26 mph range for Condition 1.0. Another exception, vehicle #004, will be discussed later.

The second approach in considering the performance of constant acceleration is inspecting individual acceleration plots as a function of distance travelled. Such plots are presented for four of the automatic transmission vehicles in Figures 5.4, 5.5, and 5.6 for Conditions 1.0, 2.0, and 3.0, respectively. The four vehicles were selected from the nine tested to represent the range of automatic transmission vehicles, and include the most difficult vehicle to operate at constant acceleration, vehicle #001, and the least difficult, vehicle #002. The individual runs presented in these figures are typical of the better constant acceleration runs obtained with these vehicles.

Several general observations are illustrated by the acceleration-versus-distance plots of Figures 5.4 to 5.6. From the acceleration plots for Condition 1.0 in Figure 5.4, it is seen that, initially, vehicles tend to overshoot slightly the required acceleration of 0.15g. Also, an excursion beyond the range of ±0.01g typically occur at the dip in acceleration associated with the 1-2 shift. Aside from these two excursions, constant acceleration is maintained fairly well. Also, it should be noted that the acceleration rate is readily resumed after the 1-2 shift. Examination of Figure 5.5 reveals that once the acceleration rate is achieved, it is maintained more closely from a moving start than from a standing start. However, this is largely due to the absence of variations in

Table 5.4

Acceleration Statistics for Constant Acceleration Tests on Automatic Transmission Vehicles

Vehicle No.	Condition No.	Mean Acceleration in g's *	Standard Deviation of Acceleration σ*	% Distance Acceleration Outside Range 0.14g to 0.16g*	Shift Speed in mph
002	1.0	0.149	0.003	2.6	16.9
	2.0	0.156	0.005	30.3	--
	3.0	0.152	0.002	0.0	--
003	1.0	0.152	0.003	0.4	11.3
	2.0	0.151	0.005	5.8	--
	3.0	0.149	0.003	0.0	--
004	2.0	0.146	0.010	50.8	--
014	1.0	0.152	0.010	24.5	24.3
	2.0	0.148	0.006	12.8	--
	3.0	0.145	0.005	14.0	--
016	1.0	0.149	0.009	31.4	20.1
	2.0	0.152	0.005	4.1	--
	3.0	0.152	0.005	9.0	--
018	1.0	0.155	0.003	10.1	25.2
	2.0	0.152	0.004	5.4	--
	3.0	0.152	0.004	0.6	--

* Statistics taken for four runs over the vehicle speed range 20 to 26 mph.

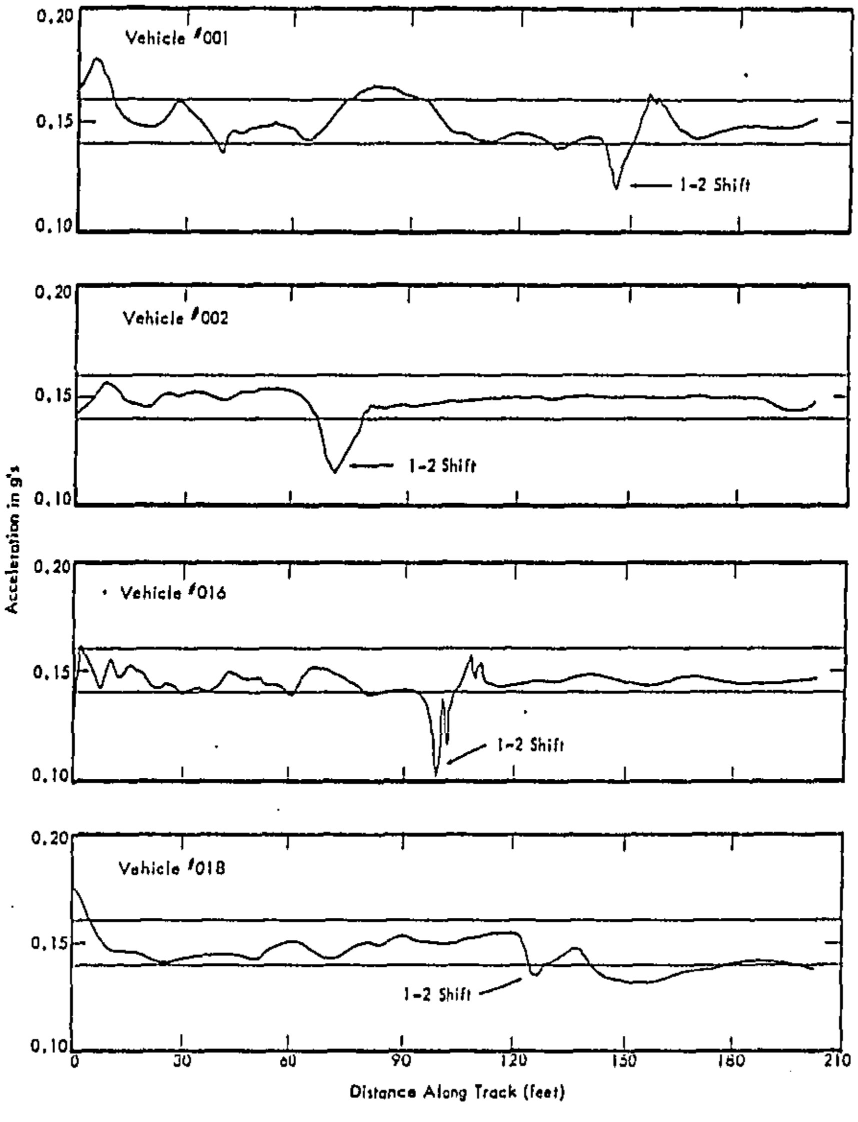

Figure 5.4. Acceleration Traces for Automatics Operating Under Condition 1.0.

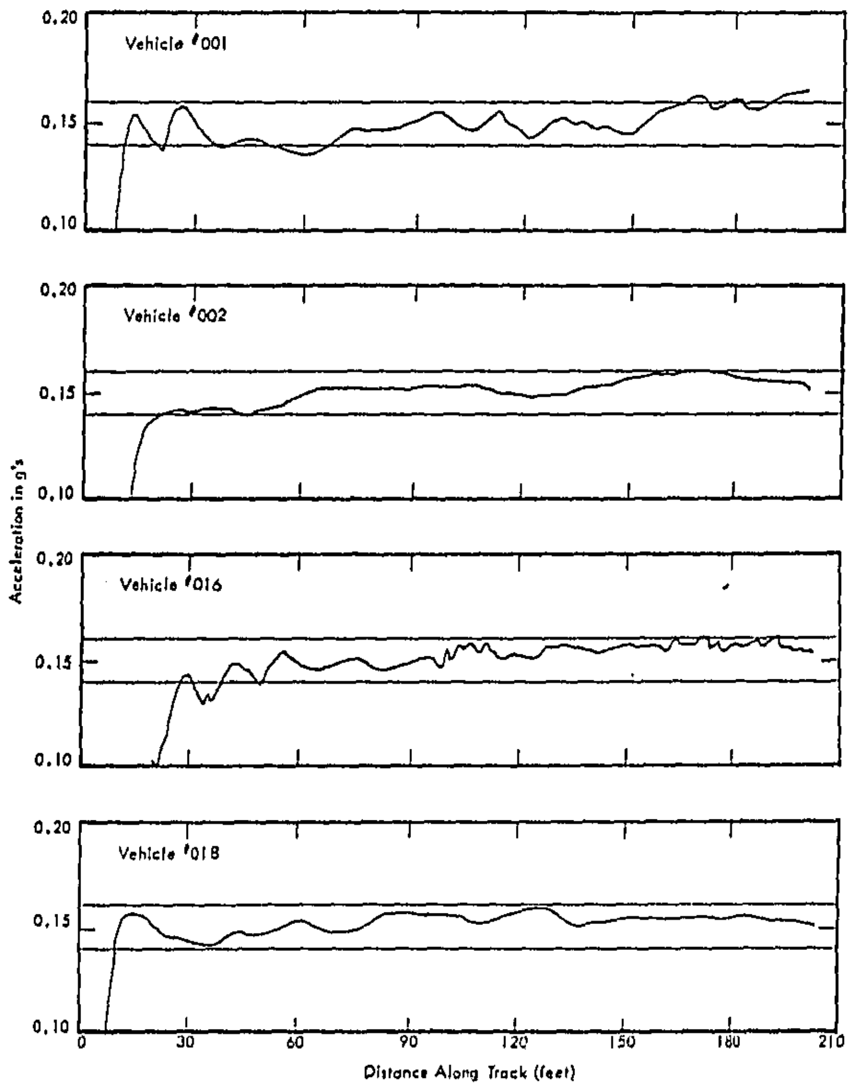

Figure 5.5. Acceleration Traces for Automatics Operating Under Condition 2.0.

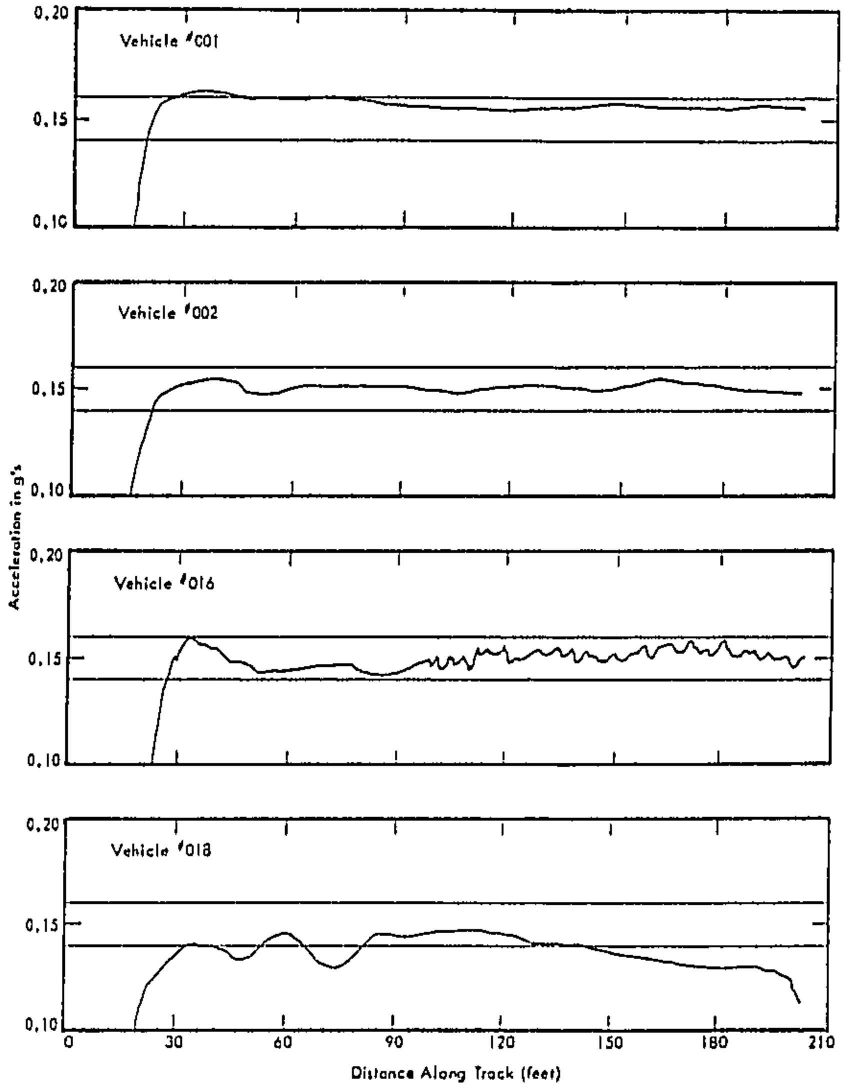

Figure 5.6. Acceleration Traces for Automatics Operating Under Condition 3.0.

acceleration that appear at the gear change with the transmission in Drive. Since Condition 2.0 is initiated from an initial velocity of 10 mph, a greater distance is required to achieve constant acceleration than for Condition 1.0, even though the actual time required to achieve the acceleration condition may be nearly the same for both conditions. From Figure 5.6 it can be seen that all vehicles except vehicle #018 could readily maintain constant acceleration in second gear when initiated from a moving start. It is inferred that the failure of vehicle #017 to maintain 0.15g after 120 feet of travel is due to its low power-to-weight ratio. The behavior after 120 feet was duplicated in each of the four runs under this condition, and hence it is concluded that the vehicle was not capable of maintaining an acceleration greater than 0.15g in second gear at speeds in excess of 27 mph.

An observation of considerable significance from the constant acceleration pass-bys for automatic transmission vehicles operated under Condition 1.0 is the considerable variation in vehicle and engine speed at which the 1-2 shift occurred from run to run for nominally identical acceleration profiles. Two examples of such variation are presented in Figures 5.7 and 5.8. In Figure 5.7 it is seen that the difference in acceleration for the two runs shown for vehicle #014 is less than 0.01g. However, the vehicle speed at the shift point differs by about 1.5 mph. Similar acceleration differences produce a 2.2 mph speed difference for vehicle #017 as shown in Figure 5.8. For these two vehicles, the range of maximum engine speed at the 1-2 shift was about 180 RPM. The cause of this variation may be that automatic transmissions sense either manifold pressure or throttle position along with other operating parameters in order to determine the optimum shift point. To maintain constant acceleration, it is necessary to make instantaneous throttle adjustments, and it is possible that these adjustments are responsible for the variability in shift point occurrence. It should also be noted that the total range in sound level at the shift point for eight runs of vehicle #018 operated under Condition 1.0 was 3.7 dB.

In the performance of the constant acceleration pass-by conditions, two automatic transmission vehicles exhibited unique characteristics. One of these vehicles was the Lincoln Continental, vehicle #003. For purposes of comparison to the Lincoln, typical performance for the Dodge Royal Monaco, vehicle #002, under Condition 1.0 is indicated in Figure 5.9 in terms of engine speed and acceleration as a function of distance. It will be noted that there is a pronounced peak in engine speed and a corresponding

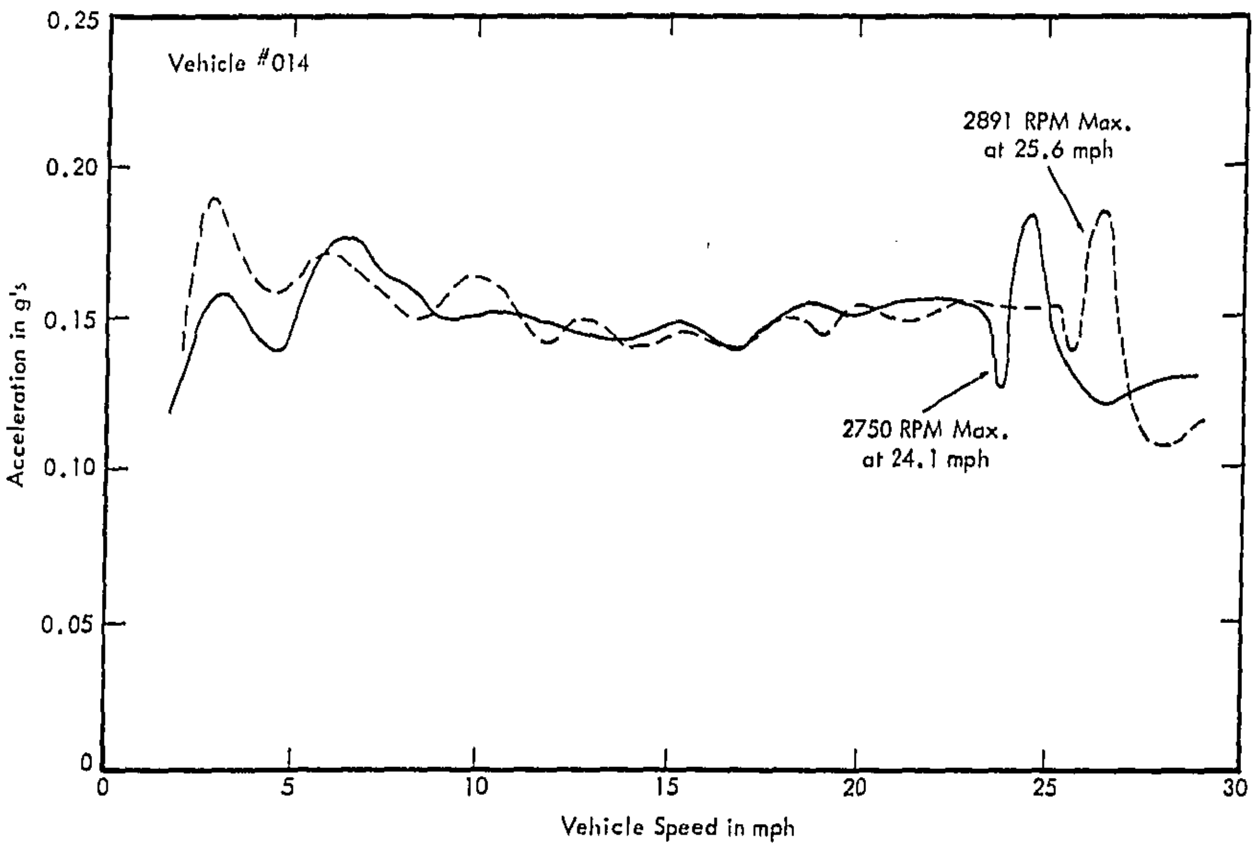

Figure 5.7. Variation in Vehicle Parameters at the Shift Point — Vehicle #014.

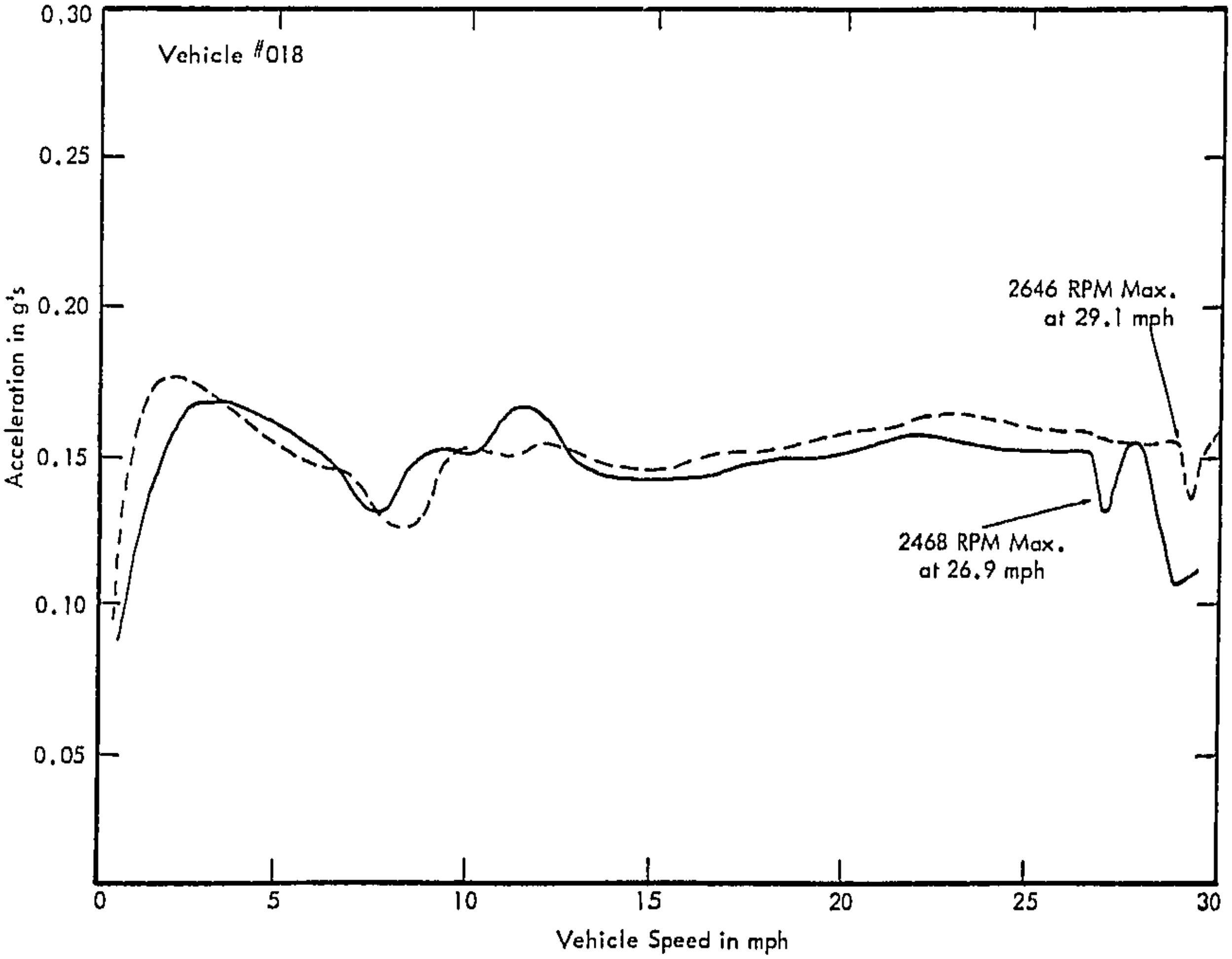

Figure 5.8. Variation in Vehicle Parameters at the Shift Point — Vehicle #018.

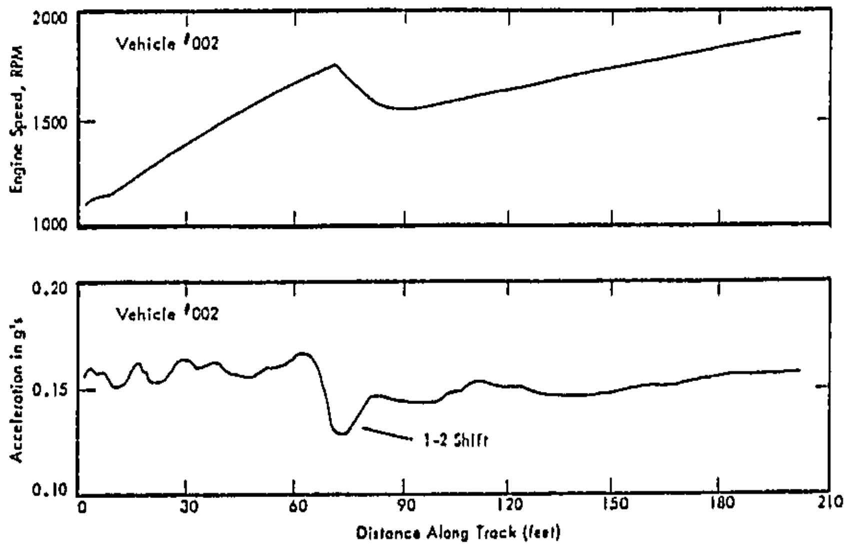

Figure 5.9. Engine Speed and Acceleration Traces for Vehicle #002.

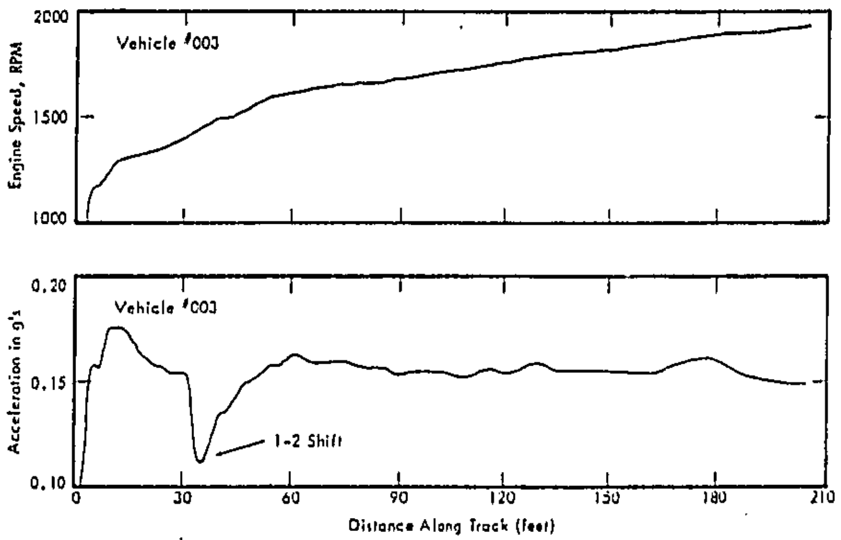

Figure 5.10. Engine Speed and Acceleration Traces for Vehicle #003.

decrease in acceleration occurring at the transmission shift from first to second gear. Similar plots are presented for the Lincoln Continental in Figure 5.10. For this vehicle, there is no identifiable peak in engine speed corresponding to the transmission shift. The Lincoln also shifted at the lowest vehicle speed of all the test vehicles, 3.0 mph lower than any other. It is suspected that this behavior is related to the powerful, large displacement engine in combination with the particular transmission design used in this luxury vehicle. This behavior had no adverse effect on the ability to achieve and maintain constant acceleration with this vehicle.

Unusual characteristics were also observed for the Toyota Corolla, vehicle #004, when it was operated under Conditions 1.0 and 3.0. A typical plot of engine speed and acceleration versus distance is presented in Figure 5.11 for this vehicle performing Condition 1.0. As indicated in the figure, the vehicle begins the test in the low gear range (highest numerical gear ratio) and maintains constant acceleration reasonably well within a range of 0.14g to 0.16g up to the first transmission shift signified by a peak in engine speed. In second gear, however, the vehicle is not capable of maintaining 0.15g at low engine speeds, and therefore, a downshift occurs. The downshift results in high engine speed which together with the partial-throttle condition required to achieve 0.15g in first gear is sensed by the transmission and causes a second transmission upshift. The cycle is then repeated. This behavior precludes the testing of this particular vehicle under 0.15g constant acceleration after the first transmission upshift. Constant acceleration pass-bys may, however, be possible after the first transmission upshift at different acceleration rates or with the transmission restrained to the low (high numerical ratio) gear as performed in Condition 2.0. Behavior similar to that described above for Condition 1.0 also occurred under Condition 3.0 for the Toyota Corolla where the vehicle is initially in its second lowest numerical gear range. Although this behavior precludes testing under constant 0.15g acceleration as specified in Condition 3.0, constant acceleration pass-bys may be possible at lower acceleration values.

The reasons for the behavior of the Toyota Corolla in Conditions 1.0 and 3.0 are not known. The vehicle does, however, have some other characteristics which may be related to its performance in these conditions. With the exception of the Lincoln Continental discussed earlier, the first upshift for the Toyota under 0.15g constant acceleration

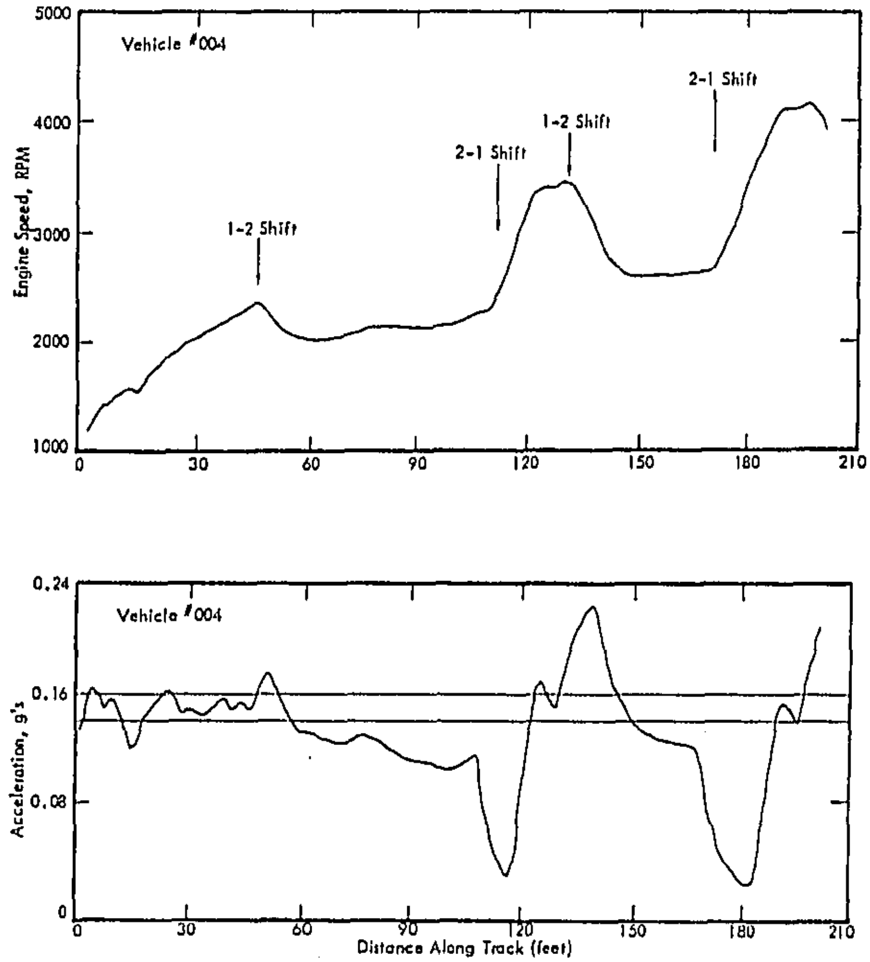

Figure 5.11. Characteristics of Vehicle #004 Under Constant Acceleration.

occurs at the lowest vehicle speed of any of the test vehicles, about 2.8 to 9.5 mph lower. Also, with the exception of the Lincoln, the percent of rated engine speed at the first upshift is the lowest of all other test vehicles — a fact also exhibited in normal driving (see Table 4.2). The results obtained from the limited number of automatic transmission vehicles tested do not warrant any general conclusions relating vehicle parameters to the occurrence of unusual behavior exhibited by the Toyota and Lincoln under constant acceleration. However, this behavior must be carefully considered in the evaluation of the constant acceleration test procedure.

One of the required outputs from the constant acceleration tests for automatic transmission vehicles was the determination of the gear range that produces the maximum sound level during low-speed, constant 0.15g acceleration at vehicle speeds below 25 mph. It was observed that some vehicles, when operated under Condition 1.0, produced higher sound levels in second gear than in first gear, as shown in Figure 5.12 by plots of sound level versus vehicle speed for the Toyota Corolla, vehicle #004, and the Lincoln Continental, vehicle #003. For a thorough evaluation of the occurrence of maximum sound level during low-speed acceleration, Table 5.5 presents the maximum sound level observed in first gear prior to the 1-2 shift for Condition 1.0 and the maximum level produced in second gear for Condition 3.0 for each of the automatic transmission test vehicles. It will be noted that in addition to the two vehicles illustrated in Figure 5.12, vehicle #002, the Dodge Royal Monaco, produced a higher level in second gear below 25 mph than in first gear. Examination of Table 5.5 also indicates that vehicles which shift at lower vehicle speeds also produce lower sound levels in first gear relative to the level produced in second gear at 25 mph as would be expected. This tendency is shown in Figure 5.13 where the difference between maximum sound level prior to 25 mph in second gear and the maximum prior to the 1-2 shift in first gear is plotted as a function of the difference between 25 mph and the vehicle speed at the 1-2 shift. It can be concluded that, generally, for constant 0.15g acceleration, higher sound levels may be produced after the 1-2 shift if the shift occurs at vehicle speeds below about 21 mph.

A final result of interest concerning constant acceleration and automatic transmission vehicles is the ability of other test drivers to operate a vehicle at constant acceleration after little or no experience in driving vehicles under this condition. The acceleration-versus-distance profiles obtained for four different drivers performing Condition 1.0 are

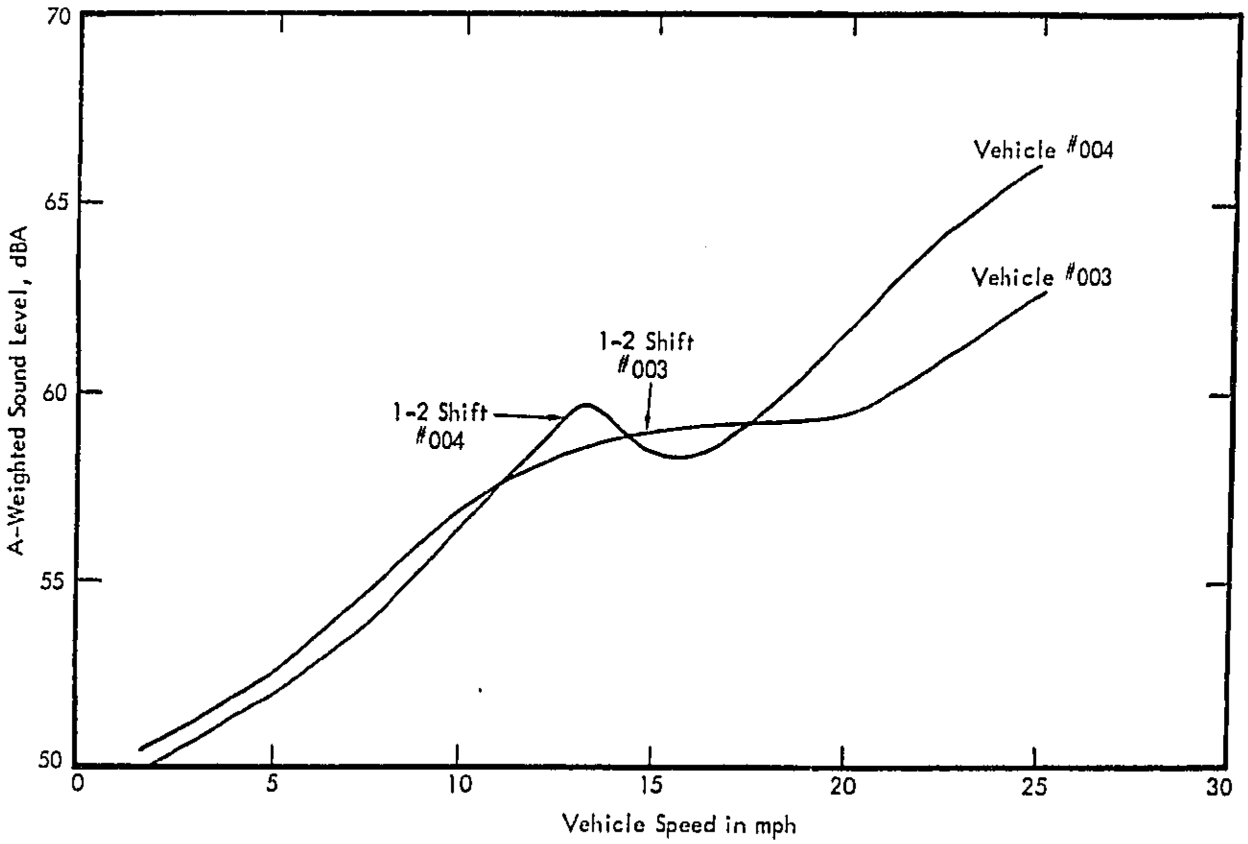

Figure 5.12. Vehicle Sound Levels Before and After the Shift Point.

Table 5.5

Comparison of Sound Levels
in First and Second Gears for Automatics

Vehicle No.	Condition No.	Data up to & Including	Max. Sound Level (dBA)*	Speed (mph)	RPM	Acceleration in g's
001	1.0	1-2 shift	66.3	25.6	2123	0.147
	3.0	25 mph	62.5	24.7	1725	0.160
002	1.0	1-2 shift	60.8	16.9	1664	0.154
	3.0	25 mph	63.6	24.6	1704	0.153
003	1.0	1-2 shift	57.9	11.3	1498	0.158
	3.0	25 mph	62.4	24.5	1816	0.149
004	1.0	1-2 shift	61.0	14.1	2362	0.148
	3.0	25 mph	(65.7)**	(25.0)	--	---
009	1.0	22 mph	68.7	22.0	2836	0.136
	3.0	25 mph	64.7	24.7	2360	0.106
014	1.0	1-2 shift	70.9	24.3	2779	0.147
	3.0	25 mph	69.8	24.6	2099	0.146
016	1.0	1-2 shift	65.6	20.1	2085	0.147
	3.0	25 mph	65.2	24.7	1908	0.148
018***	1.0	1-2 shift	64.8	28.0	2549	0.138
	3.0	25 mph	61.2	24.3	1753	0.156

* Maximum sound level produced up to and including the 1-2 shift.

** Estimated.

*** Sound level at 1-2 shift used for 1.0 due to pronounced resonance at lower speeds.

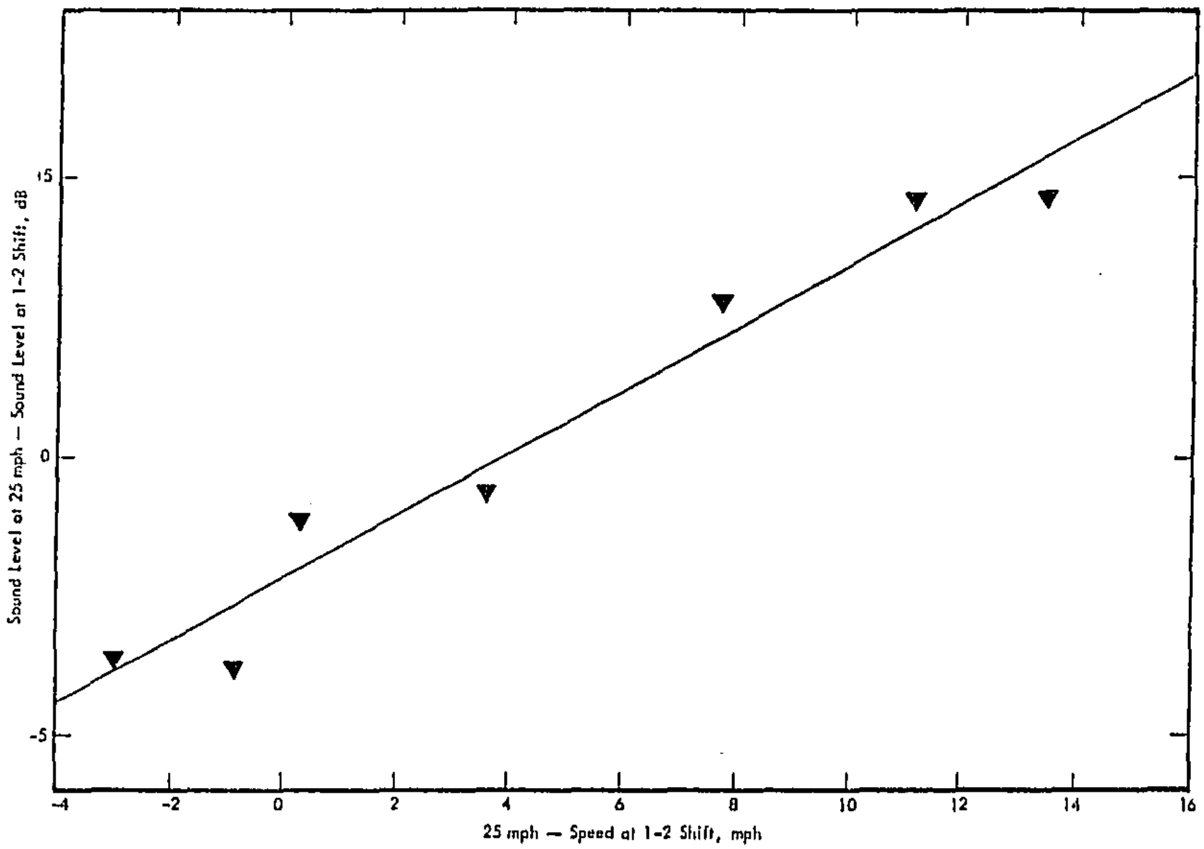

Figure 5.13. Relationship Between Sound Levels at the 1-2 Shift and 25 mph.

shown in Figure 5.14. In addition to three inexperienced drivers, a profile is shown for the test driver who performed all of the vehicle noise tests. The profiles given in Figure 5.14 are the best produced by each driver. The number of the run in each driver's sequence is indicated along with the total number of runs in the sequence. It should be noted that the vehicle used was the Oldsmobile Cutlass, vehicle #001, which was found from previous testing to be the most difficult automatic transmission vehicle to operate at constant acceleration. Inspection of profiles for drivers 1, 2, and 3 indicate that constant acceleration can be maintained quite well after very limited practice, even though in this case they were all consistently low in acceleration, averaging approximately 0.14g constant acceleration rather than 0.15g. This tendency, however, does not detract from the result that constant acceleration can apparently be performed by drivers with only minimal experience.

5.5.2 Manual Transmission Vehicles

The results of test Conditions 1.0, 2.0, and 3.0 for vehicles equipped with manual transmissions showed that constant acceleration operation of manual transmission vehicles could be achieved and maintained reasonably well, though not as well as could be done with the automatics. The evaluation of constant acceleration pass-bys for manuals was performed by using acceleration statistics and visual inspection of acceleration profiles in exactly the same manner as for automatics.

Acceleration statistics for the vehicle speed range from 20 to 26 mph are not appropriate for all manual transmission vehicles, since some reached rated engine speed at or before 26 mph. Those vehicles for which the statistics are appropriate are presented with the corresponding acceleration data in Table 5.6. In the vehicle speed range from 20 to 26mph, it is seen that, in almost all cases, the mean acceleration can be maintained at 0.15g within a ±0.01g tolerance. However, it is apparent from the standard deviation and percentage averages that some vehicles are considerably more difficult to maintain at constant acceleration than others, particularly vehicle #005. Generally, it is seen that Condition 3.0, constant acceleration in second gear, can be maintained more easily than the other two conditions.

Whereas variations in the acceleration for automatics can, and in fact does, affect the shift point in the constant acceleration tests, this is not true for manuals. Accordingly,

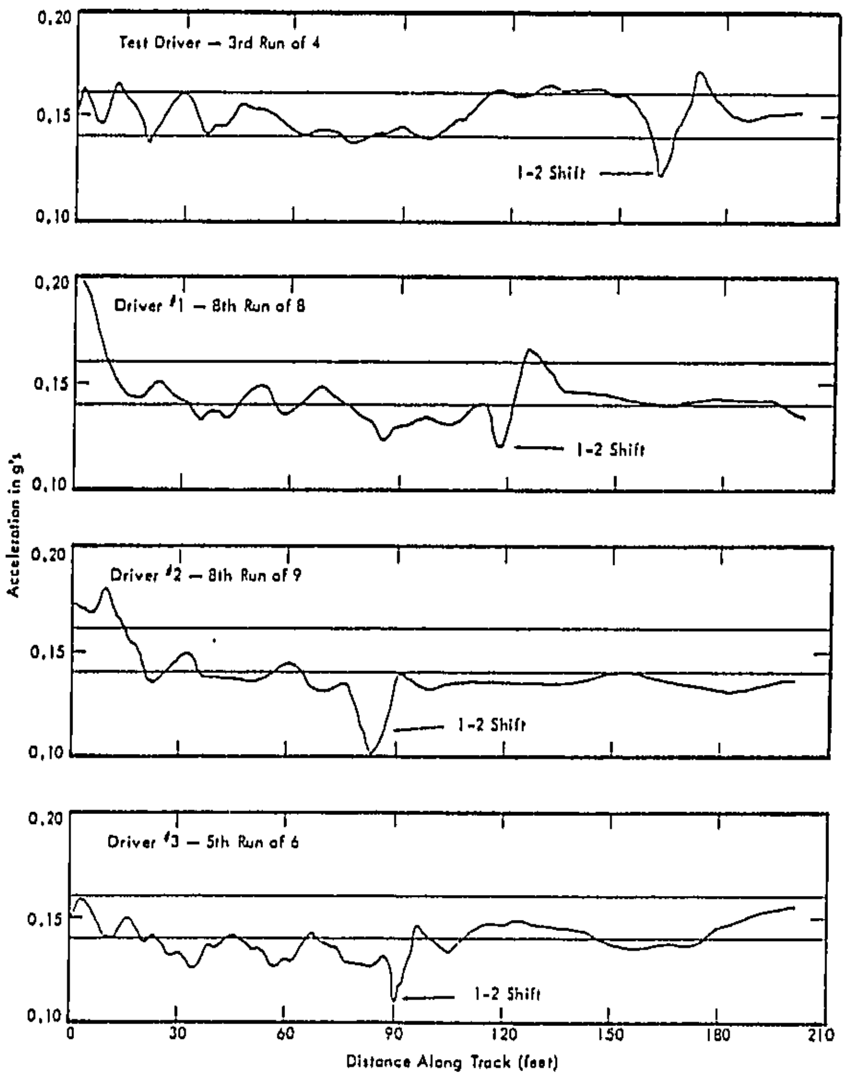

Figure 5.14. Acceleration Traces for Automatics Operated by Different Drivers.

Table 5.6

Acceleration Statistics for Constant Acceleration Tests
for Manual Transmission Vehicles

Vehicle No.	Condition No.	Mean Acceleration in g's*	Standard Deviation of Acceleration σ*	% Distance Acceleration Outside Range 0.14g to 0.16g*
005	1.0	0.145	0.026	80.9
	2.0	0.139	0.015	78.5
	3.0	0.144	0.006	25.7
007	1.0	0.147	0.006	24.3
	2.0	0.152	0.007	23.2
	3.0	0.160	0.003	49.9
008**	1.0	0.158	0.005	34.7
	2.0	0.158	0.006	36.0
	3.0	0.143	0.007	42.3
010	3.0	0.149	0.004	7.4
012	1.0	0.150	0.005	11.0
	2.0	0.160	0.007	56.3
	3.0	0.155	0.003	10.9
015**	3.0	0.152	0.006	22.7

* Statistics taken for four runs over the vehicle speed range 20-26 mph.

** Attained rated engine speed prior to 26 mph in Condition 1.

the acceleration history prior to a specific end condition is unimportant. Therefore, an alternative method of evaluating the results of the constant acceleration tests for manuals is to examine the acceleration statistics at a particular condition. In Table 5.7, the averages and ranges of acceleration values for four runs are presented, corresponding to the occurrence of the maximum sound level prior to and including, and at 75 percent rated engine speed or at 22 mph, whichever occurs first. This value of rated engine speed was selected so that the data would be directly comparable to that obtained for Condition 8.0. A maximum speed of 22 mph was selected to be representative of 0.15g acceleration (see Table 4.4). From this table, it can be seen that in all but a few cases, the average acceleration is within a range of ±0.01g about 0.15g. The ranges in the acceleration about the average values are also about ±0.01g. As will be discussed later, the total sound level range associated with the acceleration ranges of Table 5.7 are small, typically between 0.5 and 1.5 dB.

The third method of evaluating constant acceleration pass-by performance is to consider individual acceleration profiles. Plots of acceleration versus distance are presented in Figures 5.15, 5.16, and 5.17 for Conditions 1.0, 2.0, and 3.0, respectively. The plots in these figures are representative of those runs most closely approximating constant acceleration. The vehicles presented are intended to be representative and include the most difficult (#005) and the easiest (#011) vehicles in which to perform constant acceleration.

Examination of Figure 5.15 indicates several tendencies. There is a tendency to overshoot the acceleration rate initially — a tendency also found with automatics. In comparison to the automatics, the acceleration profile for manuals is considerably less smooth. However, with the exception of vehicle #005, the vehicles shown in Figure 5.15 can maintain constant acceleration quite well within a tolerance of ±0.01g after the prescribed rate of 0.15g is achieved. The initial fluctuating behavior in acceleration indicated for vehicle #005 was found to occur with several other of the test vehicles. It is speculated that this behavior is attributable to driveshaft response, the driveshaft effectively being directly connected to the engine. Such response is not encountered with automatic transmission vehicles due to the damping and slippage in the torque converter. Although not nearly as pronounced as in vehicle #005, some of the short-term variations present in the acceleration profiles of the other vehicles shown in Figure 5.15 may also be due to this phenomenon.

Table 5.7

Acceleration Statistics for Manuals
in Conditions 1.0 and 2.0

Vehicle No.	End Condition	MEAN VALUE OF ACCELERATION AND RANGE FOR FOUR RUNS			
		Up to and Including End Condition		At End Condition	
		Condition 1.0	Condition 2.0	Condition 1.0	Condition 2.0
005	75%	0.142 +0.013/-0.014	0.143 +0.001/-0.002	0.141 +0.005/-0.013	0.142 +0.004/-0.004
006	75%	0.156 +0.013/-0.012	0.147 +0.007/-0.009	0.152 +0.010/-0.009	0.147 +0.010/-0.010
007	22 mph	0.150 +0.014/-0.009	0.154 +0.014/-0.008	0.150 +0.019/-0.007	0.154 +0.010/-0.007
008	22 mph	0.159 +0.004/-0.005	0.159 +0.014/-0.007	0.160 +0.008/-0.004	0.164 +0.003/-0.007
010	75%	0.146 +0.006/-0.009	0.149 +0.005/-0.005	0.147 +0.003/-0.002	0.146 +0.006/-0.002
011	75%	0.143 +0.006/-0.010	0.144 +0.014/-0.013	0.143 +0.003/-0.004	0.145 +0.009/-0.013
012	75%	0.151 +0.010/-0.007	0.157 +0.010/-0.005	0.150 +0.002/-0.007	0.155 +0.009/-0.004
013	22 mph	0.146 +0.003/-0.005	0.143 +0.006/-0.008	0.149 +0.001/-0.004	0.144 +0.007/-0.009
015	75%	0.147 +0.021/-0.032	0.140 +0.014/-0.016	0.144 +0.014/-0.031	0.139 +0.010/-0.023

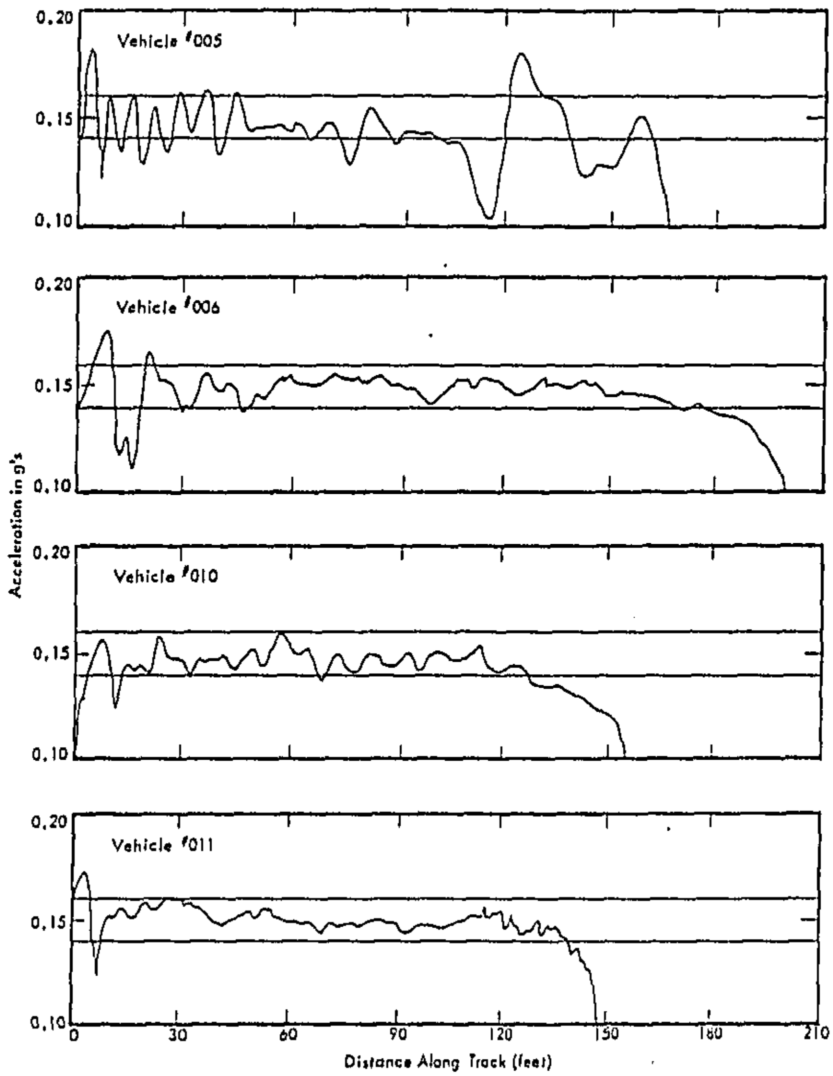

Figure 5.15. Acceleration Traces for Manuals Operating Under Condition 1.0.

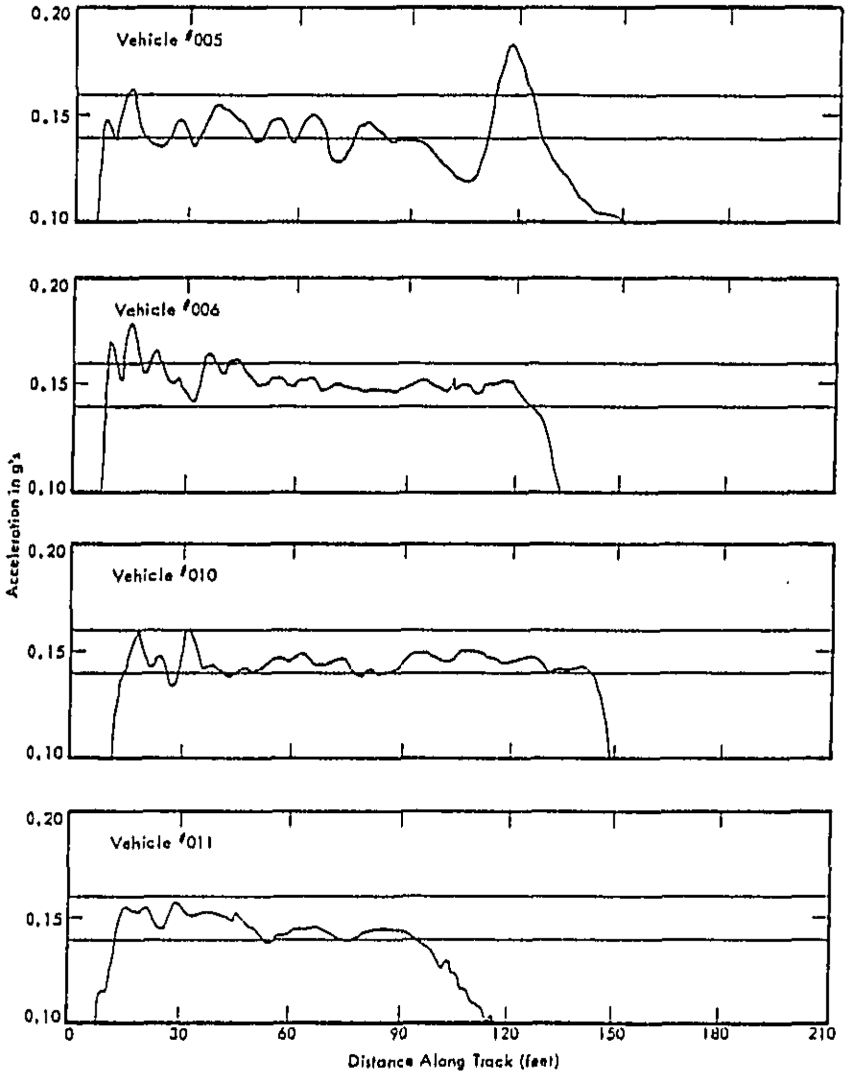

Figure 5.16. Acceleration Traces for Manuals Operating Under Condition 2.0.

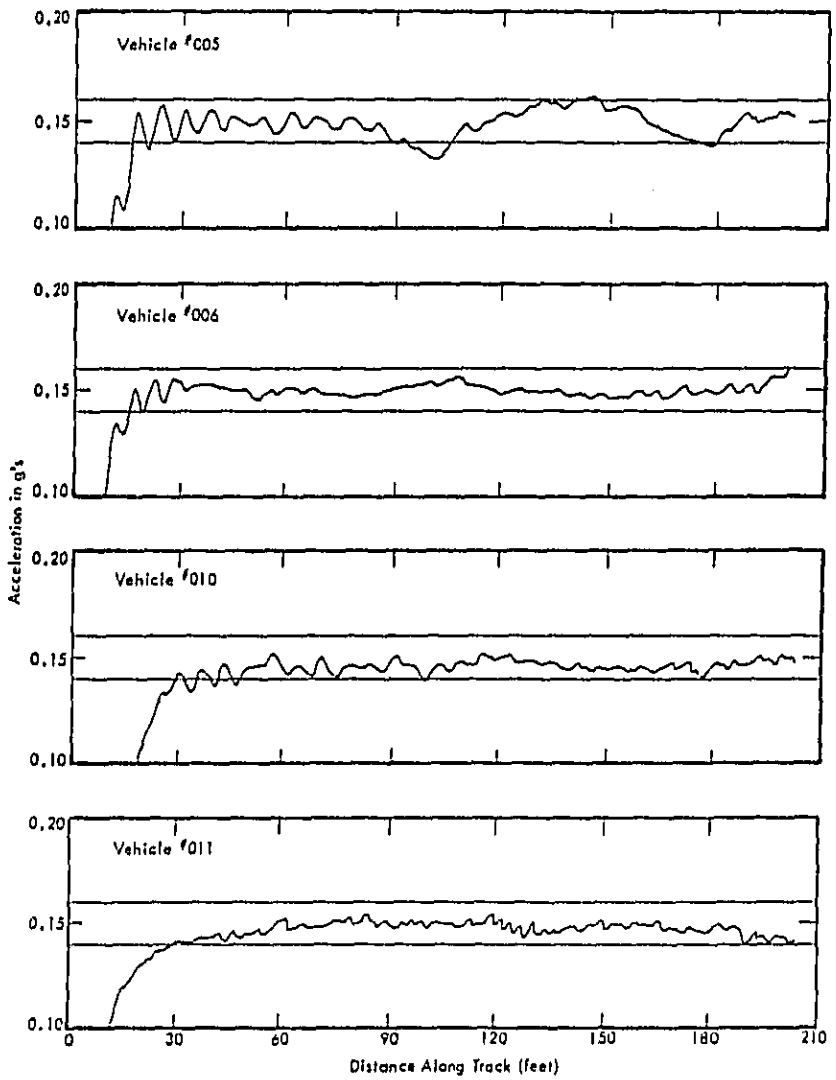

Figure 5.17. Acceleration Traces for Manuals Operating Under Condition 3.0.

In comparison to Condition 1.0, the acceleration profile in Figure 5.16 for Condition 2.0 for vehicle #005 displays very little fluctuating behavior. However, for all four vehicles, the short-term acceleration variations apparent in Condition 1.0 also occur in Condition 2.0. Because these variations are still present, there appears to be little advantage to moving starts in initiating and maintaining a constant acceleration. The plots in Figure 5.17 indicate that constant acceleration can be readily maintained in second gear for manual transmission vehicles. However, the short-term variations in acceleration that were noted for Conditions 1.0 and 2.0 in Figures 5.15 and 5.16 are also present for Condition 3.0 in Figure 5.17.

One of the manual transmission vehicles displayed unique behavior when operated under constant acceleration in Conditions 1.0 and 2.0. An example of this behavior is presented for vehicle #007 in Figure 5.18 where acceleration is plotted versus distance for Condition 1.0. This plot indicates a very pronounced peak occurring in acceleration at a distance of about 160 feet. This peak occurred regularly under both Conditions 1.0 and 2.0 and was not due to sudden throttle movement by the operator. As this particular vehicle is equipped with a 4-barrel carburetor, it is suspected that this surge in vehicle acceleration occurred when the second pair of carburetor barrels were activated. Such activation could be caused by the increasing performance demand placed on the engine at increasing vehicle speeds under constant acceleration.

A required output from the results of constant acceleration pass-by conditions for manual transmission vehicles is the comparison of maximum sound levels measured in first and second gears under 0.15g constant acceleration at speeds below 25 mph. A comparison of these sound levels is presented in Table 5.8. The sound levels reported for first gear (Condition 1.0) correspond to the maximum sound level observed at or before 75 percent rated engine speed, or 22 mph, whichever occurred first. The levels in second gear (Condition 3.0) correspond to the maximum prior to and including 25 mph. From Table 5.8, it should be noted that all the test vehicles produced higher levels in first gear than in second since the engine speed in second gear at 25 mph is substantially lower than 75 percent rated engine speed or the engine speed corresponding to 22 mph in first gear. Vehicles in which the engine speed more closely approached or exceeded 75 percent rated engine speed in second gear prior to 25 mph would exhibit higher levels in second than in first gear.

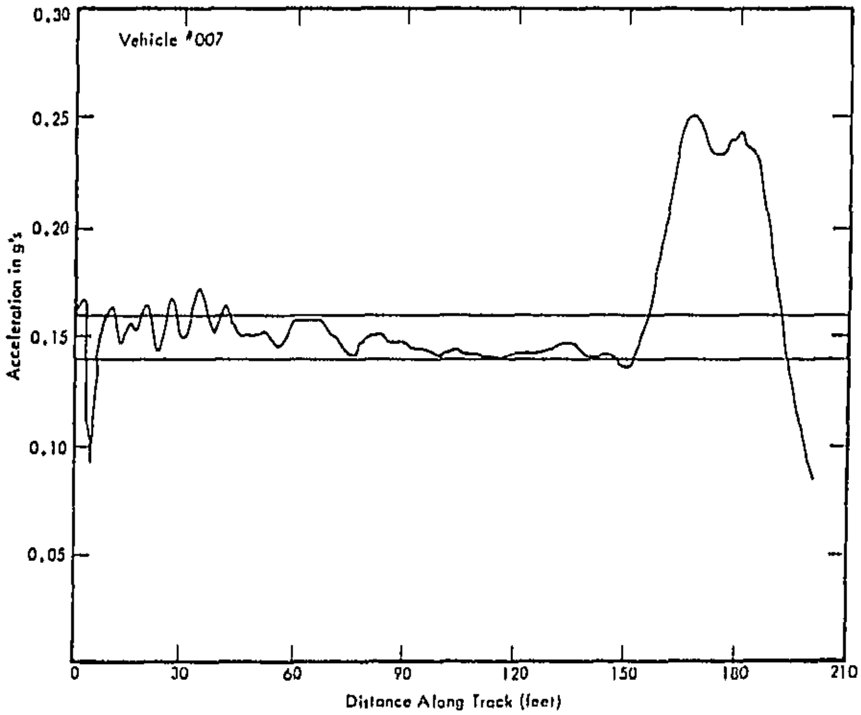

Figure 5.18. Acceleration Traces for Vehicle #007.

Table 5.8

Comparison of Sound Levels
in First and Second Gears for Manuals

Vehicle No.	Condition No.	Data up to & Including	Max. Sound Level (dBA)	Speed (mph)	RPM	Acceleration in g's
005	1.0	75%	69.6	20.2	4239	0.142
	3.0	25 mph	66.4	23.7	2795	0.145
006	1.0	75%	70.6	20.2	4047	0.156
	3.0	25 mph	64.8	24.0	2730	0.157
007	1.0	22 mph	69.0	21.2	4125	0.150
	3.0	25 mph	67.4	24.4	2909	0.161
008	1.0	22 mph	67.7	21.2	3490	0.159
	3.0	25 mph	64.3	24.6	2540	0.148
010	1.0	75%	66.3	18.2	2500	0.146
	3.0	25 mph	62.9	24.3	1863	0.150
011	1.0	75%	69.7	17.6	3911	0.143
	3.0	25 mph	68.8	24.8	3155	0.139
012	1.0	75%	71.7	20.2	4065	0.151
	3.0	25 mph	67.3	24.4	2840	0.157
013	1.0	22 mph	65.5	21.5	2620	0.146
	3.0	25 mph	63.2	23.4	2038	0.145
015*	1.0	75%	71.1	17.2	2812	0.147
	3.0	25 mph	68.0	24.7	2002	0.156

* Note: Second gear was used for Condition 1.0, and third gear for Condition 3.0. First gear had an unusually high numerical ratio.

At a given engine speed, the engine power required to accelerate a vehicle at a given rate in second gear is greater than in first gear (due to the different gear ratios), and it might be assumed that this would result in higher noise levels. Therefore, the noise level produced at 75 percent rated engine speed in second gear may be greater than at the same engine speed in first gear. From the vehicles tested, however, it is not possible to predict how close the engine speed would have to be to 75 percent rated speed for the maximum level in the two gears to occur in second at 25 mph.

To evaluate the ability of different drivers to perform constant acceleration in manual transmission vehicles, four acceleration-versus-distance plots are presented in Figure 5.19. The four plots given in this figure are the best constant acceleration pass-bys obtained by each of three inexperienced drivers and the driver used exclusively in the noise measurement program. The vehicle used, a Toyota Corolla (vehicle #005) was found to be the most difficult manual transmission vehicle to operate at constant acceleration. Comparison of the profiles of Figure 5.19 indicate that the experienced test driver was able to maintain acceleration much more closely within the range 0.14g to 0.16g than the other inexperienced drivers. Also, the experienced driver was able to minimize the variations in acceleration. However, considering the difficulty presented by this particular vehicle, it cannot be concluded that operating a manual transmission vehicle under constant acceleration requires any special ability other than practice.

5.5.3 Summary of Constant Acceleration Test Results

The test Conditions 1.0, 2.0, and 3.0 (see Tables 5.1 and 5.2) were conducted on 18 vehicles equipped with automatic and manual transmissions to evaluate the constant acceleration method of measuring the noise emissions from light vehicles under partial-throttle acceleration. The conclusions drawn from the results obtained can be summarized as follows:

- With practice, constant acceleration can be achieved and maintained for most vehicles over the vehicle speed range 0 to 25 mph for automatics and manuals. In the case of automatics, constant acceleration can be resumed after the 1-2 transmission shift. Fluctuations in the acceleration are more pronounced for manuals than automatics.

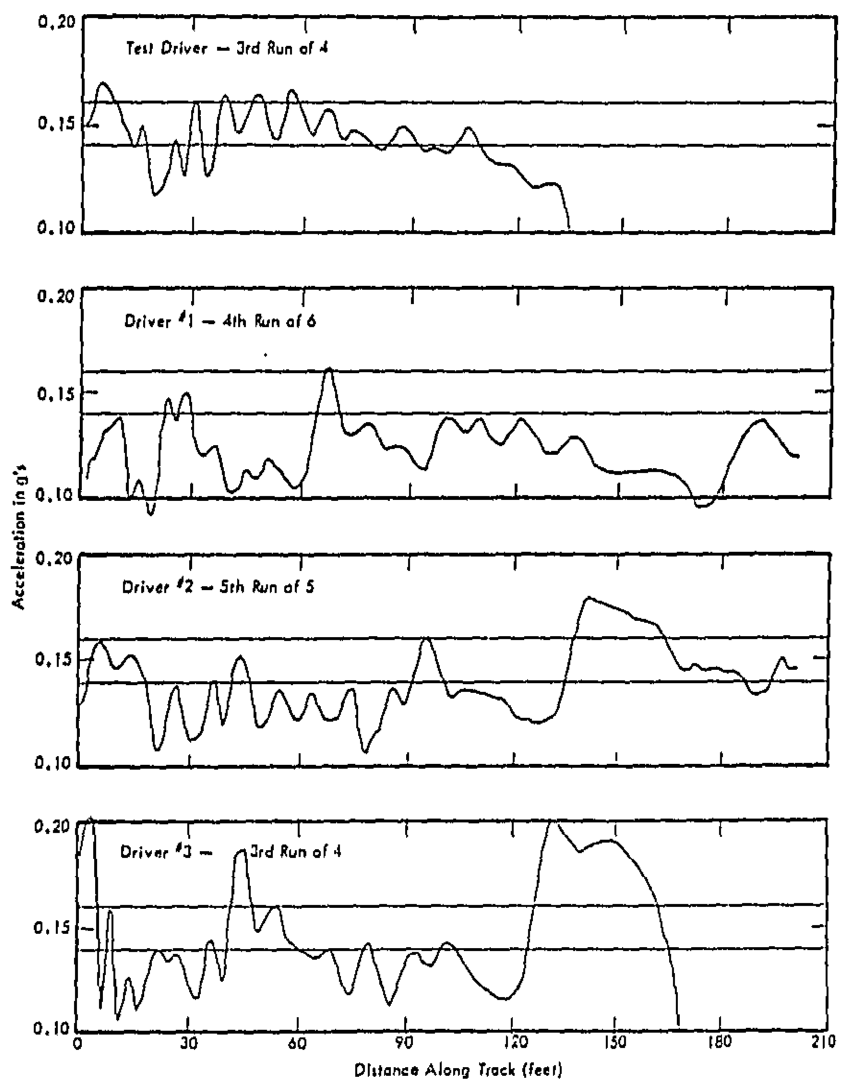

Figure 5.19. Acceleration Traces for Manuals Operated by Different Drivers.

- There appear to be no major advantages to a moving start over a standing start in terms of maintaining constant acceleration.

- There may be difficulties in maintaining constant acceleration over the complete range with some vehicles due to automatic transmission shift or carburetor characteristics. Other types of engines and drivetrains not tested in this program may also present problems. There are also a few vehicles that cannot achieve an acceleration of 0.15g over the required vehicle or engine speed range.

- It appears possible to maintain constant acceleration within a range of ±0.01g for automatics and manuals about a mean rate of 0.15g.

- The engine speed at the 1-2 transmission shift point for automatics varies from run to run for similar acceleration profiles because it is dependent on throttle position and engine speed. It is therefore necessary to impose a smaller allowable tolerance on the acceleration fluctuations for automatics than for manuals in order to obtain repeatable sound levels. With manual transmission vehicles, it is only necessary to ensure that the required acceleration is obtained at the prescribed end condition where noise data are to be taken.

- There are some vehicles equipped with automatic transmissions for which the transmission shift occurs with little or no noticeable change in engine speed. This may lead to difficulty in identifying the shift point.

- Some vehicles equipped with automatic transmissions produce higher sound levels in second gear at speeds less than 25 mph than in first gear at the 1-2 transmission shift. Thus, automatics may have to be tested in both gears to obtain the maximum sound level.

- All of the test vehicles equipped with manual transmissions produce higher sound levels in first gear at 75 percent rated engine speed, or 22 mph, whichever occurs first, than at 25 mph in second gear. Thus, manuals needed only be tested in first gear to obtain the maximum sound level.

- The vehicle sound level is proportional to X log (engine speed). Near the shift point, X = 45. The value of X decreases with decreasing engine speed for a 0.15g acceleration.

5.6 Interpolated Partial-Throttle Acceleration Noise

As discussed in Section 5.3.3, the CCMC has proposed a method for determining partial-throttle acceleration noise utilizing an interpolative technique. To use this technique, the sound level at a predetermined operating condition is interpolated from measured sound levels made under full-throttle acceleration and cruise conditions. The method is applicable only to vehicles equipped with manual transmissions.

The vehicle operating region of importance in the CCMC test procedure is partial-throttle acceleration between about 40 and 65 percent rated engine speed as determined from European light vehicle operation studies. As proposed, the CCMC procedure requires the measurement of sound levels at three conditions that bound this region of importance: full-throttle acceleration near 70 percent rated engine speed in second gear, full-throttle acceleration near 33 percent rated engine speed in third gear, and cruise at 25 mph in second gear. Linear interpolation between these three points then provides the sound level at the required partial-throttle condition.

In an attempt to simplify the instrumentation required for the test, the CCMC procedure specifies an entry engine speed and gear from which the full-throttle acceleration is initiated at a given point along the test track. Experience gained from previous tests has shown that for the specified test configuration with a single microphone, the maximum sound level is produced at an engine speed given by the entry engine speed plus a correction factor. The measured maximum sound level for the full-throttle acceleration tests are then assumed to correspond to this corrected value of the engine speed. Since the instrumentation system at the Marana test site was designed to monitor continuously all the vehicle parameters during a test run, it was not necessary to adopt this approximate correction procedure for determining the engine speed.

In addition to the above, other modifications were made to the proposed CCMC procedure so that it could be evaluated with respect to the proposed 0.15g constant acceleration procedure. For comparison purposes, sound level data from the constant acceleration test Condition 1.0 was taken at 75 percent rated engine speed or 22 mph, whichever occurred first. Since this test was conducted with the vehicle in first gear, it was decided to perform the full-throttle acceleration tests required in the CCMC procedure also in first gear. These data were taken from test Condition 4.1 — full-throttle acceleration from a standing start (see Table 5.2) — at 60 and 90 percent rated engine speed to bound the region around 75 percent rated engine speed. Finally, the cruise condition required in the CCMC procedure was taken at 80 percent rated engine speed in first gear — Condition 5.2 in Table 5.2. In this manner, the interpolative procedure could be evaluated even though it did not correspond exactly to that proposed by CCMC.

To obtain an interpolated sound level from the measurements described above, further adaptation of the original CCMC procedure was required. A normalized power curve for first gear cruise was used in place of the second gear curve normally used in the procedure. This curve was supplied by representatives of the CCMC.

In using the normalized power curves to interpolate the sound level for a given operating condition, it is necessary to assume that engine power and acceleration are linearly related at a given engine speed in first gear. Knowing the acceleration rate at full-throttle acceleration as a function of engine speed, the normalized power corresponding to 0.15g can be linearly interpolated using the full-throttle and cruise (corresponding to zero acceleration) normalized power curves for any engine speed.

With the use of the method described above, interpolated sound levels for 0.15g and 75 percent rated engine speed (or 22 mph if it occurred first) were obtained. The sound levels corresponding to the two full-throttle and the cruise conditions are presented in Table 5.9. Also presented in this table are values of acceleration produced at the full-throttle conditions. For comparison to direct measurement at the desired operating condition, the sound levels and corresponding vehicle parameters for 0.15g constant acceleration and full-throttle acceleration at 75 percent rated engine speed (or 22 mph) are presented in Table 5.10 for each of the manual transmission test vehicles. Using the values in Table 5.9 and charts of normalized full-throttle and cruise power as provided by the CCMC, the sound levels at the partial-throttle operating condition were interpolated. Examples of the application of the interpolative technique are provided in Figures 5.20 and 5.21 for two of the test vehicles demonstrating, respectively, interpolation for an operating condition of 0.15g at 75 percent rated speed and 0.15g at 22 mph. In addition to the three sound levels needed to construct the "isophonic" lines required for the interpolative procedure, the full-throttle sound level at 75 percent rated engine speed (or 22 mph) is presented. This

Table 5.9

Sound Level and Acceleration Data Required for
Evaluation of CCMC Interpolation Procedure

Vehicle No.	FULL THROTTLE AT 60% MRES		FULL THROTTLE AT 90% MRES		Maximum Sound Level (dBA) for Cruise at 80% MRES
	Maximum Sound Level (dBA)	Acceleration in g's	Maximum Sound Level (dBA)	Acceleration in g's	
005	67,6 +0,2/-0,3	0,225 +0,004/-0,005	75.8 +0,3/-0,3	0,226 +0,001/-0,001	71,2 +0,1/-0,2
006	70,3 +0,3/-0,4	0,311 +0,008/-0,008	78,2 +0,1/-0,2	0,293 +0,003/-0,003	71,3 +0,0/-0,0
007	68,5 +0,4/-0,3	0,305 +0,002/-0,002	75,2	0,280	65,3 +0,0/-0,1
008	70,7 +0,0/-0,1	0,326 +0,004/-0,005	76,1 +0,4/-0,4	0,299 +0,005/-0,006	71,1 +0,2/-0,3
010	65,3 +0,2/-0,1	0,316 +0,000/-0,000	72,0 +0,2/-0,2	0,275 +0,003/-0,003	67,8 +0,1/-0,1
011	67,7 +0,2/-0,3	0,223 +0,001/-0,002	73,3 +0,0/-0,1	0,214 +0,002/-0,002	71,7 +0,2/-0,3
012	69,8 +0,9/-0,8	0,311 +0,008/-0,007	78,3 +0,1/-0,1	0,289 +0,004/-0,004	72,8 +0,1/-0,1
013	67,7 +0,3/-0,3	0,310 +0,000/-0,000	74,6 +0,1/-0,2	0,261 +0,021/-0,021	67,4 +0,3/-0,3
015	68,8 +0,1/-0,1	0,351 +0,005/-0,005	76,5 +0,2/-0,2	0,321 +0,004/-0,004	72,5 +0,3/-0,3

Table 5.10

Data for Manuals at 75 Percent Rated Engine Speed
for Constant Acceleration

Vehicle No.	Condition No.	Data For:	Sound Level (dBA)	Speed (mph)	RPM	Acceleration in g's
005	1.0	75%	68.8 +0.6/-0.7	--	--	0.141 +0.005/-0.01_
	4.1	75%	72.5 +0.4/-0.4	20.8 +0.0/-0.0	4346 +3/-4	0.253 +0.001/-0.00_
006	1.0	75%	70.4 +1.3/-1.1	--	--	0.152 +0.010/-0.00_
	4.1	75%	72.1 +0.5/-0.6	20.2 +0.1/-0.1	4127 +2/-2	0.308 +0.006/-0.000
007	1.0	22 mph	68.3 +0.9/-1.0			0.150 +0.019/-0.007
	4.1	22 mph	71.6 +0.2/-0.2	22.1 +0.0/-0.1	4327 +18/-15	0.317 +0.004/-0.004
008	1.0	22 mph	66.8 +0.4/-0.6			0.160 +0.008/-0.00_
	4.1	22 mph	72.9 +0.0/-0.0	22.0 +0.0/-0.0	3661 +1/-2	0.320 +0.003/-0.0_
010	1.0	75%	65.8 +0.1/-0.3			0.147 +0.003/-0.00_
	4.1	75%	67.6 +0.1/-0.1	18.5 +0.0/-0.0	2558 +4/-5	0.297 +0.004/-0.00_
011	1.0	75%	69.0 +1.2/-0.8			0.143 +0.003/-0.004
	4.1	75%	70.8 +0.5/-0.5	17.3 +0.0/-0.0	3894 +0/-1	0.228 +0.001/-0.00_
012	1.0	75%	71.3 +0.5/-0.4			0.150 +0.002/-0.00_
	4.1	75%	74.2 +0.0/-0.1	20.4 +0.0/-0.1	4124 +6/-6	0.311 +0.002/-0.00_
013	1.0	22 mph	65.4 +0.5/-0.4			0.149 +0.001/-0.00_
	4.1	22 mph	69.9 +0.6/-0.6	22.1 +0.0/-0.0	2706 +23/-24	0.303 +0.001/-0.002
015	1.0	75%	70.9 +0.7/-0.1			0.144 +0.014/-0.03_
	4.1	75%	72.3 +0.0/-0.1	16.3 +0.1/-0.2	2853 +5/-6	0.338 +0.003/-0.00_

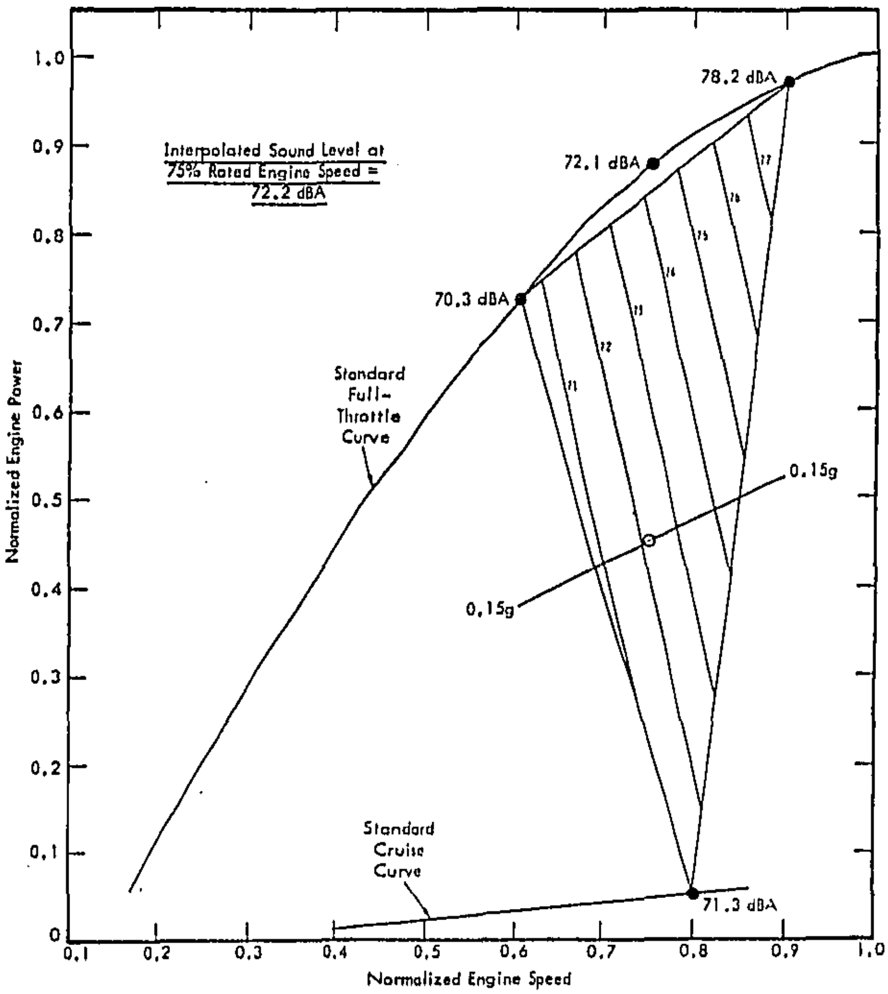

Figure 5.20. Interpolation Graph for Vehicle #006.

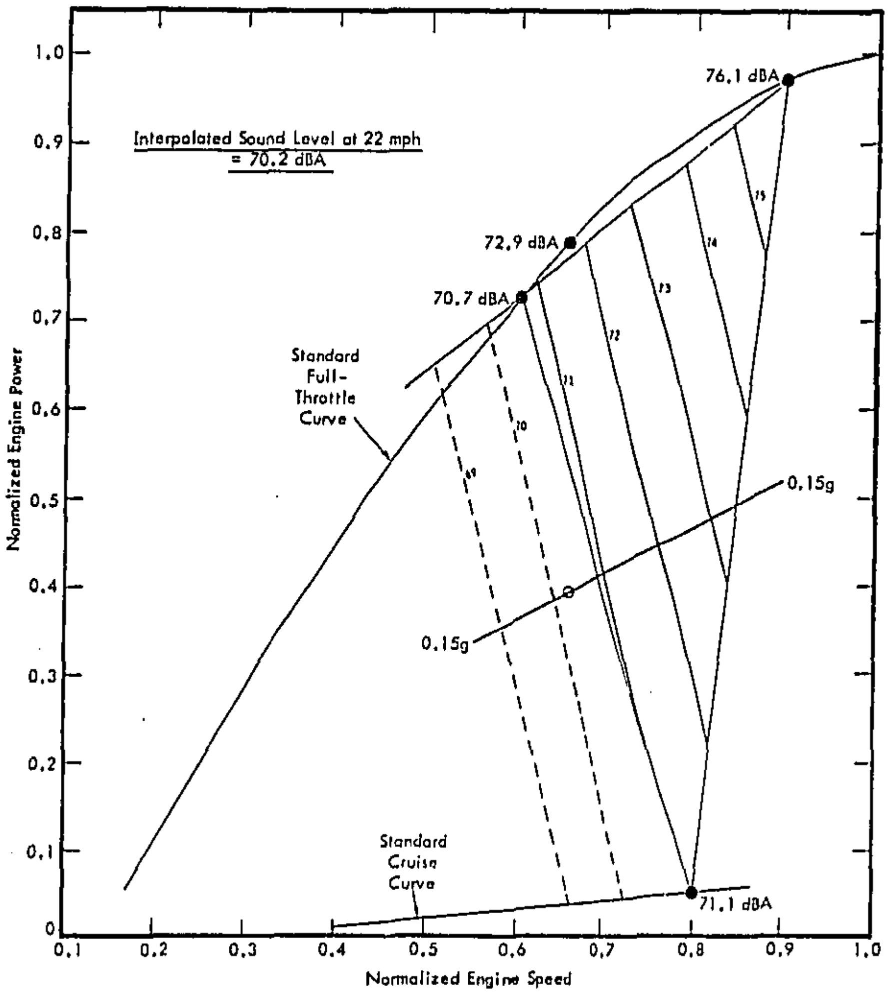

Figure 5.21. Interpolation Graph for Vehicle #008.

provides a comparison of the actual measured full-throttle sound level to the assumed level established by the linear interpolation between full-throttle sound levels at 60 and 90 percent rated engine speed.

Graphs similar to those of Figures 5.20 and 5.21 were produced for the other manual transmission vehicles with one exception. Using the sound levels of Table 5.9, a graph was produced for vehicle #011, the Chevrolet Chevette, as indicated in Figure 5.22. It will be noted that in this figure the "isophonic" lines slope in a positive direction, contrary to those of Figures 5.20 and 5.21. This implies that this vehicle is louder at cruise than at any other operating condition including full-throttle acceleration. As it was suspected that a resonance may be occurring at this particular engine speed accounting for the lack of dependence on acceleration, the sound level at a different cruise condition was considered. In Figure 5.23, the interpolation graph obtained using the cruise sound level at 60 percent rated engine speed is shown for vehicle #011. As indicated in this figure, the use of the cruise sound level at 60 percent rated RPM produces "isophonic" lines with negative slopes as was found with the other vehicles. It should be noted that use of this sound level gives an interpolated sound level 1.4 dB lower than before.

The interpolated sound levels corresponding to 0.15g at 75 percent rated engine speed or 22 mph are presented in Table 5.11 for the nine manual transmission vehicles tested. Also in Table 5.11 are the directly measured sound levels at the corresponding condition taken from the constant acceleration tests. It will be noted that the interpolated levels are consistently higher than the directly measured levels for all cases except vehicle #007, the Mazda RX-4. The average difference between these levels is 1.5 dB, the maximum difference being 3.4 dB. The explanation for this consistent overestimation is not known. Because of the consistency in the difference, it cannot be assumed that the discrepancy is attributable to the occurrence of resonances or anti-resonances in the 0.15g acceleration direct measurement condition.

In order to check the linear dependence of sound level on engine speed for full-throttle acceleration assumed in the interpolative procedure, a comparison of the interpolated and directly measured sound levels at 75 percent rated engine speed, or 22 mph, is presented in Table 5.12. Whereas the interpolated sound levels for partial-throttle

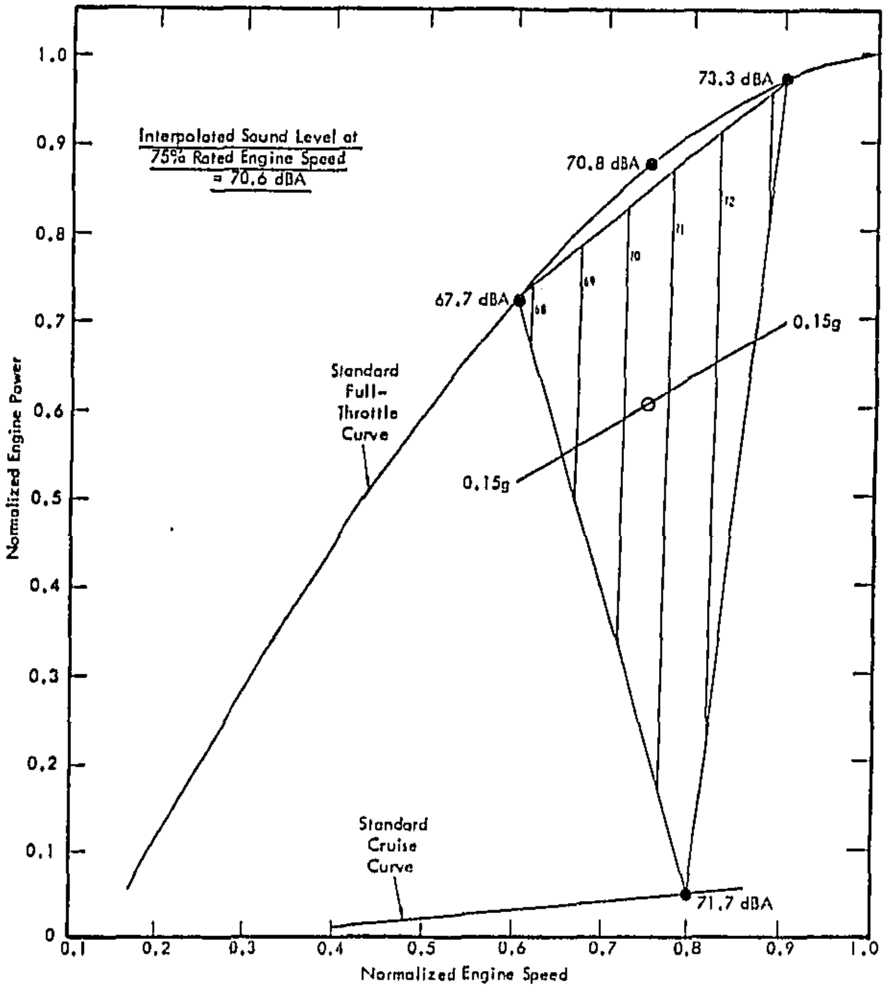

Figure 5.22. Interpolation Graph for Vehicle #011.

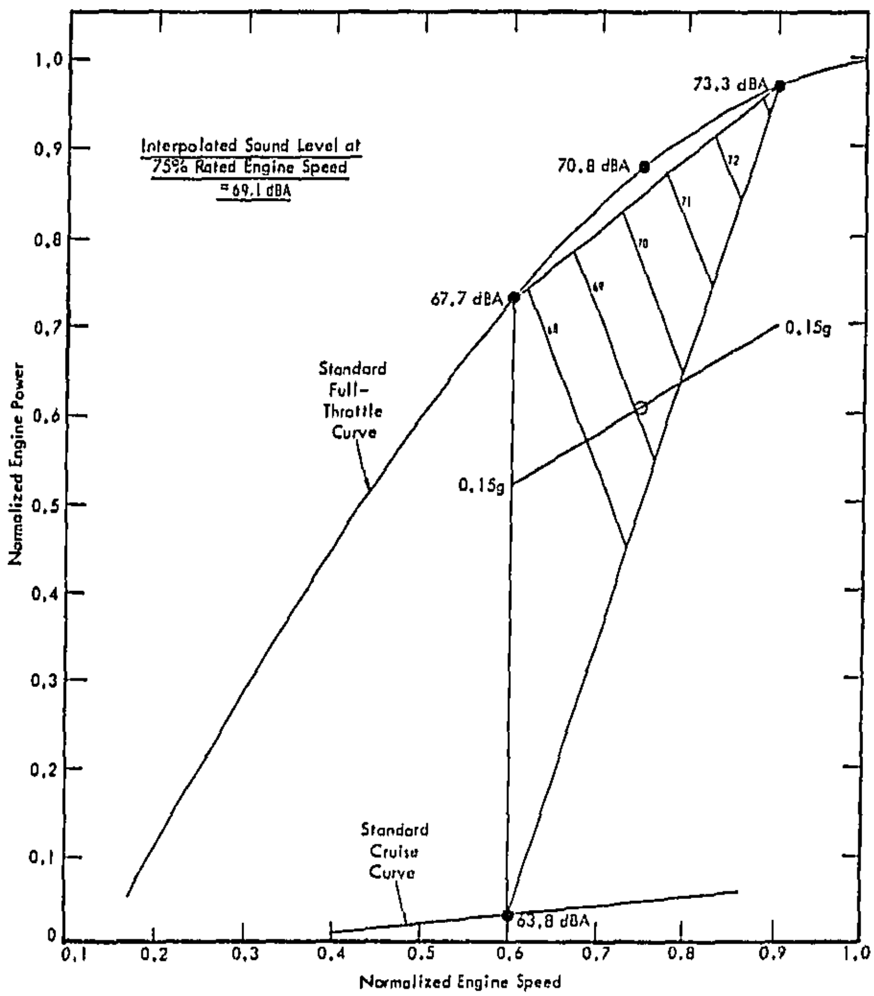

Figure 5.23. Modified Interpolation Graph for Vehicle #011.

Table 5.11

Comparison of Interpolated and Direct Measurements of Sound Level for Partial-Throttle Acceleration

Vehicle No.	Operating Condition	Interpolated Level (dBA)	Measured Level at Operating Condition (dBA)	Difference: Interpolated – Direct
005	75%	71.0	68.8	2.2
006	75%	72.4	70.4	1.8
007	22 mph	67.8	68.3	-0.5
008	22 mph	70.2	66.8	3.4
010	75%	67.8	65.8	2.0
011	75%	69.2*	69.0	0.2
012	75%	72.8	71.3	1.5
013	22 mph	67.4	65.4	2.0
015	75%	71.9	70.9	1.1

* Using the modified interpolation chart of Figure 5.23.

Table 5.12

Comparison of Interpolated and Direct Measurements of Sound Level for Full-Throttle Acceleration

Vehicle No.	Operating Condition	Interpolated Level (dBA)	Measured Level at Operating Condition (dBA)	Difference: Interpolated – Direct
005	75%	71.8	72.5	-0.7
006	75%	74.5	72.1	+2.3
007	22 mph	71.4	71.6	-0.2
008	22 mph	71.8	72.9	-1.1
010	75%	68.8	67.6	+1.2
011	75%	70.8	70.8	0.0
012	75%	74.1	71.3	+2.8
013	22 mph	69.6	69.9	-0.3
015	75%	72.8	72.3	+0.5

acceleration shown in Table 5.11 are consistently higher than the measured values, there is no such consistency between the interpolated and measured full-throttle sound levels shown in Table 5.12. This variability indicates that the assumption of linear dependence of the sound level on both normalized engine power and normalized engine speed will not be valid for all vehicles.

5.7 Test Results for Constant-Throttle Operation

The vehicle tests conducted for Condition 8.0 were designed to evaluate the constant-throttle procedure as proposed by General Motors. This procedure requires the selection of a maximum, but not necessarily full, throttle setting by trial-and-error, such that when the throttle is rapidly opened to this setting, the vehicle will travel 100 feet in 5 seconds from a standing start. It is applicable only to vehicles equipped with automatic transmissions, although a modified version for manuals is under review by General Motors and was included in the test program.

Upon review of the results of the above procedure, it was considered desirable to conduct further tests using the constant-throttle technique to achieve an end condition specified by vehicle acceleration at the 1-2 shift point rather than by time and distance. A description of both these procedures is contained in the following subsections.

5.7.1 Constant-Throttle Procedure For Automatics With End Conditions of Time and Distance

The performance of a constant-throttle test requires a device fitted in the throttle linkage to provide a limit to the throttle depression. This device is then adjusted so that the vehicle travels 100 feet in 5 seconds when the throttle is rapidly depressed to this limit. To obtain repeatable results, this device must provide a firm limit to throttle depression. A restricting device applied to the linkage at the carburetor was found to provide the most repeatable results, but was difficult to install and adjust and required many different modifications for application to all the vehicles to be tested. Accordingly, the method suggested by the domestic automobile manufacturers was used, involving a flexible but inextensible chain with a turnbuckle attached at one end to the throttle pedal and at the other end to a rigid point on the steering column or dashboard. The turnbuckle was then adjusted by the driver to achieve the required vehicle operation. With this equipment there were no major difficulties in setting the maximum throttle depression.

In performing the constant-throttle procedure for automatics, three methods were used to measure the elapsed time. The first method utilized an observer giving the vehicle driver a signal to initiate the acceleration while simultaneously starting a stopwatch. The observer was located at the 100-foot position and recorded the time for the vehicle to pass this position. This method, however, was found to be unsatisfactory because it involved three separate reaction times, those of the timekeeper, the driver, and that due to vehicle response. It was found that the elapsed time measured for identical throttle-stop positions was highly variable, being as much as 0.3 second.

The second method allowed the driver to time himself by simultaneously starting the watch and depressing the throttle and then stopping the watch when the vehicle passed the 100-foot mark. This method proved to be no more consistent than the first even though it involved only the response times of the driver and the vehicle. For a given throttle setting, the total range of variation in elapsed time was typically 0.3 to 0.4 second as measured by the driver. To evaluate this variation further, a comparison of the elapsed time as measured by the driver and the time measured by the data acquisition system is presented in Table 5.13. The time given by the acquisition system corresponds to the time elapsed from when the computer was activated by the vehicle passing the activation switch at 0 feet to when the vehicle passed the deactivation switch at 100 feet. In making this measurement, the vehicle was consistently positioned on the test pad as close to the computer activation switch as possible. However, because the time measured by the computer does not include the response time of the vehicle to throttle depression, the time should not necessarily be identical to that measured by the driver. As would be expected, Table 5.13 indicates that the variation in elapsed time as measured by the computer is less than that measured by the driver. It is also apparent that the combined response time of the vehicle and the driver is on the order of 0.2 to 0.3 second. This is important since the GM procedure specifies an allowable tolerance of ±0.1 second in the elapsed time to travel 100 feet, and it is assumed that this is the accuracy required to achieve repeatable sound level data. It appears that differences in response time alone may be comparable to this tolerance.

To evaluate the sources of variability in the elapsed time, a contact switch was installed on the throttle linkage in order to produce a pulse when the throttle was depressed. The pulse was transmitted via the telemetry system to activate the computer. With this

Table 5.13

Comparison of Elapsed Time for Constant-Throttle Procedure as Measured by the Driver and the Computer

Vehicle No.	Measured Time to Travel 100 Feet (secs.)	
	Stopwatch*	Computer
002	4.9 5.0 4.9 5.2	4.61 4.62 4.64 4.77
Mean & Range	5.0 +0.2 -0.1	4.66 +0.11 -0.05
004	5.2 5.3 4.9 4.9	4.70 4.99 4.80 4.99
Mean & Range	5.1 +0.2 -0.2	4.87 +0.12 -0.17

* Held by Driver.

method, driver reaction was eliminated and the performance of the vehicle was directly monitored. The elapsed times measured with this technique for two vehicles are presented in Table 5.14. As indicated in this table, with the throttle switch timing method only small variations in elapsed time occurred from run to run for the same throttle setting. For vehicle #014, the total range in elapsed time was 0.08 second, and for vehicle #018, the range was 0.16 second. From these results it is apparent that the variability observed using a stopwatch activated by the driver is due, primarily, to variations in the response of the driver rather than the response of the vehicle. Further, it is apparent that the use of a throttle-switch-controlled timing device is required to maintain the accuracy of the elapsed time measurement.

The throttle-switch technique also allowed the determination of vehicle hesitation in the performance of the 100-foot test. To make this evaluation, the time from the depression of the throttle to the time the vehicle moves 0.7 foot was determined from the computer printout. This measurement was quite precise as a distance of 0 feet corresponds to the position of the vehicle when the throttle is depressed rather than a specific point on the test pad. The average time required for each of the vehicles tested to travel the 0.7 foot is presented in Table 5.15, together with the standard deviation and the number of samples included in the average. From this table it will be observed that there is significant variability in the time taken for the vehicle to move 0.7 foot after depression of the throttle. The average time varies by as much as 0.23 second, with standard deviations, in general, less than 0.15 second. Although the results of Table 5.15 indicate that the average hesitation is different for various vehicles, it is not known if similar variation exists among nominally identical vehicles due to production variations or minor misadjustments.

The issues of elapsed time measurement and vehicle hesitation as discussed above are particularly important for the repeatability of a procedure specified by time and distance. As an example, Figure 5.24 shows the acceleration versus vehicle speed for two nominally identical runs made at slightly different throttle settings for vehicle #002. The difference in elapsed time for these runs is 0.2 second; however, there is a difference of about 3 mph in the speed at which its shift point occurs. Further, there is a difference of about 0.03g between the two profiles prior to the 1-2 shift. These variations result in a difference of 234 RPM in maximum engine speed at the 1-2 shift. More radical differences

Table 5.14

Elapsed Time for Constant-Throttle Operation Over 100 Feet as Measured by Computer Activated by Throttle Linkage

Vehicle No.	Elapsed Time (secs.)
014	5.15 5.10 5.07 5.07
Mean & Range	5.10 +0.05 -0.03
018	4.83 4.92 4.80 4.96 4.76
Mean & Range	4.85 +0.11 -0.05

Table 5.15

Average Time for Vehicle to Travel 0.7 Feet Under Constant-Throttle Operation

Vehicle No.	Mean Time to Travel 0.7 Ft.	Standard Deviation of Time	No. of Samples
001	0.252	0.126	17
002	0.379	0.178	8
004	0.251	0.145	12
018	0.397	0.092	15
019	0.167	0.096	7

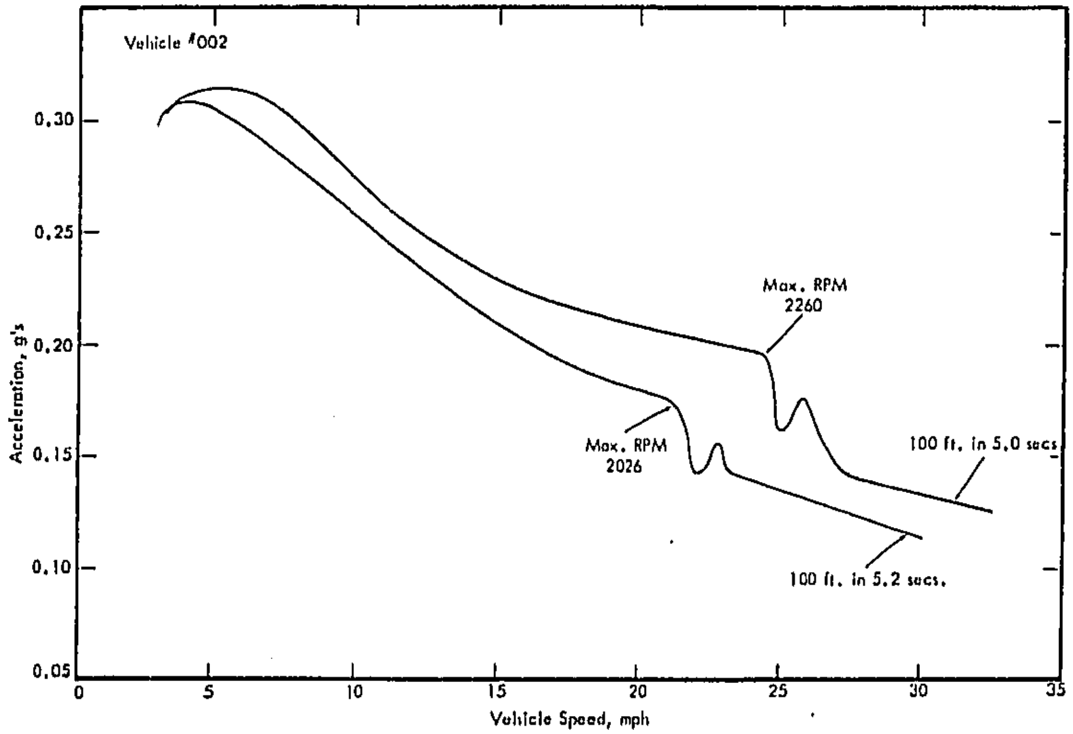

Figure 5.24. Constant-Throttle Shift Characteristics for Vehicle #002.

in vehicle parameters for even smaller differences in elapsed time were observed for vehicle #004. Acceleration profiles for two runs for this vehicle are presented in Figure 5.25. The difference in elapsed time for the two indicated runs is only 0.1 second; however, the vehicle shifts into second gear in one run but not in the other. This results in a difference in acceleration of more than 0.07g between the runs prior to reaching 100 feet. The engine speed corresponding to the two runs for vehicle #004, shown in Figure 5.25, is plotted versus vehicle speed in Figure 5.26. This indicates a difference in maximum engine speed of about 1200 RPM prior to 100 feet of travel. Based on other data taken for vehicle #004, this corresponds to a difference of about 7 dB in maximum sound level during the run.

The results of this series of tests provided further information on the performance of vehicles tested using a specification of time and distance. In Figure 5.27, a plot is presented of maximum engine speed at the 1-2 shift versus elapsed time for 100 feet of travel for five test vehicles. Each grouping of points for a given vehicle represents runs conducted at the same throttle setting. The curves are the best fit for three or four different settings. With some exception, most of the vehicles display a well-behaved function of maximum RPM with elapsed time. Three of the vehicles, #001, #018, and #019, display behavior which makes them well suited to this type of test procedure. For each of these three vehicles, there appears to be little variation in engine speed with variations in time of 0.2 second for a given throttle setting. This is particularly apparent for vehicle #001 as seen for the elapsed times from 4.55 to 4.73 seconds, and 5.02 to 5.17 seconds. This behavior is also evident for vehicle #018 between 5.91 and 6.11 seconds and vehicle #011 between 5.90 and 6.09 seconds. Unlike these examples, vehicle #002 displays a gradually decreasing engine speed with increasing elapsed time for a given throttle setting, as evidenced for times from 5.05 to 5.30 seconds. Similar behavior is seen for vehicle #004 at elapsed times ranging from 5.50 to 5.70 seconds. The almost multi-valued dependence of engine speed on elapsed time, as discussed in regard to Figures 5.25 and 5.26, is also indicated for this vehicle at elapsed times less than 5.2 seconds.

The repeatability of constant-throttle runs for a given throttle setting is indicated in Table 5.16 for automatics set to achieve an end condition of 100 feet in 5 seconds. In this table, the engine speed and acceleration data are taken for the condition at which the

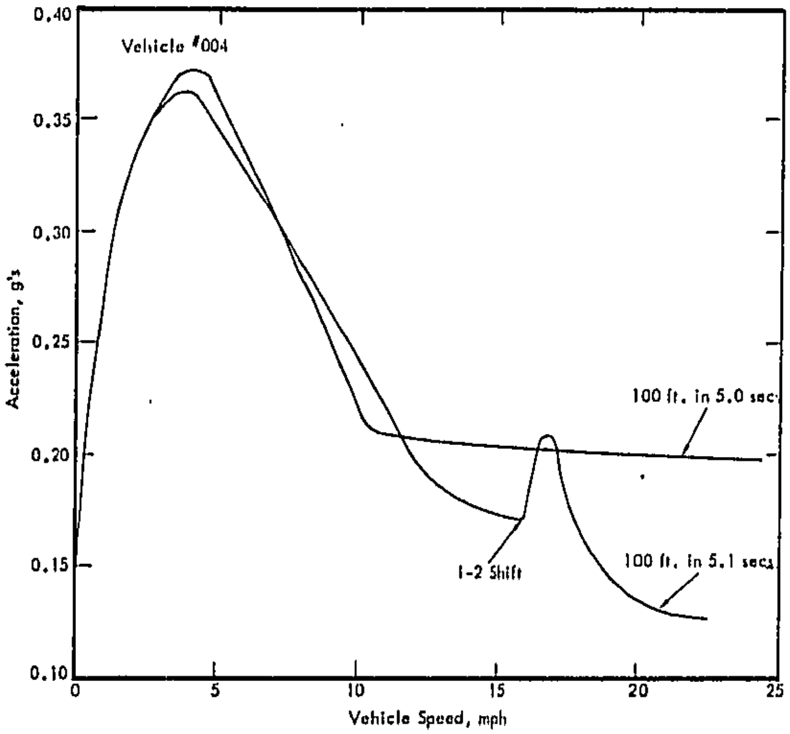

Figure 5.25. Constant-Throttle Shift Characteristics for Vehicle #004.

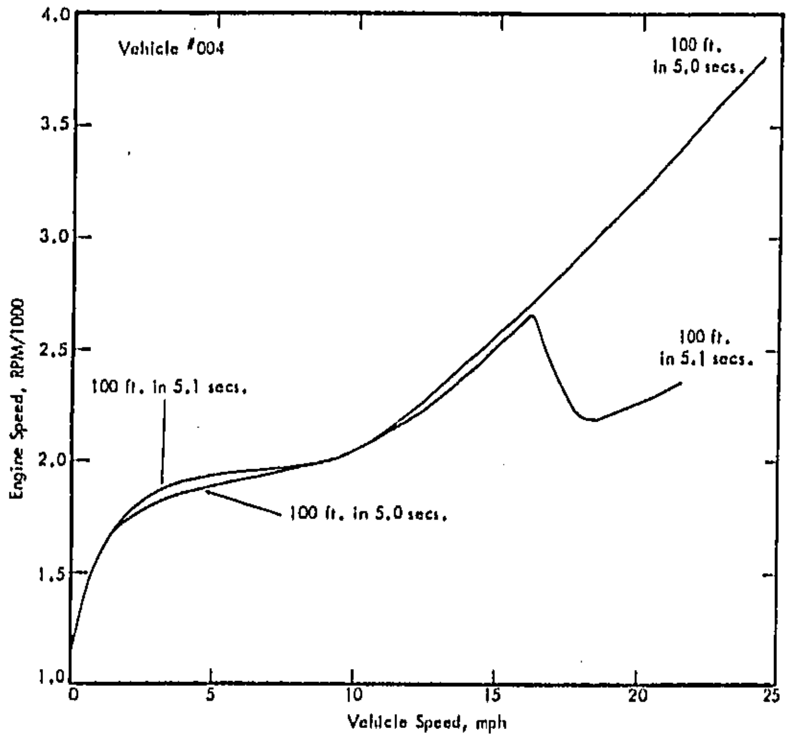

Figure 5.26. Engine Speed History for Constant-Throttle Operation of Vehicle #004.

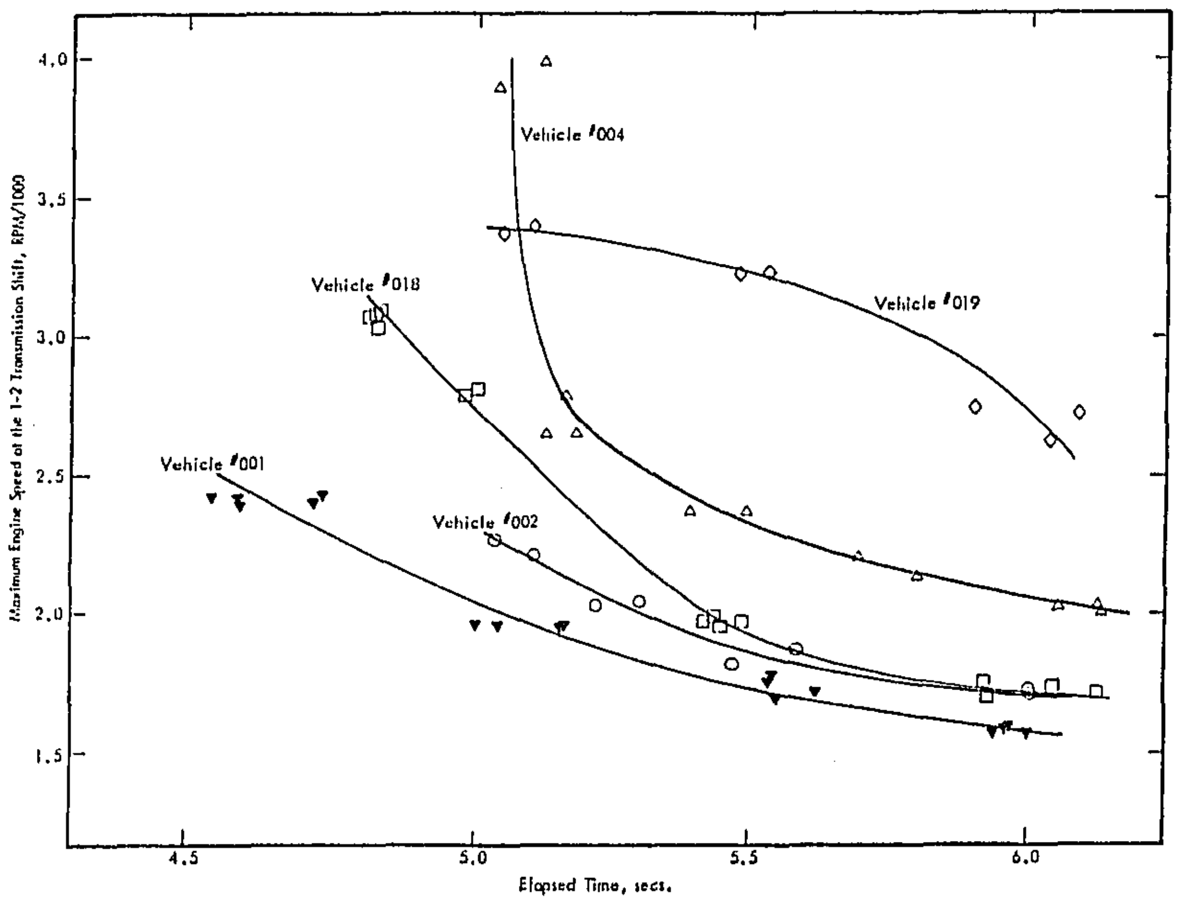

Figure 5.27. Constant-Throttle Operation at Different Throttle Settings.

Table 5.16

Mean Values and Ranges of Engine Speed and Acceleration at Maximum Sound Level for Automatics With Constant Throttle Set for 100 Feet in 5 Seconds

Vehicle No.	Mean Value and Range for Four Runs	
	RPM	Acceleration (g's)
001**	1909 +29 -32	0.138 +0.002 -0.002
002*	1849 +30 -45	0.143 +0.023 -0.023
003*	1717 +77 -43	0.163 +0.014 -0.016
004*	2605 +23 -28	0.190 +0.013 -0.006
009**	2720 +2 -3	0.141 +0.006 -0.003
014**	2707 +55 -104	0.160 +0.007 -0.006
016*	1951 +42 -19	0.128 +0.009 -0.015
018**	2764 +151 -318	0.181 +0.005 -0.003

* Elapsed time measured by driver using stopwatch.

** Elapsed time measured using throttle switch and computer.

maximum sound level is produced during the run — this being, generally, the maximum engine speed prior to the 1-2 transmission shift. The range in engine speed for any given vehicle is generally small, except for #018, where it corresponds to a range of about 3 dB in sound level. The repeatability for different settings will not be so good. The data shown in Figure 5.27 indicate that a variation of ±0.1 second in the time to travel 100 feet will result in changes in maximum engine speed of ±8 percent and ±5 percent for vehicles #018 and #001, respectively. The corresponding ranges in sound level are about ±1.5 dB and ±1.0 dB, respectively.

5.7.2 Constant-Throttle Procedure for Manuals

The constant-throttle procedure for manuals as proposed by General Motors requires a throttle setting to achieve 0.15g at 22 mph or at rated engine speed, whichever occurs first. The sound level is then measured at 75 percent rated engine speed or 22 mph, whichever occurs first during the run at this setting. The test is initiated from a moving start at 25 percent rated engine speed in first gear.

This procedure was conducted on nine manual vehicles with little difficulty. The mean values and ranges of engine speed and acceleration are shown in Table 5.17. Again, it is noted that there is a considerable spread in the mean acceleration amongst the vehicles at the end condition, ranging from 0.155g to over 0.27g. It was noted that for some vehicles, the requirement to achieve 0.15g at 22 mph or rated engine speed involved close to full-throttle operation at the measurement end condition. This was particularly true for vehicle #011 which was set to achieve 0.15g at 22 mph, corresponding to 94 percent rated engine speed. At the measurement condition of 75 percent rated engine speed, the acceleration was 0.184g compared with 0.228g at full throttle. This would indicate that a throttle setting to achieve 0.15g at such a high engine speed does not correspond to normal driving operation, and that a lower engine speed, say 70 or 75 percent, would be more appropriate.

5.7.3 An Alternative Constant-Throttle Procedure

The results obtained from the constant-throttle procedure for automatics proposed by General Motors requiring end conditions of distance and time show that for different vehicles, there is considerable difference in acceleration at the point where maximum

Table 5.17

Mean Values and Ranges of Engine Speed and Acceleration at Maximum Sound Level Up to and Including the End Condition for Manuals According to GM Constant-Throttle Procedure

Vehicle No.	End Condition	Mean Value and Range for Four Runs	
		RPM	Acceleration (g's)
005	75%	4173 +160 -225	0.156 +0.011 -0.017
006	75%	4023 +113 -103	0.173 +0.032 -0.021
007	22 mph (68%)	4105 +42 -18	0.159 +0.008 -0.007
008	22 mph (62%)	3482 +18 -18	0.155 +0.000 -0.000
010	75%	2427 +62 -25	0.215 +0.021 -0.004
011	75%	3874 +41 -63	0.184 +0.014 -0.014
012	75%	4080 +34 -57	0.158 +0.022 -0.017
013	22 mph (65%)	2605 +79 -55	0.156 +0.002 -0.005
015	75%	2858 +7 -19	0.271 +0.011 -0.009

sound level is produced. The range of acceleration values is greater than that exhibited in the vehicle operation measurements described in Section 4.0, and may lead to significant differences in engine speed and hence sound level at the shift point. The reasons for the variations may be related to driver operation at the time of the test run. The large variations in acceleration can be eliminated, to a large extent, if the throttle is set to achieve an acceleration of 0.15g at the 1-2 transmission shift (test Condition 9.0). This condition has been identified as typical of normal driving operation (see Section 4.4) and is the point at which maximum sound level is produced in first gear.

A review of the behavior of vehicle acceleration in the vicinity of the shift point, however, indicates a considerable variation over a relatively short period of time — see Figure 5.24 for example. Therefore, to set the throttle for the above condition, it is necessary to define more precisely the acceleration at the 1-2 transmission shift. Accordingly, tests were conducted on seven automatic vehicles with the throttle set to achieve approximately 0.15g at the 1-2 transmission shift. The relationships between acceleration and engine speed in the vicinity of the shift are shown in Figure 5.28. In each case, the values of acceleration are plotted up to and including the maximum engine speed prior to the 1-2 shift. Note that in some cases, the acceleration rate has already begun to drop sharply even though the engine speed is still increasing, due to the action of the automatic transmission. However, it is also apparent that in all cases except one (vehicle #003) there is a plateau in the curve that occurs 50 to 150 RPM prior to the maximum engine speed at the shift, over which the acceleration is constant within a range of ±0.005g. Therefore, for this alternative procedure (identified as Condition 9.0), the throttle was set to achieve 0.15g at 100 RPM prior to the maximum engine speed at the 1-2 transmission shift. The case of vehicle #003, which does not exhibit an acceleration plateau, will be discussed in Section 6.2.1.

The results obtained for four vehicles, according to this alternative procedure, are shown in Table 5.18. The range of values for the engine speed and acceleration are comparable to those shown in Table 5.16 for the "100 feet in 5 seconds" procedure, but the acceleration at the shift point is constrained to be much closer to 0.15g as required.

It was also shown in Chapter 4.0 that a vehicle speed of 22 mph is the maximum at which an acceleration of 0.15g is typical in urban driving. Accordingly, test

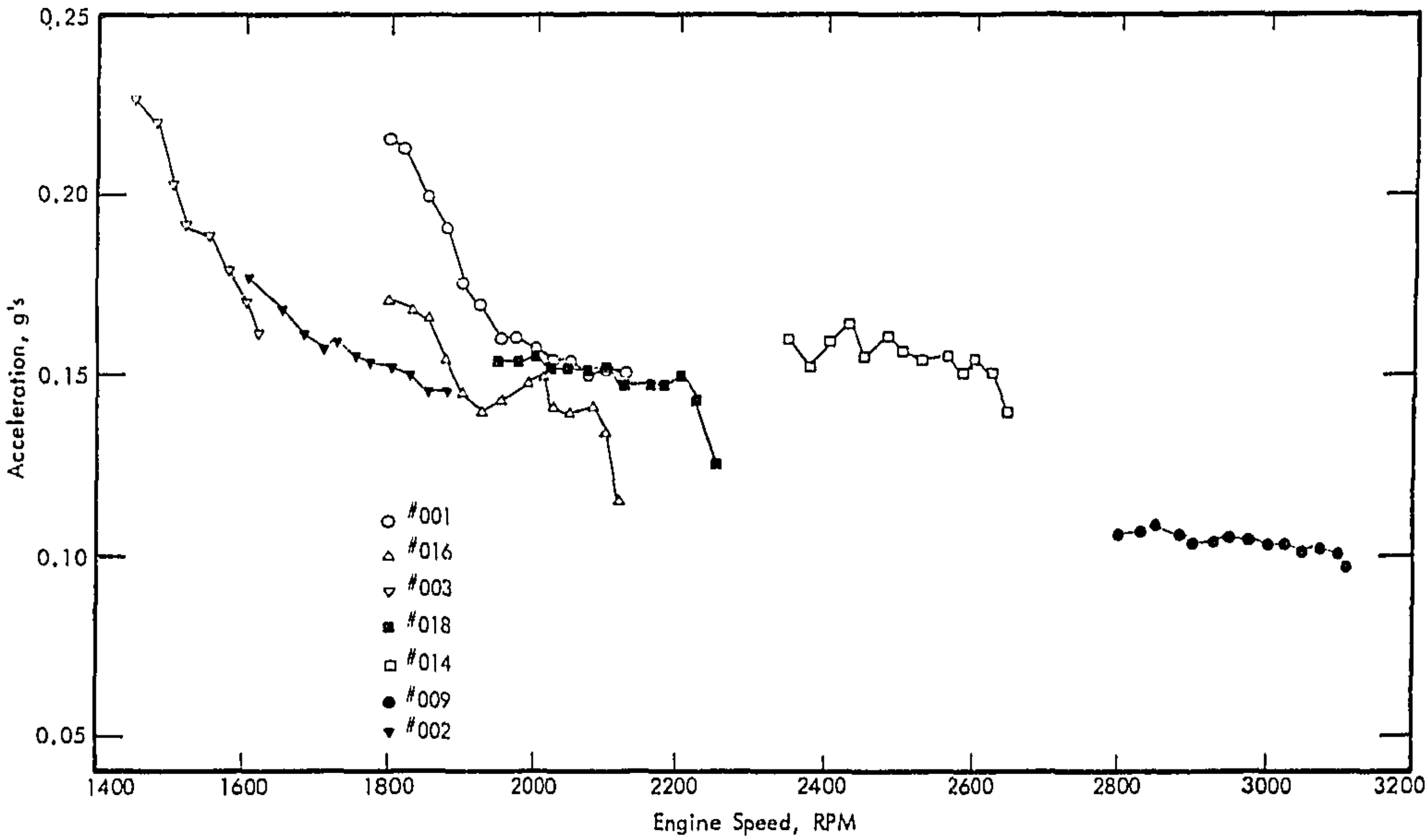

Figure 5.28. Acceleration as a Function of Engine Speed for a Single Constant-Throttle Operation Near the 1-2 Shift.

Table 5.18

Mean Values and Ranges of Engine Speed and Acceleration at Maximum Sound Level for Automatics Operating Under Test Conditions 9.0 and 10.0

Vehicle No.	Mean Value and Range for Four Runs			
	0.15g at 100 RPM Prior to the 1-2 Shift (9.0)		0.15g at 22 mph (10.0)	
	RPM	Acceleration	RPM	Acceleration
001	2119 +12 -28	0.143 +0.010 -0.008	1856 +32 -30	0.160 +0.010 -0.011
014	2563 +88 -95	0.148 +0.006 -0.011	2511 +29 -32	0.153 +0.004 -0.004
016	1997 +24 -23	0.142 +0.008 -0.003	2137 +51 -37	0.150 +0.004 -0.006
018	2191 +25 -45	0.147 +0.001 -0.004	2041 +26 -27	0.150 +0.003 -0.002

Condition 10.0 was established, requiring a constant-throttle operation to achieve 0.15g at 22 mph. The results of these tests are also included in Table 5.18, and indicate ranges in parameters similar to those obtained at the 1-2 transmission shift.

5.7.4 Summary of Constant-Throttle Test Results

The test Condition 8.0 (see Tables 5.1 and 5.2) was conducted on 18 vehicles equipped with automatic and manual transmissions to evaluate the constant-throttle method of measuring the noise emissions from light vehicles under partial-throttle acceleration. Modifications to this condition, namely Conditions 9.0 and 10.0, were also tested. The conclusions drawn from the results can be summarized as follows:

- There are no major difficulties in determining and setting the throttle position necessary for the constant-throttle procedure, provided that a rigid location is used for the restricting chain mechanism.
- Timing the vehicle over a distance of 100 feet using a stopwatch held by an observer or by the driver was found to be inadequate due to the significant variations in time for a given throttle setting. More accurate methods are required to provide satisfactory repeatability.
- The hesitation in the vehicle upon rapid opening of the throttle is highly variable from vehicle to vehicle.
- For some vehicles, slightly different throttle settings, as may be obtained by different operators adjusting to a given test condition, can significantly affect the vehicle and engine speeds at the 1-2 transmission shift for automatics when time and distance alone are specified. In some cases, these different settings can determine whether the vehicle shifts or not during the test. Accordingly, some vehicles are more suited to this test procedure than others.
- For a number of runs at a single throttle setting, the variation in engine speed and acceleration at the 1-2 transmission shift is fairly low for automatics.
- There is a significant difference in acceleration at the shift amongst different vehicles when time and distance alone are specified.

- The repeatability of the constant-throttle test procedure, and its consistency from vehicle to vehicle, can be improved by setting the throttle to achieve an end condition of a given acceleration at the 1-2 transmission shift.

- There are no significant problems with the constant-throttle procedure as applied to manuals. However, the proposed GM procedure, whereby the throttle is set to achieve a given acceleration rate at rated engine speed, results in exceedingly high acceleration rates for some vehicles at 75 percent rated engine speed.

5.8 Comparative Evaluation of Constant Acceleration and Constant Throttle

The operational procedures of interest in developing a test methodology for measuring directly (as opposed to indirectly through interpolation) the noise emissions of light vehicles can be summarized as follows:

- Condition 1.0 (Manuals and Automatics) — Constant 0.15g acceleration.

- Condition 8.0 (Automatics only) — Constant-throttle acceleration to achieve 100 feet in 5 seconds.

- Condition 8.0 (Manuals only) — Constant-throttle acceleration to achieve an acceleration of 0.15g at 22 mph or rated engine speed.

- Condition 9.0 (Automatics only) — Constant-throttle acceleration to achieve an acceleration of 0.15g at 100 RPM prior to the maximum engine speed at the 1-2 transmission shift.

- Condition 10.0 (Automatics only) — Constant-throttle acceleration to achieve an acceleration of 0.15g at 22 mph.

These "direct measurement" procedures are evaluated for repeatability in this section. A comparative discussion of the applicability of the "direct measurement" procedure and the CCMC procedure, which uses an indirect method to determine vehicle noise emissions at partial throttle, is provided in Chapter 6.

To assist in the evaluation of the procedures, the average and range of the maximum sound levels measured prior to or at a specific operating condition under the constant acceleration and constant-throttle procedures, together with the range in other vehicle parameters are presented in Tables 5.19 and 5.20 for manuals and automatics, respectively. For the manual transmission vehicles, the operating condition used in this comparison is 75 percent rated engine speed or 22 mph, whichever occurred first. For the automatic transmission vehicles, the operating condition used in the comparison for all but vehicle #009 is the 1-2 transmission shift.

Two main observations can be made from the average values of sound level presented in these tables. First, for manual transmission vehicles it will be noted that there is little difference in the sound level at 75 percent rated engine speed (or 22 mph) as measured under Conditions 1.0 and 8.0. This leads to the conclusion that the operation of the vehicle prior to the end condition does not significantly affect the measured sound level. This conclusion is verified by Figures 5.29, 5.30, and 5.31, where the A-weighted sound level as measured under Conditions 1.0 and 8.0 is shown as a function of engine speed for three manual transmission vehicles. From these figures it is seen that the sound levels measured under the two procedures are within 1 dB of each other except at low engine speeds. The divergence of the sound level curves for each vehicle can be explained by the differences in the two procedures. At low engine speeds, considerably less throttle is required to maintain an acceleration of 0.15g than that used for constant-throttle condition. Thus, in this region, the constant-throttle sound levels are higher. As the vehicle speed increases, increasing throttle settings are required to maintain 0.15g and hence the throttle positions of the two procedures become more similar. At some point, depending on vehicle performance and gearing, the sound level produced under constant acceleration can become higher as the throttle position increases beyond that required for the constant-throttle procedure. Such a crossover does not occur for vehicle #011 (Figure 5.31), because, as noted in Section 5.7.2, this vehicle is almost at full throttle for Condition 8.0.

A second observation concerning the data given in Table 5.20 is that the sound levels measured for automatic transmission vehicles can be significantly affected by the vehicle operation prior to the maximum sound level. This behavior is primarily due to the dependence of the maximum engine speed at the 1-2 shift on the manner in which the shift is approached. This influence of vehicle operation on the occurrence of the shift was found to vary from vehicle to vehicle. For some vehicles, constant-throttle operation

Table 5.19

Total Data Range for Maximum Sound Level
Prior to and Including End Condition —
Manual Transmission Vehicles

Veh. No.	Test Cond.	End Cond.	Max. Sound Level (dBA)	Range of Sound Level (dB)	Range of Vehicle Parameters at Maximum Sound Level			
					Distance (ft)	Speed (mph)	Engine Speed	Accel. (g's)
005	1.0	75%	69.6	1.4	9.1	0.9	168	0.027
	8.0	75%	70.4	1.1	15.8	2.0	385	0.023
006	1.0	75%	70.6	1.7	13.6	0.7	163	0.025
	8.0	75%	70.2	0.8	10.5	0.9	216	0.053
007	1.0	22 mph	69.0	1.1	3.2	1.1	238	0.023
	8.0	22 mph	69.4	0.3	2.8	0.1	60	0.015
008	1.0	22 mph	67.7	1.1	4.2	0.4	63	0.009
	8.0	22 mph	66.8	0.2	0.0	0.1	36	0.000
010	1.0	75%	66.3	0.6	10.5	1.5	202	0.015
	8.0	75%	67.3	1.2	6.3	0.7	87	0.025
011	1.0	75%	69.7	0.8	7.7	0.2	29	0.016
	8.0	75%	71.0	1.0	2.8	0.4	104	0.028
012	1.0	75%	71.7	0.8	10.5	1.0	202	0.017
	8.0	75%	71.9	0.5	13.3	0.6	91	0.039
013	1.0	22 mph	65.5	0.6	11.9	1.0	122	0.008
	8.0	22 mph	64.5	0.3	35.7	1.1	134	0.007
015	1.0	75%	71.1	1.4	8.4	0.6	100	0.053
	8.0	75%	71.8	0.6	0.7	0.2	26	0.020
Avg.	1.0			1.0	7.9	0.7	129	0.019
	8.0			0.6	8.8	0.6	114	0.021

Table 5.20

Total Data Range for Maximum Sound Level Prior to and Including End Condition – Automatic Transmission Vehicles

Veh. No.	Test Cond.	End Cond.	Max. Sound Level (dBA)	Range of Sound Level (dB)	Range of Vehicle Parameters at Maximum Sound Level: Distance (ft)	Speed (mph)	Engine Speed	Accel. (g's)
001	1.0	1-2	66.3	2.9	28.7	3.0	225	0.020
	8.0	1-2	61.5	0.9	11.2	0.6	61	0.004
	9.0	1-2	63.2	1.5	10.5	0.7	40	0.018
	10.0	22 mph	61.6	0.2	13.3	1.2	62	0.021
002	1.0	1-2	60.8	1.2	14.7	2.2	116	0.034
	8.0	1-2	62.9	2.1	5.6	0.8	75	0.046
004	1.0	1-2	61.0	1.6	3.5	0.7	105	0.006
	8.0	1-2	65.1	2.4	3.5	0.1	51	0.019
009	1.0	22 mph	68.7	1.3	6.1	0.3	54	0.006
	8.0	100 ft.	68.0	0.8	2.1	0.1	5	0.009
	9.0	22 mph	68.9	0.8	0.7	0.2	38	0.003
014	1.0	1-2	70.9	2.9	27.3	2.4	174	0.016
	8.0	1-2	70.0	1.6	11.2	1.4	159	0.013
	9.0	1-2	69.2	0.7	14.7	1.8	183	0.016
	10.0	22 mph	68.8	0.4	7.7	0.9	61	0.008
016	1.0	1-2	65.6	2.5	20.3	2.9	263	0.023
	8.0	1-2	65.6	0.5	4.2	0.8	61	0.024
	9.0	1-2	65.9	0.6	2.8	0.4	47	0.012
	10.0	22 mph	66.5	0.5	11.9	1.2	88	0.010
018	1.0	1-2	68.7	3.7	18.9	1.7	658	0.013
	8.0	1-2	69.9	2.5	67.6	6.6	469	0.008
	9.0	1-2	63.2	0.9	8.4	1.1	70	0.005
	10.0	22 mph	62.2	0.4	7.1	0.8	53	0.005
Averages of 1.0 and 8.0 Only								
Avg.	1.0		--	2.3	17.1	1.9	228	0.017
	8.0		--	1.5	15.4	1.5	126	0.017
Averages of 1.0, 8.0, 9.0, and 10.0								
Avg.	1.0		--	2.7	20.3	2.1	275	0.016
	8.0		--	1.3	19.3	1.9	151	0.011
	9.0		--	0.9	7.4	0.8	76	0.011
	10.0		--	0.5	8.1	0.9	60	0.009

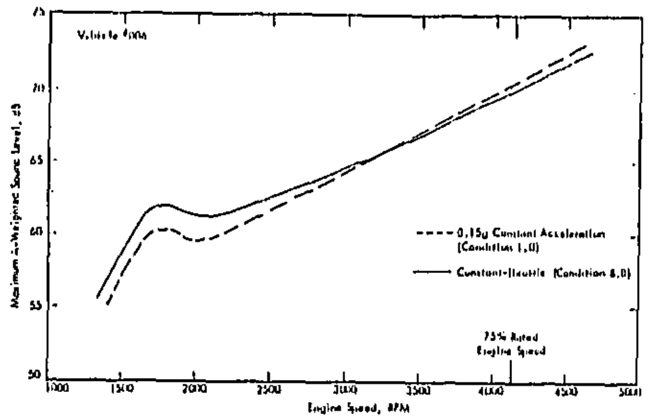

Figure 5.29. Comparison of Sound Levels Under Constant Acceleration and Constant Throttle for Vehicle #006.

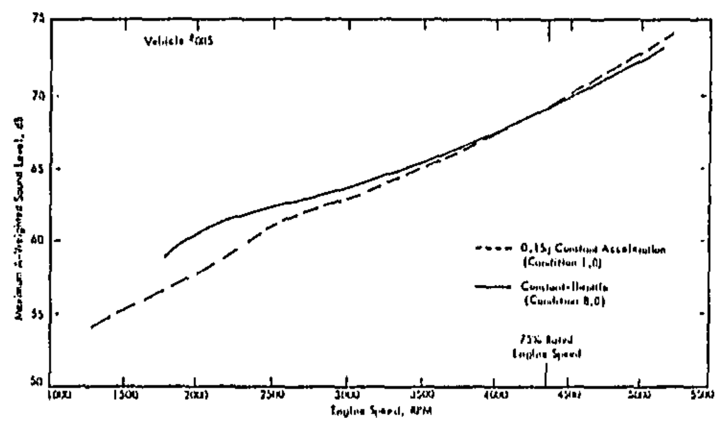

Figure 5.30. Comparison of Sound Levels Under Constant Acceleration and Constant Throttle for Vehicle #005.

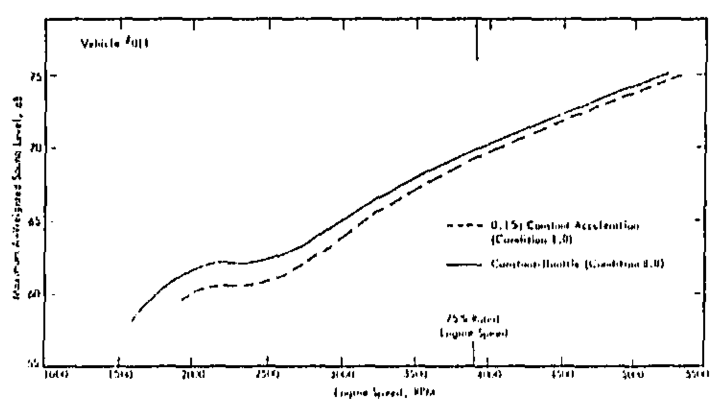

Figure 5.31. Comparison of Sound Levels Under Constant Acceleration and Constant Throttle for Vehicle #011.

produced a 1-2 shift at vehicle speeds considerably less than for constant acceleration even though the acceleration immediately prior to the shift was the same in both cases. An example of this behavior is shown in Figure 5.32 for vehicle #014. For some vehicles, the shift occurred at almost identical vehicle speeds for constant acceleration and constant-throttle operation, as shown in Figure 5.33 for vehicle #016. Finally, for some vehicles constant acceleration operation will cause the 1-2 shift to occur at lower vehicle speeds than constant throttle even though acceleration just prior to the shift is identical. This behavior was observed for vehicle #002 as shown in Figure 5.34. As can be seen from these figures, the specification of vehicle operation through an entire acceleration is of concern for a partial-throttle acceleration noise test procedure for automatic transmission vehicles because of the influence it has on maximum engine speed and hence maximum sound level at the shift point. It should be noted that the two vehicles with the greatest difference in sound levels between Conditions 1.0 and 9.0, namely vehicles #001 and #018, were the most difficult to operate at constant acceleration.

In considering the repeatability of the procedure for automatics, paimary attention should be given to the variation in maximum sound level in Table 5.20. The variation in distance at which the maximum sound level is produced indicates how repeatably the relationship between vehicle position at maximum sound level and microphone position will be attained from run to run. The other vehicle parameters are also of importance, particularly engine speed as it is generally indicative of the variation in shift point. Examination of the ranges in Table 5.20 indicates that, generally, the two constant-throttle conditions, 8.0 and 9.0, were performed with less variability than the constant acceleration condition, 1.0. To aid in overall comparison, the average of the ranges of each of the parameters are also given at the bottom of Table 5.19. The averages are calculated for Conditions 1.0 and 8.0 and for 1.0, 8.0, 9.0 and 10.0 separately since Conditions 9.0 and 10.0 indicate that the constant-throttle procedure, on the average, produced less variation than the constant acceleration procedure. The limited data comparison of the averages for Conditions 1.0, 8.0, 9.0, and 10.0 indicate that Conditions 9.0 and 10.0 consistently produced the least variation of all three procedures for all vehicle parameters.

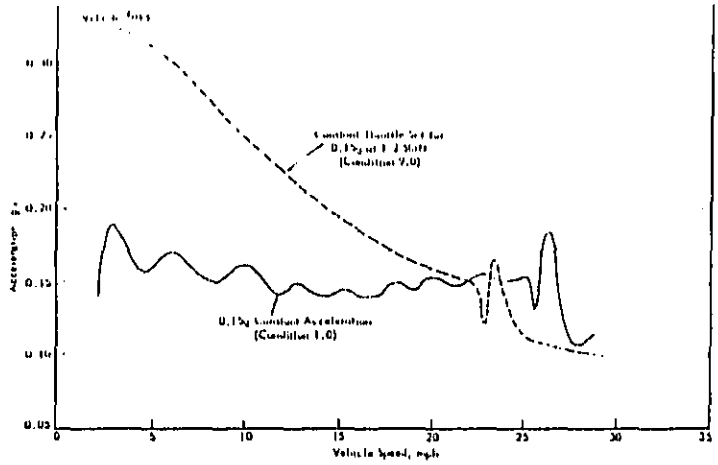

Figure 5.32. Acceleration as a Function of Vehicle Speed Under Constant Acceleration and Constant Throttle for Vehicle #014.

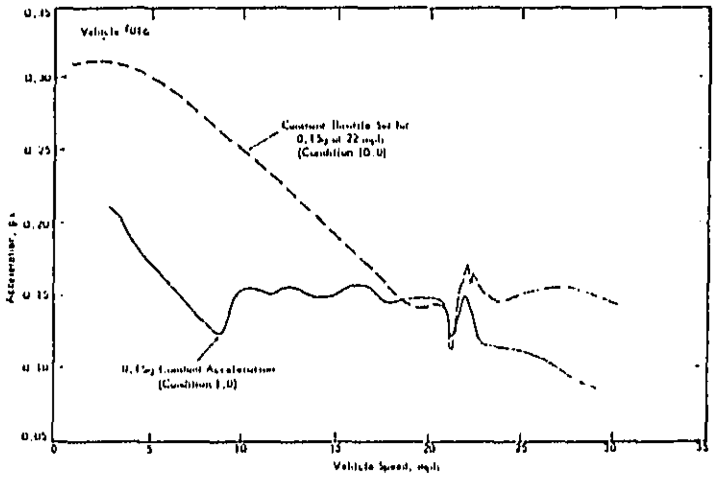

Figure 5.33. Acceleration as a Function of Vehicle Speed Under Constant Acceleration and Constant Throttle for Vehicle #016.

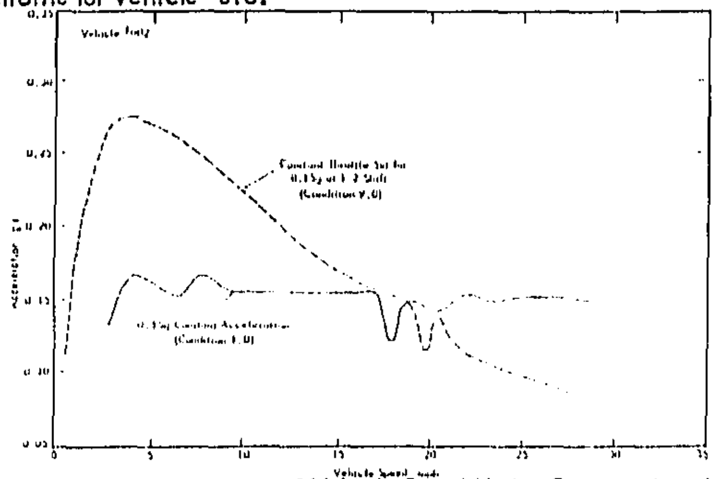

Figure 5.34. Acceleration as a Function of Vehicle Speed Under Constant Acceleration and Constant Throttle for Vehicle #002.

The total data ranges presented in Table 5.19 for manual transmission vehicles display substantially less difference in the variability between constant acceleration and constant-throttle procedures than was indicated for the automatics. The average of the ranges for Conditions 1.0 and 8.0 are very similar for all parameters. The average sound level range displayed by both procedures is, however, smaller than the corresponding ranges for automatic transmission vehicles.

6.0 DEVELOPMENT AND PRELIMINARY IMPLEMENTATION OF TEST PROCEDURE

The results obtained from the light vehicle measurements provided sufficient information on the different proposed test procedures to define a preliminary urban acceleration test procedure for light vehicles. This section describes the rationale used in selecting the type of procedure most suited to light vehicles, specifying the requirements to be met in implementing this procedure, and presents the results of tests which were conducted on a limited number of vehicles in order to identify potential difficulties.

6.1 Direct Measurement Versus the Interpolation Technique

The test procedures reviewed in the previous chapter concentrated mainly on the direct measurement of vehicle sound level, but also included the CCMC procedure in which the sound level is interpolated from data taken under full-throttle and cruise conditions. The advantages of the CCMC procedure are the ease of performance and the minimal vehicle instrumentation required to monitor vehicle operation. However, these advantages are achieved at the expense of probable inaccuracies in determining engine speed at maximum sound level using standard correction factors for all vehicles. To correlate engine speed and sound level would require added instrumentation and remove one of the advantages of the procedure.

The CCMC procedure contains the assumption that the vehicle sound level is a linear function of engine speed and power. The CCMC has measured and plotted sound level data for several vehicles as a function of engine speed and power, and the curves indicate that the assumption of linearity is correct to within about ±2 dB. The data shown in Table 5.11 also show a difference of about ±2 dB between directly measured and interpolated sound levels. It is recognized that the tests in this program were not conducted in strict accordance with the CCMC operating procedure. However, the range of error is expected to be representative of the procedure. Furthermore, the three-point interpolation does not always reduce the errors that may be observed in a single sound level measurement — see Figures 5.22 and 5.23.

A related consideration appears to be that values of noise reduction achieved by many engineering treatments under full-throttle condition do not provide the reduction that would be projected by the interpolation method in partial-throttle operating conditions.

This is due to certain vehicle components emitting highly disproportionate levels of noise under full throttle compared to their contribution under less severe operating conditions.

Finally, the CCMC proposed procedure is applicable to manual transmission vehicles only. Thus, the partial-throttle mode of operation for automatics cannot be measured by interpolation but must be measured directly.

In view of the potential inaccuracies inherent in the CCMC test procedure, and the absence of a similar procedure for automatics, which form the major portion of the U.S. light vehicle fleet, it was decided to adopt a procedure involving the direct measurement of vehicle sound levels under partial-throttle operation.

6.2 Selection of Vehicle Test Operation

In Chapter 5.0, the advantages and disadvantages of various proposed "direct measurement" test procedures were evaluated in terms of vehicle operation. It was determined that, in general, the maximum sound level at speeds less than 25 mph occurs at the 1-2 transmission shift point, and that this is the level that should be measured. The suitability of each of the proposed test procedures in measuring this maximum sound level must now be evaluated in terms of the criteria established in Section 2.1. These criteria can be restated as follows:

- The vehicle operation must simulate the vehicle parameters exhibited during typical driving in urban areas.
- The vehicle operation must allow the measurement of the maximum sound level at the 1-2 shift point.
- The procedure must be uniformly applicable to all automobile types and configurations.
- The vehicle operation and sound levels must be repeatable.
- The procedure must be practical in terms of cost and time.

With regard to the first two of these criteria, the vehicle operation data presented in Chapters 3 and 4 have identified an acceleration rate of 0.15g at speeds less than about 22 mph as being fairly typical. This information is sufficient for vehicles equipped with manual transmissions, where the engine speed at the shift point (defined as 70 percent rated engine speed) is not dependent on the acceleration-time history. But for automatics, it has been shown that the acceleration-time history is important in determining engine speed at the shift point. The question is — which procedure that specifies an acceleration of 0.15g at the shift point will result in a maximum engine speed for automatics that compares well with the maximum engine speed produced in urban driving?

To provide a satisfactory answer to this question, it is necessary to take the results of the light vehicle operation study conducted at Marana (see Chapter 4.0) and compare the vehicle parameters at the shift point with those obtained using the proposed test procedures evaluated in the previous section. The comparison is shown in Table 6.1 where the maximum percent rated engine speed at the 1-2 shift, and the acceleration at 100 RPM prior to the shift, are given for the Marana operational study and for the various procedures tested in the noise study. It should be remembered that the percent rated engine speed shown for the Marana operational data is about 5 percent lower than that reported for street driving conditions — see Section 4.3. This table, together with the results of the noise tests, will be used to select the optimum test procedure according to the criterion detailed above.

The third column in Table 6.1 shows the vehicle parameters at the 1-2 shift for the procedure requiring a constant acceleration of 0.15g. The maximum engine speed at the shift — the parameter which largely determines the maximum vehicle sound level — agrees reasonably well with that obtained in the operational data for two of the cases but is a little high in the other two cases. This procedure was difficult to conduct for some vehicles (see Section 5.5.1) and the variabilities in engine speed and sound level at the 1-2 shift were by far the greatest for all procedures tested.

The next three columns present the data for the constant-throttle test procedure stipulating distance and time — namely, 100 feet in 5.0, 5.5, and 6.0 seconds. Of the three, the procedure requiring the vehicle to travel 100 feet in 5.5 seconds is closest in representing the Marana operational data. However, there are several aspects of this procedure that do not make it completely suitable according to the established criteria. The lack of definition of vehicle acceleration and engine speed at the 1-2 shift, resulting from the specification of vehicle operation in terms of distance and time, leads to a lack

Table 6.1

Comparison of Potential Test Procedures

Vehicle No.	PERCENT RATED ENGINE SPEED AND ACCELERATION AT THE 1-2 SHIFT					
	Marana Operational Data*	0.15g Constant Acceleration	100 Feet in:			0.15g at 1-2 Shift
			5.0 Secs.	5.5 Secs.	6.0 Secs.	
001	46% 0.126g	56% 0.152g	51% 0.141g	45% 0.124g	41% 0.109g	56% 0.155g
002	46% 0.133g	48% 0.160g	62% 0.198g	51% 0.149g	48% 0.123g	52% 0.155g
004	38% 0.136g	41% 0.147g	69% 0.194g	41% 0.159g	35% 0.115g	41% 0.159g
018	70% 0.169g	80% 0.154g	88% 0.162g	61% 0.123g	54% 0.104g	70% 0.147g
019	55% 0.116g	-- --	70% 0.143g	66% 0.094g	56% 0.093g	65% 0.147g

* The engine speed data presented differs from that described previously at the Measurement Methodology Workshop held at Marana on June 22 and 23, 1977.[16] The original data contained a correction factor to obtain a "sound energy weighted" engine speed at the shift point. This factor is omitted from the data in Table 6.1.

of definition of the location at which the shift occurs. This variation makes the microphone placement extremely sensitive. In some cases, minor variations in the time to travel 100 feet may completely change the shift characteristics and the maximum sound level. Finally, this form of constant-throttle test can be performed only with automatics. There is no equivalent test procedure for manuals.

The final column in Table 6.1 presents the data for the constant-throttle test stipulating an acceleration of 0.15g at 100 RPM prior to the 1-2 shift point. The agreement between the maximum engine speed achieved in this test and that for the operational data is about the same as for the constant-throttle test requiring the vehicle to travel 100 feet in 5.5 seconds. However, if the Marana operational data are corrected by adding 5 percent to each value of rated engine speed to account for urban driving conditions (see Section 4.3), the test specifying 0.15g prior to the shift point provides the best agreement of the two — see Table 6.2. The definition of a given acceleration at the shift point improves the repeatability of the procedure, and its consistency from vehicle to vehicle. The variation in maximum engine speed — and hence sound level — at the shift point can be controlled by suitable limitations in the variation of acceleration. Furthermore, the definition of vehicle operation is exactly equivalent to that for manuals, where the 1-2 shift point is defined as 70 percent rated engine speed. For these reasons, this procedure was adopted for measuring the noise emissions from light vehicles operating at low speed in urban areas.

6.3 Definition of Test Conditions

With the selection of the constant-throttle technique as the optimum method of achieving the required vehicle operating condition, it is now necessary to define the details of the test procedure. Vehicles equipped with automatic transmissions will be discussed first.

6.3.1 Automatics

The basic test procedure for automatics requires the selection of a maximum throttle setting that, with the transmission in Drive, will produce an acceleration of 0.15g at 100 RPM prior to the maximum engine speed at the 1-2 transmission shift. The sound level is then measured at the maximum engine speed. It was noted in the light vehicle noise tests that the vehicle speed at which the shift occurs varies considerably from vehicle to

Table 6.2

Comparison Between Engine Speed at the 1-2 Shift
For Corrected Marana Operational Data and Test Data

Vehicle No.	Percent Rated Engine Speed at the 1-2 Shift		
	Marana Operational Data Corrected for Urban Conditions*	100 Feet in 5.5 Seconds	0.15g at 1-2 Shift
001	51	45	56
002	51	51	52
004	43	41	41
018	75	61	70
019	60	66	65
Mean of (Corrected Operational Data − Test Data)		-3.2	0.8
Standard Deviation		7.4	4.4

* Obtained by increasing the Marana operational data by 5 percent — see Section 4.3.

vehicle — see Table 5.5 for example. The review of operational data in Chapter 3.0 showed that an acceleration rate of 0.15g was typical only at speeds less than about 22 mph, and that in the speed range 22 to 25 mph an acceleration of 0.12g was more typical. Therefore, it would be unrepresentative to require an acceleration of 0.15g at the 1-2 shift if this shift occurred at speeds greater than 22 mph. Accordingly, the basic test procedure applies only to those vehicles that shift at speeds less than 22 mph when the throttle is set to achieve 0.15g at the shift point. For those vehicles that shift at higher speeds, the basic test procedure must be modified to require a constant-throttle setting that will produce an acceleration of 0.15g at 22 mph. However, the maximum sound level occurs, and is still to be measured, at the maximum engine speed prior to the 1-2 transmission shift.

It was also noted in the light vehicle noise tests that some automatics produce higher sound levels in second gear at speeds of 25 mph than they do at the maximum engine speed prior to the shift point in first gear — see Figure 5.12. Since the purpose of the test procedure is to measure the maximum vehicle sound levels up to a speed of 25 mph, it is clear that a test in second gear is also required for automatics. As mentioned above, the appropriate acceleration rate for this speed range is 0.12g. It is most unlikely that any vehicle equipped with an automatic transmission and subjected to the rate of acceleration required in the constant-throttle test will shift into third gear at speeds less than 25 mph. Therefore, with the vehicle in second gear, there will be no transmission shift in this speed range. Note that a test in second gear must be initiated from a moving start (15 mph was found to be adequate in the vehicle noise tests) to prevent the 1-2 transmission shift from occurring. This second constant-throttle test for automatics therefore requires the selection of a maximum throttle setting that, with the transmission in second gear, will produce an acceleration of 0.12g at 25 mph when the test is initiated from a steady speed of 15 mph. The sound level is then measured at 25 mph. In the event that this condition cannot be achieved, the throttle position must be adjusted to obtain the highest possible acceleration at 25 mph without downshifting to first gear. Vehicles that shift from first to second gear at speeds greater than about 22 mph when subjected to the basic procedure are most unlikely to produce higher levels in second gear at 25 mph, and are therefore not required to be tested in second gear (see Figure 5.13).*

* Data presented in "Light Vehicle Noise — Volume II"[4] show that the cutoff speed of 22 mph can be reduced to 19 mph.

At this point, it is necessary to note one additional modification to the basic test procedure that is required for certain vehicles. In the noise tests it was noted that one vehicle (#003) shifted from first to second gear without any appreciable change in engine speed. Whereas all the other vehicles exhibited changes in engine speed ranging from 330 RPM to almost 900 RPM at the 1-2 shift, the engine speed for vehicle #003 changed by only 77 RPM. Moreover, the change in engine speed with increasing vehicle speed was very small, making it almost impossible to define accurately the required 100 RPM prior to the maximum engine speed at the shift point. For this reason, vehicles exhibiting this behavior cannot be tested according to the basic procedure in first gear. Since the small change in engine speed at the shift point will result in a correspondingly small change in sound level (as shown in Figure 5.12 for vehicle #003), a higher level is to be expected in second gear. Accordingly, the vehicle should be set to achieve 0.12g at 25 mph. Although there is no quantitative basis for the selection of a criterion that would identify vehicles exhibiting this kind of characteristic, a reasonable criterion is that the change in engine speed at the 1-2 shift is less than 150 RPM.

6.3.2 Manuals

The test procedure for vehicles equipped with manual transmissions also requires a measurement of the sound level at the 1-2 transmission shift with the vehicle accelerating at 0.15g. As a result of the Marana vehicle operation study and data subsequently obtained from the domestic automobile manufacturers (see Chapter 4.0), an engine speed of approximately 70 percent of the rated value appears appropriate for the 1-2 shift and hence was adopted for the test procedure.

The vehicle noise tests showed that there was little difference between the constant acceleration and constant-throttle methods for achieving the required operating condition in a repeatable manner. The constant-throttle method was, however, selected in order to provide a vehicle operation that was similar for both automatics and manuals.

To obtain the maximum sound level at the 1-2 shift it is, of course, necessary to operate the vehicle in first gear. Some vehicles, however, are designed to accelerate from rest in second gear under normal conditions, the first gear having a much higher gear ratio for use in off-road conditions and on steep hills. Since the purpose of the test procedure is to measure sound levels under normal operating conditions, it is necessary to define the gear normally selected. Merely stating that the transmission shall be placed in the gear recommended by the manufacturer for normal operating conditions may lead to some ambiguity for some vehicles that are designed for on- and off-road use. An alternative approach can be adopted by noting that almost all vehicles shift at speeds less than 25 mph. A vehicle with a very high first gear ratio that is designed for on- and off-road use will shift from first to second gear at a very low speed, but will most likely shift from second to third gear at a speed less than 25 mph so that its performance is compatible with the other vehicles on the highway. Accordingly, the procedure for manuals should specify the selection of the highest gear (lowest numerical ratio) consistent with the shift at 70 percent rated engine speed occurring at a vehicle speed less than or equal to 25 mph. This ensures that vehicles with a very high first gear numerical ratio that shift into third gear at speeds less than 25 mph would be tested in second gear.

There may be some high-performance vehicles for which the 1-2 shift occurs at speeds greater than 25 mph. For these vehicles, the test should be conducted in first gear.

With the transmission selected in the manner described above, a maximum throttle setting must be determined to achieve an acceleration of 0.15g at 70 percent rated engine speed from an initial moving start. For the same reasons presented in the previous section, the vehicle speed at which this acceleration condition occurs shall not be greater than 22 mph. The sound level is then measured at 70 percent rated engine speed (the shift point) or 22 mph, whichever occurs first. The data given in Table 5.8 indicate that no test is required in the next highest gear.

6.4 Allowable Tolerance in Acceleration

In the development of a test procedure, it is, of course, necessary to specify tolerances in the test parameters that are identified in the various conditions to be achieved. The parameter of major importance in this test procedure as applied to automatics is the acceleration at the shift point, since this determines the engine speed at which the sound level is measured. To assess the importance of restricting the range in acceleration, a series of constant-throttle tests were conducted at a number of different throttle settings with six representative vehicles. For each setting, the maximum engine speed at the

1-2 transmission shift was recorded together with the acceleration at 100 RPM prior to the shift. The results are shown in Figure 6.1, where it can be seen that, with one exception (vehicle #003), the engine speed at the shift point increases monotonically with the acceleration. Within a range of ±0.005g about the desired acceleration of 0.15g, the maximum range in engine speed for the five vehicles is ±4 percent, corresponding to a range in sound level of approximately ±0.6 dB. It would therefore appear adequate to specify the acceleration required in the test procedure as 0.15g (or 0.12g) ±0.005g.

Vehicle #003 exhibits a characteristics that is different to that of the other vehicles in the range of engine speed shown in Figure 6.1. At low engine speeds, the corresponding acceleration for constant-throttle operation increases with increasing engine speed as the throttle depression is increased. However, for engine speeds greater than about 1700 RPM, increasing the throttle depression results in lower values of acceleration at the shift point. There are thus two possible throttle settings that will achieve an acceleration of 0.15g at the shift point. A review of the computer printouts for vehicle #003 operating at a constant acceleration of 0.15g, indicated that the engine speed at the 1-2 shift was in the range 1400 to 1500 RPM. This indicates that the constant-throttle should be set to achieve 0.15g in this engine speed range, rather than the higher values around 2000 RPM as indicated by the curve in Figure 6.1. Accordingly, it is necessary to determine the correct throttle setting by working upwards from low settings, and not downwards from high settings.

Before the tolerance in acceleration was finalized, however, it was necessary to determine the repeatability of the procedure for automatics to see if different attempts at setting the throttle would result in significant variations in engine speed at the shift point. Three vehicles were selected and the basic test procedure performed at throttle settings that were reset on consecutive days. The results are shown in Table 6.3. The first point to be noted is the relatively small variation in engine speed between the various settings for each vehicle — the variation for vehicle #019 being ±3 percent, which corresponds to a variation of approximately ±0.5 dB. The second point is that in all but one series of runs, the acceleration at the shift point varied by only ±0.003g. Finally, the variation in engine speed for any given throttle setting was very small, in general less than ±1 percent. Thus, for a limited number of vehicles with automatic transmissions, the feasibility of achieving repeatable results was demonstrated.

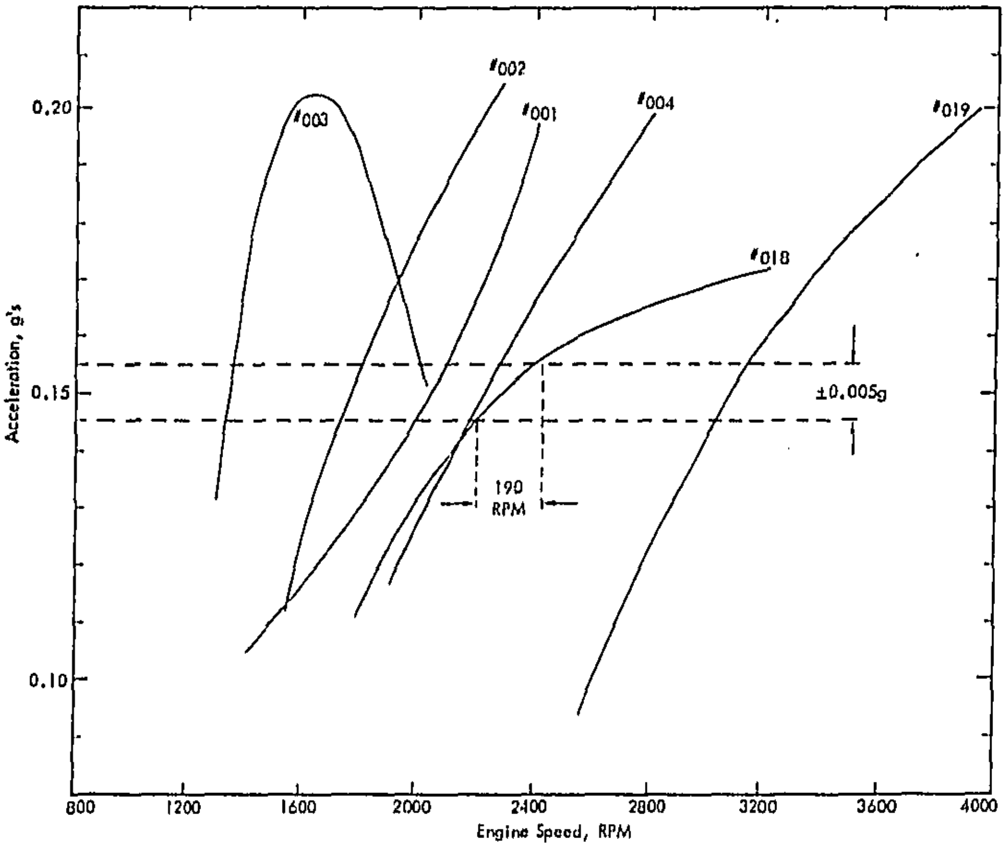

Figure 6.1. Acceleration as a Function of Engine Speed at the 1-2 Shift Point for Different Constant-Throttle Settings.

Table 6.3

Comparison of Throttle Settings
Determined on Different Days

Vehicle No.	Acceleration 100 RPM Prior to 1-2 Shift		Maximum RPM at 1-2 Shift	
	Avg.*	Range	Avg.*	Range
019	0.156g	+0.002/-0.002	3234	+11/-14
	0.152g	+0.003/-0.002	3337	+31/-40
	0.144g	+0.002/-0.003	3140	+11/-23
002	0.155g	+0.002/-0.002	1880	+4/-4
	0.152g	+0.002/-0.001	1832	+25/-12
001	0.150g	+0.001/-0.000	2066	+9/-16
	0.147g	+0.007/-0.005	2043	+16/-20

* Average of four runs.

For manuals, the engine speed is specified in the test procedure, and so a variation in acceleration may cause changes in sound level due to the change in vehicle power. It is known that the noise level has a much greater dependence on engine speed than on acceleration (see Figures 5.20 to 5.23) and thus the allowable tolerance in acceleration for manuals could be greater than 0.005g. How much greater, though, remained to be established in the preliminary implementation of the test procedure (see Section 6.6).

6.5 Microphone Locations

In order to complete the development of a procedure for the measurement of noise from vehicles, it is necessary to examine the directivity of the sound radiated by the vehicle at the measurement condition so that suitable microphone locations can be selected to characterize adequately the noise emissions of each vehicle. To assess microphone placement, plots of the A-weighted sound level versus microphone position were made for all the test vehicles at various specific operating conditions. Examples of such plots are presented in Figures 6.2, 6.3, and 6.4 where the A-weighted levels as measured by each of the eight microphone positions (see Figure 5.2) at the stated vehicle operating conditions are plotted as a function of microphone position relative to the vehicle position at that condition. Thus, a distance of 0 feet in the figures represents the vehicle position (actually the front bumper) with the microphone positions arrayed about that point.

In Figure 6.2, the sound level at 70 percent rated engine speed as measured under Condition 1.0 (constant acceleration) is presented for vehicle #005. Examination of this figure indicates that a plateau in sound level occurs in the vicinity of 0 feet. This plateau includes the maximum level and extends from about -24 feet to +28 feet over which the sound level is fairly constant. Although continuous data are not available as a function of distance over this plateau, it appears that a microphone placed at any position along the plateau would record the same measured sound level within a tolerance of ±0.5 dB. A plateau can also be observed for vehicle #018 at the 1-2 transmission shift operated under Condition 8.0 (constant throttle) as shown in Figure 6.3. In this case, the plateau over which the sound level is constant extends from about -45 feet to at least +10 feet.

Similar plateaus about the vehicle location (0 feet) were observed for the other test vehicles operated under Conditions 1.0, 3.0, and 8.0 with the exception of vehicle #014.

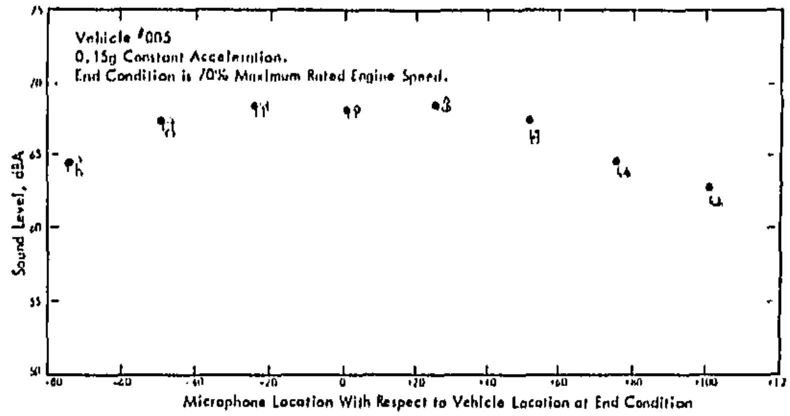

Figure 6.2. Sensitivity of Microphone Location for Vehicle #005.

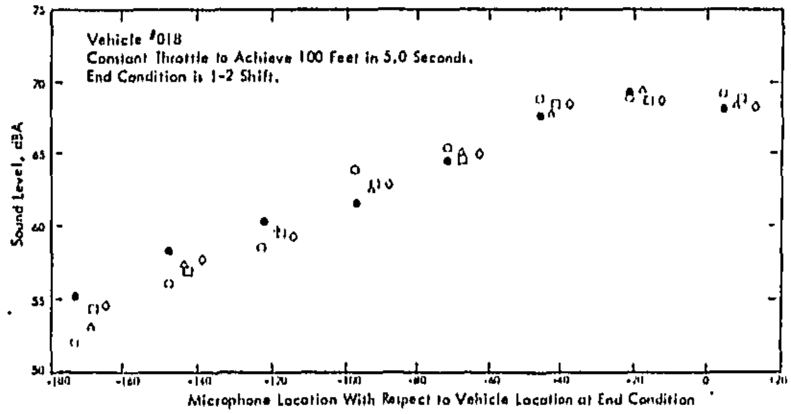

Figure 6.3. Sensitivity of Microphone Location for Vehicle #018.

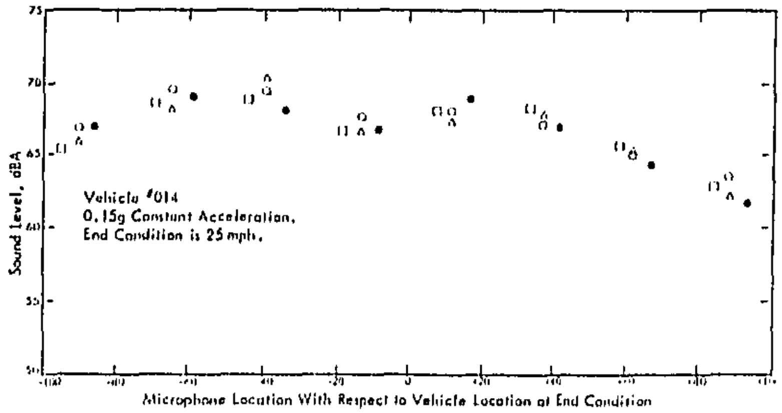

Figure 6.4. Sensitivity of Microphone Location for Vehicle #014.

The sound level as a function of microphone position is shown in Figure 6.4 for this vehicle as operated under Condition 3.0 at 25 mph, and it is seen that a sound level plateau occurs to the rear of the vehicle, ranging from about -65 feet to -46 feet. Near 0 feet, the sound level is about 2 to 3 dB lower than it is at the plateau. It is suspected that the sound level plateau lies behind the vehicle for two reasons. Compared to the other test vehicles, vehicle #014 (a Ford van) is lengthy and hence affords maximum separation of the engine and exhaust noise sources. Also, unlike any of the others, this vehicle has dual rear wheels which are equipped with four mud-and-snow tires. The front tires are conventional and therefore tire noise is accentuated to the rear of the vehicle. It should be noted that the A-weighted coast-by sound levels produced by this vehicle at 25 mph are approximately 65 dB compared to about 57 to 58 dB for conventionally equipped vehicles.

To evaluate the numerous plots produced similar to those of Figures 6.2, 6.3, and 6.4, the data from the microphone position plots are presented in Table 6.4 showing the microphone position relative to the vehicle position at which the average maximum sound level was observed for the given vehicles and test conditions. It will be observed that the position of the average maximum varies considerably from vehicle to vehicle and condition to condition. The total range of this variation is from -40 feet to +35 feet. Also presented in the table is the range of microphone positions over which the sound levels are within 1 dB of the maximum level. This range defines the plateau of maximum sound level as discussed in regard to Figures 6.2 and 6.3. A microphone placed within the indicated range would measure within 1 dB of the maximum sound level. Typically, the range extends from at least -10 feet to +10 feet — the two exceptions being vehicle #001 under Condition 8.0 and vehicle #014 under Condition 3.0. Thus, for most vehicles, a microphone placed adjacent to the vehicle at the position where the desired operating condition occurred would measure within 1 dB of the maximum sound level produced along the line parallel to the vehicle path.

For the preliminary implementation of the test procedure, additional microphones were displayed to ensure that the maximum sound level would be monitored. These were placed 25 feet on either side of the microphone position at which the maximum level was expected, in a line parallel to the vehicle path. Similar arrays of three microphones were placed on both sides of the track to monitor the sound levels from both sides of the vehicle. Each microphone was placed 4 feet above the surface of the test pad.

Table 6.4

Evaluation of Microphone Placement

Vehicle No.	Test Condition	End Condition	Mean Position of Microphone at Max. Sound Level (ft.)*	Range of Microphone Position Within 1 dB of Max. Sound Level (ft.)*
001	8.0 3.0	1-2 25 mph	-5 -5	-10 to 0 -30 to +20
002	8.0 3.0	1-2 25 mph	-25/0 0	-30 to +20 -10 to +20
003	8.0 3.0	1-2 25 mph	-10 0	-20 to +25 -30 to +30
004	8.0 3.0	1-2 25 mph	+10 +10	-10 to +20 -40 to +40
005	8.0	70%	+10	-20 to +30
006	8.0	70%	-20	-30 to +25
007	8.0	70%	-10	-40 to +15
008	8.0	70%	-16	-20 to +10
009	3.0	25 mph	+15	-10 to +20
010	1.0	70%	-10	-35 to +15
011	8.0	70%	+35	-10 to +40
012	8.0	70%	-10	-34 to +25
013	8.0	70%	-10	-15 to +20
014	8.0 3.0	1-2 25 mph	-40 -40	-70 to +30 -70 to -30 / +10 to +20
015	8.0	70%	-5	-30 to +20
016	8.0 3.0	1-2 25 mph	+5 +20	-40 to +30 -30 to +30
018	8.0 3.0	1-2 25 mph	-20 -25	-20 to +10 -40 to +30

* With respect to vehicle position.

The six microphones described above were located 50 feet from the vehicle path – the standard distance used in the United States for motor vehicle noise measurements. In Europe, the standard measurement distance is 25 feet, and it was considered desirable to include measurements at this distance for comparison purposes. As the instrumentation system was limited at this time to 8 acoustic channels, it was only possible to provide 2 microphones at 25 feet.

It should be noted carefully that a total of 8 microphones were used in order to obtain additional data for defining the exact number that would be required in the final test procedure. It was not proposed that 8 microphones would be required in the final test procedure.

With the microphones located as described above, it was necessary to ensure that the vehicle achieved the desired end condition at the correct place along the track – namely, the end point (see Figure 6.5). This was achieved by performing a trial run after the appropriate throttle setting had been determined, and noting the vehicle position at the end condition. The test was then initiated at a point along the track such that the end condition occurred as close as possible to an imaginary line drawn between the center microphones on either side of the track. Based upon the data in Table 6.4, an allowable tolerance or end zone of ±10 feet was specified within which the end condition must be achieved.

6.6 Preliminary Test Procedure

(Subsequently modified as indicated in Chapter 7.0.)

Automatic Transmission Vehicles

CONDITION 1

Gear Selection: The automatic transmission gear selector shall be placed in the Drive position.

Vehicle Operation: Using a throttle-stop technique, maintain constant throttle initiated from rest to achieve 0.15g at 100 RPM prior to the maximum RPM at the first transmission upshift or at 35 km/h (22 mph), whichever occurs first. Exception: An engine speed which decreases 150 RPM or less at the

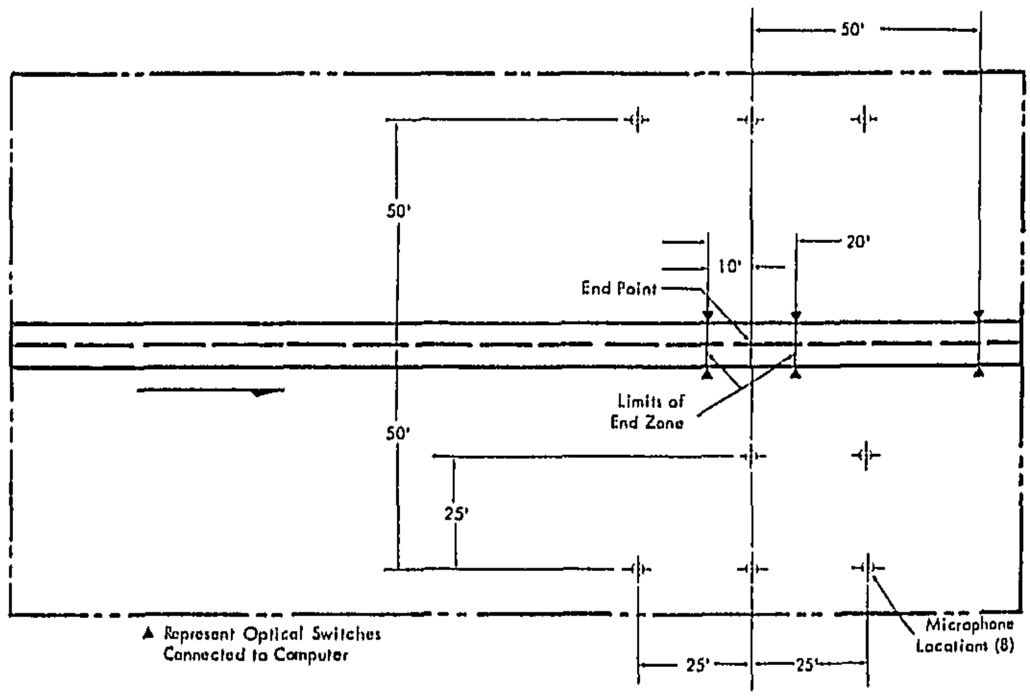

Figure 6.5. Test Section Layout for Preliminary Implementation of Test Procedure.

first transmission gear change when operated as above shall not be considered to be an upshift for purposes of this procedure. Vehicles exhibiting this characteristic shall be set to achieve 0.15g at 35 km/h (22 mph).

End Condition: The end condition is 100 RPM prior to the maximum RPM at the first upshift exhibited by the above operating condition or 40 km/h (25 mph), whichever occurs first.

CONDITION 2

Gear Selection: The automatic transmission selector shall be placed in that position which corresponds to the gear attained after the first transmission upshift under Condition 1. If a transmission upshift is not attained in Condition 1 prior to 35 km/h (22 mph), the vehicle is not required to be operated under Condition 2.

Vehicle Operation: Using a throttle-stop technique, maintain constant throttle initiated from 25 km/h (15 mph) to achieve 0.12g at 40 km/h (25 mph). If 0.12g at 40 km/h cannot be achieved in the selected gear, adjust the throttle position to achieve the greatest possible acceleration at 40 km/h without producing a downshift out of the selected gear.

End Condition: The end condition is 40 km/h (25 mph).

Manual Transmission Vehicles

Gear Selection: The vehicle shall be operated in the gear with the lowest numerical ratio which will produce 70 percent rated engine speed at or below 40 km/h (25 mph). If 70 percent rated engine speed cannot be achieved prior to or at 40 km/h in any gear, operate the vehicle in the gear with the highest numerical ratio.

Vehicle Operation: Using the selected gear and a throttle-stop technique, maintain constant throttle initiated from 25 percent rated engine speed to achieve 0.15g at 70 percent rated engine speed or at 35 km/h (22 mph), whichever occurs first. If 0.15g cannot be achieved in the selected gear, operate the vehicle at the greatest attainable acceleration.

End Condition: The end condition is 70 percent rated engine speed or 40 km/h (25 mph), whichever occurs first.

End Condition

Vehicle Position: The position at which to initiate the prescribed vehicle operation shall be such that the vehicle end condition is achieved at an established end point. The end condition will be achieved within ±3m (10 feet) of the end point.

Vehicle Operation: When the vehicle end condition is reached, the throttle shall be released sufficiently to minimize further increase in vehicle engine speed.

6.7 Implementation of Preliminary Test Procedure

The full test procedure as defined above was implemented on ten of the vehicles used in the previous noise tests to ensure that there were no problems in vehicle operation and measurements, and to define more accurately the allowable tolerances. The layout of the test track and location of the eight microphones is shown in Figure 6.5. Each vehicle completed four runs across the track after the required constant-throttle setting had been determined and the correct initiation point established so that the end condition was achieved as close as possible to the end point. Runs where the end condition was achieved outside the end zone were discarded.

The light vehicle noise tests (described in Chapter 5.0) were conducted using a fairly sophisticated instrumentation system in order to obtain detailed information on vehicle noise characteristics and operating parameters throughout the duration of each test run.

Two of the more complex portions of the instrumentation were the telemetry system and the digital computer. The telemetry system was used to transmit vehicle operation data and interior sound levels to the control room. The computer was used to acquire, store, and print the data after each run. Even though it is convenient to use such a system, it was not considered necessary for conducting the developed test procedure. An alternative approach that is less complex and costly is to record vehicle speed, acceleration, and engine speed on a strip-chart recorder installed in the vehicle, thus eliminating the need for both the computer and the telemetry system. This method was tried and proved to be completely practical, with the advantage that the driver could monitor the vehicle operation at the completion of each run, thus reducing the time to establish the required throttle setting for each condition. An example of a strip-chart recording obtained in this way is shown in Figure 6.6. Having established the feasibility of this approach, the telemetry system was again installed, and the strip-chart recorder placed in the control room. In this way, vehicle operation data taken from the strip-chart recorder could be compared and checked for accuracy with that from the computer printout.

The results of the tests are shown in Tables 6.5 through 6.7 indicating the vehicle operating parameters at the end condition together with the maximum sound levels measured by the three microphones on each side of the vehicle. The arithmetic average is taken for all parameters over the four runs. The following conclusions can be drawn from these results:

- A comparison of the acceleration at the end condition as measured by the strip-chart recorder and the computer shows agreement generally within ±0.001g, indicating that sufficient accuracy can be obtained with a simplified measurement system.
- The range in acceleration at the end condition taken over four runs is generally less than ±0.005g for automatics in Conditions 1 and 2. The range in engine speed is also small, resulting in sound level variations that are generally within ±0.5 dB. Thus the allowable tolerance of ±0.005g for automatics is both acceptable and achievable.
- The range in acceleration at the end condition for manuals tends to be within ±0.005g except for vehicle #015 where the range is greater than ±0.01g. This agrees with the trends observed in the constant acceleration tests. The allowable tolerance for manuals was therefore increased to ±0.01g, recognizing that for a few vehicles this might involve additional runs. The range in sound levels is slightly greater than ±0.5 dB.
- Vehicle position at the end condition is within ±5 feet of the end point which is satisfactory. However, based on the study of microphone placement, there is no need to change the allowable tolerance from ±10 feet.

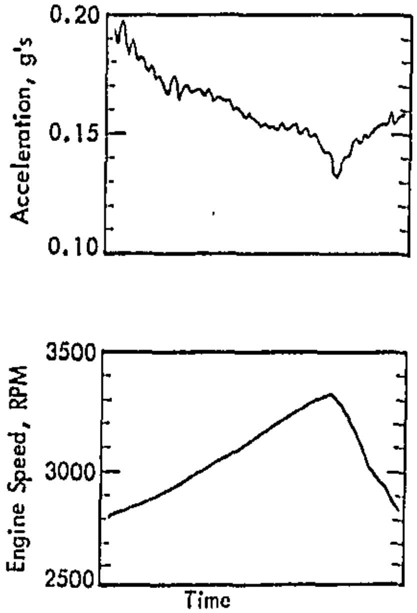

Figure 6.6. Example of Strip-Chart Recording of Engine Speed and Acceleration.

Table 6.5

Test Data For Vehicles Equipped With Automatic Transmissions — Condition 1 (Average Values and Range for Four Runs in Each Direction)

VEHICLE	Strip Chart Accel At End Condition	Computer Accel At End Condition	Max RPM At 1-2 Shift	Speed At Max RPM	Vehicle Position** at End Condition	RIGHT SIDE Max SL*	RIGHT SIDE RPM at Max SL	RIGHT SIDE Vehicle Pos at Max SL	LEFT SIDE Max SL*	LEFT SIDE RPM at Max SL	LEFT SIDE Vehicle Pos at Max SL
Toyota Corolla (#004)	.148 +.003 / -.006	.149 +.007 / -.004	2190 +40 / -45	13.0 +0.4 / -0.2	8.8 +3.6 / -1.8	59.2 +1.4 / -1.3	2181 +49 / -50	8.7 +1.1 / -1.0	59.2 +1.5 / -1.3	2174 +43 / -65	9.0 +2.9 / -3.4
Chevrolet Chevette (#019)	.153 +.005 / -.003	.152 +.003 / -.002	3337 +31 / -40	18.9 +0.2 / -0.1	9.3 +3.3 / -2.3	69.1 +0.1 / -0.2	3101 +32 / -18	-2.1 +14.7 / -6.3	66.2 +0.2 / -0.2	3318 +50 / -40	9.3 +4.0 / -2.3
Dodge Royal Monaco (#002)	.147 +.003 / -.003	.152 +.002 / -.001	1832 +25 / -12	19.9 +0.4 / -0.2	7.5 +3.0 / -1.9	63.6 +0.6 / -0.3	1803 +12 / -11	0.7 +2.8 / -2.1	62.2 +0.0 / -0.2	1800 +57 / -42	2.1 +5.6 / -4.9
Ford Van F-350 (#014)	.147 +.003 / -.003	.147 +.002 / -.003	2576 +22 / -13	22.7 +0.0 / -0.1	5.6 +1.9 / -3.7	68.7 +0.5 / -0.1	2185 +134 / -25	16.1 +2.1 / -1.4	69.2 +0.4 / -0.5	2217 +117 / -86	15.9 +0.2 / -0.5
Olds. Cutlass (#001)	.146 +.004 / -.006	.147 +.007 / -.005	2043 +16 / -20	24.6 +0.3 / -0.2	5.1 +1.9 / -3.7	62.5 +0.3 / -0.4	2031 +16 / -39	2.6 +1.6 / -1.2	62.9 +0.4 / -0.3	1999 +55 / -62	5.3 +8.7 / -8.1
Mercedes Benz 240 D*** (#009)	---	.140 +.004 / -.004	---	---	17.6 +0.5 / -0.9	71.0 +0.2 / -0.2	3161 +13 / -20	16.2 +0.5 / -0.2	---	---	---

* At any of the 3 microphones (50 ft).

** Reference point is start of end zone.

*** Vehicle would not achieve 0.15g at 35 km/h and did not shift at speeds below 40 km/h. Measurements on loudest side only.

Table 6.6

Test Data For Vehicles Equipped With
Automatic Transmissions — Condition 2
(Average Values and Range For
Four Runs in Each Direction)

VEHICLE	Strip Chart Accel at 25 mph	Computer Accel at 25 mph	Maximum Speed for Runs	Vehicle Position** at 25 mph	RIGHT SIDE			LEFT SIDE		
					Max SL*	Speed at Max SL	Vehicle Pos at Max SL	Max SL	Speed at Max SL	Vehicle Pos at Max SL
Toyota Corolla (#004)	.122 +0.0 / -.001	.125 +.003 / -.002	26.1 +0.0 / -0.2	12.4 +5.8 / -8.9	63.6 +0.2 / -0.3	25.2 +0.4 / -0.3	15.9 +2.3 / -1.9	65.4 +0.4 / -0.2	25.2 +0.4 / -1.1	16.1 +7.0 / -5.6
Chevrolet Chevette (#019)	.121 +.001 / -.001	.120 +.002 / -.003	25.8 +0.1 / -0.3	8.4 +4.2 / -2.8	68.2 +0.2 / -0.5	24.7 +0.2 / -0.5	3.7 +4.0 / -4.4	64.3 +0.3 / -0.3	25.2 +0.3 / -0.3	11.0 +8.6 / -4.7
Dodge Royal Monaco (#002)	.122 +.002 / -.002	.121 +.003 / -.003	25.9 +0.2 / -0.3	13.0 +4.5 / -4.6	61.7 +0.4 / -0.3	25.0 +0.2 / -0.4	12.4 +1.6 / -1.2	61.8 +0.3 / -0.2	25.2 +0.5 / -0.4	16.1 +3.5 / -3.5
Ford Van F-350 (#014)	.120 +.002 / -.001	.120 +.001 / -.002	26.0 +0.4 / -0.6	8.6 +1.2 / -0.9	68.5 +0.6 / -0.8	25.4 +0.7 / -0.9	15.9 +10.0 / -13.0	69.3 +0.7 / -0.3	25.2 +0.2 / -0.3	12.4 +4.4 / -4.7

* At any of the 3 microphones (50 ft).

** Reference point is start of end zone.

Table 6.7

Test Data For Vehicles Equipped With Manual Transmissions (Average Values and Range For Four Runs in Each Direction)

VEHICLE	Rated Engine Speed	Strip Chart Accel at 70% Rated RPM	Computer Accel at 70% Rated RPM	Max RPM During Runs	Vehicle Position at 70% Rated RPM (Feet)**	RIGHT SIDE: Max SL*	RIGHT SIDE: RPM at Max SL	RIGHT SIDE: Vehicle Pos at Max SL	LEFT SIDE: Max SL*	LEFT SIDE: RPM at Max SL	LEFT SIDE: Vehicle Pos at Max SL
VW Rabbit (#020)	5500	.158 (+.002 / -.002)	.155 (+.003 / -.003)	3984 (+29 / -16)	8.9 (+2.3 / -4.5)	67.9 (+0.1 / -0.2)	3961 (+7 / -12)	14.3 (+0.9 / -1.7)	69.3 (+0.4 / -0.3)	3951 (+14 / -20)	15.1 (+3.1 / -2.5)
Chevrolet Chevette (#011)	5200	.149 (+.001 / -.002)	.150 (+.002 / -.001)	3718 (+117 / -83)	10.7 (+0.5 / -0.2)	67.9 (+0.7 / -0.4)	3698 (+120 / -99)	14.2 (+5.4 / -3.0)	66.9 (+1.2 / -0.6)	3449 (+140 / -188)	11.7 (+5.8 / -5.4)
Ford Pickup F150 (#015)	3800	.160 (+.013 / -.019)	.154 (+.015 / -.017)	2760 (+34 / -60)	5.3 (+1.7 / -2.5)	70.7 (+0.8 / -0.8)	2739 (+54 / -121)	10.4 (+6.4 / -5.5)	70.0 (+0.3 / -0.6)	2680 (+92 / -87)	16.2 (+9.7 / -7.0)
Ford Granada (#010)	3400	.155 (+.003 / -.004)	.153 (+.003 / -.005)	2500 (+30 / -49)	12.4 (+1.6 / -3.3)	67.0 (+1.0 / -0.6)	2343 (+23 / -17)	9.6 (+1.6 / -1.9)	66.3 (+0.3 / -0.4)	2371 (+45 / -24)	11.0 (+3.0 / -1.9)

* At any of the 3 microphones (50 ft).

** Reference point is start of end zone.

- The sensitivity of microphone placement is analyzed further in Table 6.8, where the maximum sound level measured by any of the three microphones on the loudest side of the vehicle is compared to the second highest level measured on the same side. The difference between these two levels is generally less than 1 dB. Note that the center microphone (0 feet) measures the highest or second highest level in all cases. The error introduced by taking the readings from the center microphone only is in general less than 0.5 dB.

The results of the trial implementation of the preliminary test procedure indicate no major problems with either vehicle operation or sound level measurement. The repeatability of all parameters is within allowable tolerances. Accordingly, it is considered that validation of the proposed test procedure for light vehicles has been demonstrated.

Subsequent to the development of the basic test procedure, a total of 66 light vehicles were tested to develop a data base for the 1977 model year.[4] In these tests, sound levels were measured at distances of 25 feet and 50 feet from the centerline of the vehicle path. The results showed that both microphone distances were suitable for characterizing light vehicle noise emissions. Comments received from domestic and foreign light vehicle manufacturers[16] were largely in favor of standardizing the microphone distance at 25 feet, to allow greater flexibility in the selection of test sites. This modification was incorporated in the finalized test procedure presented in Section 7.0.

Table 6.8

Sensitivity of Microphone Placement

Vehicle No.	Microphone Receiving Highest Level		Microphone Receiving 2nd Highest Level		Difference in Level	Error in Taking Center Microphone Only (dB)
	Position*	Level	Position*	Level		
001	0	62.9	-25	62.3	0.6	0
002	0	63.3	-25	62.9	0.4	0
004	0	65.4	+25	64.7	0.7	0
009	+25	71.0	0	70.2	0.8	0.8
010	0	67.0	-25	66.2	0.8	0
011	+25	67.9	0	67.4	0.5	0.5
014	-25	69.2	+25	68.6	0.6	1.2
015	-25	70.5	0	70.3	0.2	0.2
019	-25	69.1	0	69.0	0.1	0.1
020	+25	69.3	0	68.1	1.2	1.2

* Position Relative to End Point in Feet.

7.0 FINALIZED NOISE TEST PROCEDURE

This section contains the finalized version of the urban acceleration noise test procedure for light vehicles incorporating modifications as determined necessary from the preliminary implementation and data base development.[4]

Urban·Acceleration Noise Test Procedure for Light Vehicles

1.0 INTRODUCTION

The test procedure described in the following sections is designed to provide a measurement of the noise emissions of light vehicles operating under acceleration conditions typical of those in urban areas. Sound level measurements are made for a vehicle operation in which a given acceleration rate is achieved at a particular engine RPM or vehicle speed. A constant partial-throttle setting is used for the test. Appropriate test conditions are provided for vehicles equipped with either manual or automatic transmissions. The sound level is measured by a microphone located 25 feet (7.5m) from the centerline of the vehicle path. Criteria for the selection of the site, the instrumentation and the test condition appropriate for a particular vehicle are specified in the procedure.

2.0 DEFINITIONS

Automatic Transmission: Any transmission which does not require action on the part of the driver to change gears.

Manual Transmission: Any transmission which requires direct action on the part of the driver to change gears.

Numerical Gear Ratio: The ratio between input and output shaft speeds in a transmission, excluding the torque converter. A ratio greater than 1:1 is a reduction. Note that the ratio of gears commonly called "low" have higher numerical ratio (e.g., 3:1) than gears commonly called "high". In this test procedure, the term numerical gear ratio is used to avoid ambiguity.

Test Run: The complete operation of a vehicle in a prescribed manner from initiation to termination of vehicle motion in the prescribed direction.

End Zone: The section of the vehicle path, 20 feet in length, within which the end condition must be achieved for a run to be valid.

End Condition: A particular value of vehicle speed or engine speed which must be achieved during testing for a run to be valid.

Excessive Speed: A 1.6-mph greater vehicle speed, or a 4-percent greater engine speed, than that specified by the end condition.

Operating Condition: A combination of vehicle acceleration and vehicle or engine speed which is simultaneously achieved when the vehicle is operated according to this test procedure.

Rated Engine Speed: An engine speed specified by the manufacturer which is either the speed at which maximum power occurs or the maximum allowable speed.

Synchronized Instrumentation System: An arrangement where all vehicle and acoustic data are simultaneously recorded with a common time reference. This usually requires some degree of telemetry between the vehicle and a fixed position.

Unsynchronized Instrumentation System: An arrangement where acoustic data are not measured on a common time reference with vehicle data.

Test Condition: A complete specification of gear, throttle stop, starting point, and vehicle operation.

Test Sequence: A series of runs employing a single throttle-stop setting, of which a minimum of four runs are valid runs.

Throttle Stop: An adjustable device which limits the opening of the vehicle's throttle but does not interfere with closing the throttle.

3.0 TEST SITE

3.1 The test site shall consist of a test pad over which the vehicle travels and sound level measurements are made, plus approach and departure paths. The site shall be located in an area free of reflecting structures and sources of acoustic interference. The dimensions of the site are shown in Figure 7.1.

3.2 The following points shall be established on the test pad:

3.2.1 An end zone consisting of a 20-foot section of the vehicle's path of travel.

3.2.2 A microphone position located within the trapezoidal area shown in Figure 7.1 at a point 25 feet from the center of the end zone on a line parallel to and 25 feet from the vehicle's path of travel.

3.3 If space and equipment permit, a double-sided test pad with microphones located on both sides of the vehicle path may be employed to permit simultaneous measurement of the sound level or both sides of the test vehicle. Both sides of the site must meet the requirements specified in this section.

3.4 The surface material of the test pad shall be homogeneous over the entire area, and shall consist of sealed asphaltic concrete. The surface shall be smooth and flat within ±2 inches (0.05m) over the entire area, and shall be free of loose gravel and other particles, snow, ice, etc. The path over which the test vehicle travels shall be dry and free of snow and ice.

3.5 The approach and departure paths shall have their centerlines aligned with the vehicle path on the test pad, and shall be long enough to provide for accelerating the vehicle to test speed and safe stopping after the test. They shall be dry and free of snow, ice, and any loose material which might be carried onto the test pad by the test vehicles.

3.6 There shall be no reflecting obstacles located within 50 feet (15m) of the vehicle path on the pad or any microphone positions – see Figure 7.1. The ambient sound level at the site, produced by sources other than the vehicle being tested, shall be at least 10 dB lower than the sound level measured from the test vehicles as it is operated according to the procedure described in Section 6.

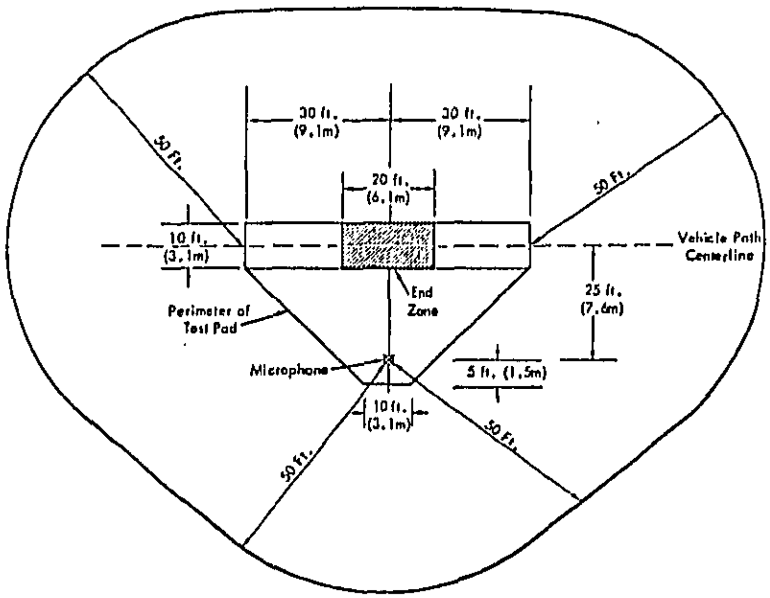

Figure 7.1. Layout of Test Site for the Urban Acceleration Noise Test Procedure.

4.0 INSTRUMENTATION

4.1 Instrumentation System

Instrumentation is required to measure both acoustic data and vehicle parameters, including vehicle speed, acceleration, and engine speed. The instruments for measuring vehicle parameters are usually mounted in the vehicle, while instruments for measuring sound level are stationary. Obtaining a record in which all data are synchronized with respect to a common time reference usually requires some degree of telemetry between the vehicle and the fixed acoustic instrumentation. Such a synchronized system is not necessary to conduct the test, although it may be desired for research or other purposes. Therefore, this test provides alternative procedures for two instrumentation systems.

4.1.1 An unsynchronized instrumentation system requires that vehicle parameters be recorded with a common time reference, but synchronization with sound level data is not required.

4.1.2 A synchronized instrumentation system requires that a common time reference be used in recording vehicle parameters and sound level data. The synchronization method must be accurate to within ±50 msec.

4.1.3 Field calibration of the complete vehicle and acoustic instrumentation systems shall be performed immediately before and after each series of test sequences on a vehicle on the same day.

4.2 Acoustic Instrumentation

4.2.1 Acoustic measurements shall be made using instruments meeting the specifications of ANSI S1.4 (1971), "Specification for Sound Level Meters", for a Type 1 sound level meter. The meter shall be set to A-weighting and "fast" response. The field calibration device used shall have an accuracy of at least ±0.5 dB.

4.2.2 The microphones shall be oriented so as to provide the most uniform directivity in the plane of the vehicle travel and positioned at a height of 4 feet (1.2m) above the test pad surface. Windscreens shall be placed on all microphones in accordance with microphone and manufacturer's recommendations.

4.2.3 If a synchronized instrumentation system is used, sound levels must be recorded during each run such that the time history of the sound level is available. If an unsynchronized system is used, maximum levels may be read directly from the sound level meter, using one trained person for each channel in a double-sided test pad arrangement.

4.2.4 If a recording system is utilized, it must meet the requirements of ANSI S6.1 (1973), and "Qualifying a Sound Data Acquisition System" (SAE J184).

4.3 Vehicle Instrumentation

4.3.1 The vehicle shall be instrumented to record continuously vehicle speed, acceleration, and engine speed during each run. In addition, the times at which the vehicle enters and exits the end zone must be marked or otherwise recorded for each run. The measurements must be made to within the following accuracy:

Vehicle Acceleration	—	±0.002g
Engine Speed	—	±50 RPM
Vehicle Speed	—	±0.2 mph (0.3 km/h)
Time*	—	±50 msec

* Times at which the vehicle enters and exits the end zone.

4.3.2 The recording system must be such that vehicle parameters may be checked after each run to ensure that the operation specified in Section 6 has been satisfied.

4.3.3 To provide smoothing of vehicle parameter signals, a time constant of 100 to 150 msec is to be used. To assure proper time alignment, the same time constant must be used in all non-acoustic channels. No filtering shall be applied to acoustic data other than that associated with "fast" response.

4.3.4 For an unsynchronized instrumentation system, displays of vehicle speed and engine speed, as appropriate for the specified end condition, must be clearly visible to the driver during the test. These provide information needed by the driver to avoid excessive speed (see Section 6.3).

5.0 TEST VEHICLE PREPARATION

5.1 The test vehicle shall be tuned according to the manufacturer's specifications.

5.2 Prior to the test, the engine of the test vehicle shall be at its normal operating temperature.

5.3 The test vehicle shall contain only the driver and the instrumentation necessary for conducting the test.

5.4 An adjustable stop mechanism must be installed in the throttle linkage. This throttle stop must provide a positive, repeatable, stopping point at partial throttle, and not interfere with normal closing of the throttle. A continuously adjustable stop mechanism, such as provided by a screw thread, is recommended.

5.5 All auxiliary equipment on the test vehicle which can be turned off from the passenger compartment shall be in the off position during the test.

6.0 VEHICLE OPERATION

The purpose of this test is to measure the maximum sound level produced by light vehicles under partial-throttle acceleration at speeds up to 25 mph. The vehicle is operated at a constant-throttle setting in first gear to achieve a specified acceleration immediately prior to, or at, the shift to second gear. For vehicles with manual transmissions, shifting is defined to occur at 70 percent rated engine speed. For vehicles with automatic transmissions, the shift occurs at an engine speed controlled by the transmission. The maximum sound level up to and including the shift is then measured, unless the shift occurs at a speed above 25 mph, in which case the measurement is made at 25 mph.

For some vehicles with automatic transmissions, the sound level produced under acceleration in second gear at 25 mph is higher than that measured at the shift from first to second gear. A second test condition is therefore given for such vehicles, corresponding to 25 mph in second gear.

The following subsections describe, for each test condition, the vehicle operation, the appropriate adjustment of the throttle-stop setting, the starting point on the vehicle path, as well as the requirements for a valid test sequence. Preliminary runs will be needed to establish the throttle-stop setting for the test sequence. A correct starting point cannot be established until completion of these preliminary runs.

6.1 Operation of Manual Transmission Vehicles

Step 1. Gear Selection: Place the transmission gear selector in first gear unless operation in a lower numerical ratio gear will produce 70 percent rated engine speed at or below 25 mph (40 km/h), in which case use the lowest numerical ratio gear which will produce 70 percent rated engine speed at or below 25 mph (40 km/h).

Step 2. Throttle-Stop Adjustment/Operating Mode: Adjust the throttle stop such that an operating condition of 0.15g acceleration at 70 percent rated engine speed or at 22 mph (35.4 km/h), whichever occurs first, is achieved during the operation of the vehicle as specified in Step 4. Allowable tolerances in the acceleration are specified in Section 6.4. Completion of this step will normally require preliminary runs.

Step 3. Starting Point/End Condition: Adjust the starting point such that the specified operation of the vehicle in Step 4 will result in the end condition occurring when the front-most edge of the front bumper is within the end zone. The end condition is 70 percent rated engine speed or 25 mph (40.2 km/h), whichever occurs first. The starting point can be established by performing a preliminary run in the reverse direction, initiating the vehicle operation in the end zone and noting the point where the end condition is achieved.

Step 4. Vehicle Operation: With the appropriate gear selected, approach the starting point at 25 percent rated engine speed, maintaining constant engine speed. At the starting point, rapidly open the throttle to the adjusted throttle-stop position. Maintain the throttle at the adjusted throttle-stop position until the end condition is achieved.

6.2 Operation of Automatic Transmission Vehicles

There are two test conditions for vehicles equipped with automatic transmissions. Test Condition 1 applies to all such vehicles; Test Condition 2 applies to vehicles exhibiting certain characteristics when operated according to Test Condition 1.

6.2.1 Test Condition 1

Step 1. Gear Selection: Place the automatic transmission gear selector in the Drive position.

Step 2. Throttle-Stop Adjustment/Operating Mode: Adjust the throttle stop such that an operating condition of 0.15g acceleration at 100 RPM prior to the maximum RPM at the first transmission upshift, or 0.15g at 22 mph (35.4 km/h), whichever occurs first, is achieved during the operation of the vehicle as specified in Step 4. Allowable tolerances in the acceleration are specified in Section 6.4. Completion of this step will normally require preliminary runs. If an acceleration of 0.15g cannot be achieved, the throttle stop shall be adjusted to achieve the maximum acceleration possible. If the vehicle operating condition can be achieved at two different vehicle speeds, the transmission upshift at the lower speed shall be selected.

Exception: If in achieving the operating condition, the engine speed decreases 150 RPM or less from the maximum engine speed noted at the first transmission upshift, the vehicle shall be tested only under Test Condition 2.

Step 3. Starting Point/End Condition: The starting point shall be such that the specified operation in Step 4 of the vehicle will result in the end condition occurring when the front-most edge of the front bumper is within the end zone. The end condition is the maximum RPM at the first transmission upshift or 25 mph (40.2 km/h), whichever occurs first. The starting point can be established by performing a preliminary run in the reverse direction, initiating the vehicle operation in the end zone and noting the point where the end condition is achieved.

Step 4. Vehicle Operation: With the appropriate gear selected, position the vehicle at the starting point with the engine idling and the brake set. Simultaneously release the brake and rapidly open the throttle to the adjusted throttle-stop position. Maintain the throttle at the adjusted throttle-stop position until the end condition is achieved.

6.2.2 Test Condition 2

Criteria for testing under Condition 2:

1. Vehicles for which the first transmission upshift occurs at a vehicle speed less than 19 mph* (30.6 km/h) when operated according to Test Condition 1 shall also be tested under Test Condition 2.

2. Vehicles that exhibit the characteristics specified in the Exception for Test Condition 1 shall be tested under Test Condition 2.

Step 1. Gear Selection: Place the automatic transmission selector in that position which corresponds to the gear attained after the first transmission upshift under Condition 1.

Step 2. Throttle-Stop Adjustment/Operating Mode: Adjust the throttle stop such that an operating condition of 0.12g acceleration at 25 mph (40.2 km/h) is achieved during the operation of the vehicle as specified in Step 4. Allowable tolerances in the acceleration are specified in Section 6.4. Completion of this step will normally require preliminary runs. If an acceleration of 0.12g at 25 mph cannot be achieved, the throttle stop shall be adjusted to achieve the maximum acceleration possible at 25 mph without producing a downshift from the selected gear.

Step 3. Starting Point/End Condition: Adjust the starting point such that the specified operation of the vehicle in Step 4 will result in the end condition occurring when the front-most edge of the front bumper is within the end zone. The end condition is 25 mph (40.2 km/h). The starting point can be established by performing a preliminary run in the reverse direction, initiating the vehicle operation in the end zone and noting the point where the end condition is achieved.

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* As determined from a review of the data obtained from 66 light vehicles.[4]

Step 4. Vehicle Operation: With the appropriate gear selected, approach the starting point at 15 mph (24.1 km/h), maintaining constant vehicle speed. At the starting point, rapidly open the throttle to the adjusted throttle-stop position. Maintain the throttle at the adjusted throttle-stop position until the end condition is achieved.

6.3 Throttle Closing After End Condition

If an unsynchronized instrumentation system is used, the throttle shall be closed after the end condition is achieved to avoid excessive vehicle or engine speed. Excessive vehicle speed is 1.6 mph (2.6 km/h) greater than the specified end condition speed. Excessive engine speed is 4 percent rated engine speed greater than the engine speed specified for the end condition. It is permissible, but not required, to release the throttle after achieving the end condition when a synchronized instrumentation system is used.

6.4 Obtaining a Valid Test Sequence

6.4.1 If a synchronized instrumentation system is used, a run shall be considered valid when the end condition is achieved within the end zone.

6.4.2 If an unsynchronized instrumentation system is used, a run shall be considered valid when the end condition is achieved within the end zone and excessive vehicle or engine speed, as specified in Section 6.3, is avoided.

6.4.3 In order to characterize satisfactorily the sound level on each side of a vehicle for a specified test condition, a series of runs employing a single throttle-stop setting shall be obtained. For a site having a single microphone, a minimum of four valid runs in each direction (a total of eight runs) are required. For a site having a microphone on both sides of the vehicle path, a minimum of four valid runs are required. Thereby, a minimum of four valid sound level measurements for each side of the vehicle are obtained. Such a series of runs conducted at the same partial-throttle setting shall be termed a test sequence.

6.4.4 A test sequence shall be considered valid when the average of the measured acceleration values of all valid runs, at the engine or vehicle speed specified for the operating condition, are within the following tolerances:

maximum value measured for the two sides of the vehicle. For automatic transmission vehicles, the reported level shall be the higher of the average maximum levels produced by Test Conditions 1 and 2.

8.0 ENVIRONMENTAL CONDITIONS

8.1 Noise measurements shall be conducted only when the wind speed — including gusts — is less than 10 mph (16 km/h) measured on the test pad at the microphone height.

8.2 Noise measurements shall not be conducted when the ambient temperature is less than -4°F, nor under temperature or humidity conditions outside of the specified range allowable for the instrumentation being used.

8.3 Noise measurements shall not be conducted in rain, snow, sleet, or hail.

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1. Unpublished results of preliminary testing by Wyle under EPA Contract No. 68-01-3518 (the same contract supporting the work reported herein). Vehicles were tested at cruise and at various rates of constant acceleration.

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4. "Light Vehicle Noise – Volume II: Implementation and Evaluation of a Test Procedure to Measure the Noise Emissions of Light Vehicles Operating in Urban Areas", Wyle Research Report WR 78-13, prepared for the U.S. Environmental Protection Agency, Washington, D.C., November 1978.

5. California Vehicle Code, Article 10, Section 1040, 1973.

6. Data provided by G. Frietzsche, Heinrich Gillet KG, Edenkoben, W. Germany.

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8. Draft Proposed SAE Recommended Practice for the Measurement of Light Vehicle Exhaust Sound Level Under Stationary Conditions, Society of Automotive Engineers, New York, 1977.

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11. Gray, R.F., "A Survey of Light Vehicle Operations", General Motors Engineering Publication 6313, Milford, Missouri, 1975.

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13. Data obtained from American Motors Corporation.

14. Data obtained from Ford Motor Company.

15. "Proposals for a New Test Procedure for the Measurement of Exterior Noise of Passenger Cars", Committee of Common Market Automobile Constructors Report N/17/77, 1977.

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APPENDIX A

Review of GM Chase-Car Data

A.1 Introduction

The General Motors Chase-Car Study of 1974 has been most often cited as the appropriate data base from which vehicle operation information should be taken. A review of this study has revealed a number of limitations which render its use questionable for the determination of noise impact. The limitations identified in the study can be grouped into five areas:

- Improper sampling of traffic density conditions.
- Inclusion of questionable vehicle trips.
- Excessive tolerance in the definition of acceleration.
- Possible errors in determining vehicle acceleration.
- Failure to isolate urban situations.

The remaining discussion in this Appendix presents a detailed examination of each of these limitations. In this discussion, information is also drawn from the DOT/TSC analysis of the GM Chase-Car data tapes.

A.2 Traffic Density Sampling

The first area of concern in the GM Chase-Car Study is the failure to provide a representative sample of all traffic volume and density conditions. The time distribution of trips monitored in the study is shown in Figure A-1 together with a typical example of the time distribution of traffic flow in urban areas. This figure indicates that the data do not adequately represent the peak traffic conditions occurring between 7 a.m. and 8 a.m., and between 4 p.m. and 6 p.m. The bulk of the GM data was taken at mid-day corresponding to substantially lower traffic volume conditions. The concentration on the off-peak traffic conditions has a number of implications. First, a large portion of daily driving has been statistically excluded. Second, since it is most probably that peak traffic volume is directly related to peak traffic density, the most congested traffic conditions have been excluded. Finally, the data sample is biased toward mid-day trips which may be substantially different in nature than the home-to-work and work-to-home trips occurring during the peak traffic hours.

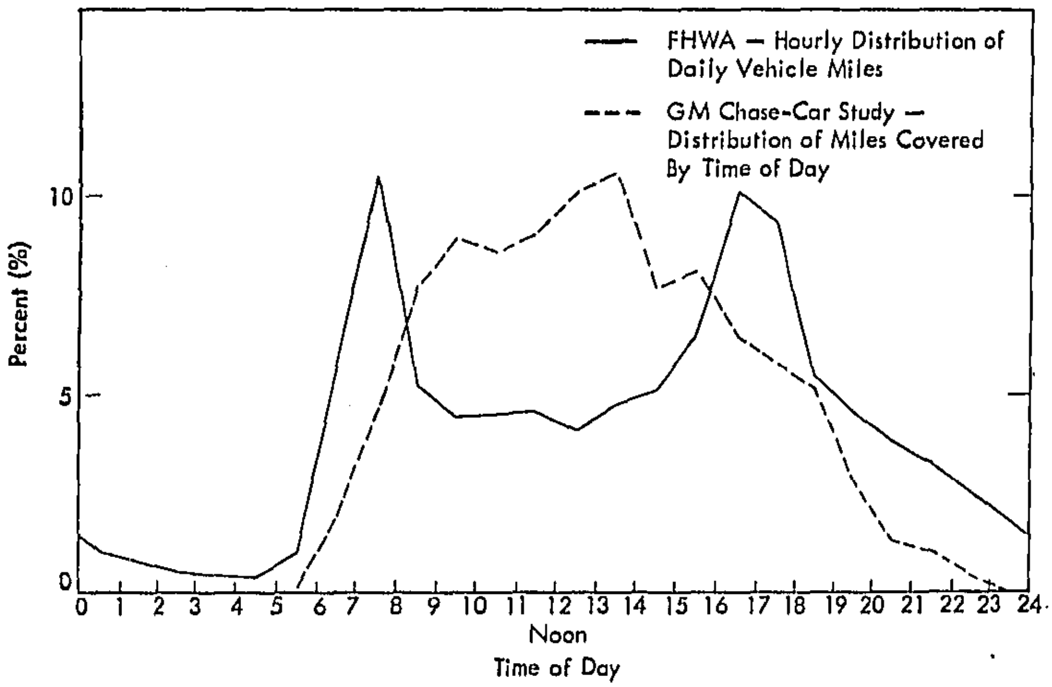

Figure A-1. Hourly Distributions — GM Chase-Car Data and Daily Urban Traffic.

In addition to the limitation presented by the tendency towards mid-day sampling, another limitation is inherent in the chase-car technique itself. This limitation concerns the inability of one automobile to chase another inconspicuously and accurately in light or heavy traffic flow. In light traffic, the problem of remaining unobserved by the driver in the chased car precluded data collection in the light traffic volume hours between 10 p.m. and 6 a.m. This time period accounts for about 11.5 percent of daily urban traffic. In heavy traffic, it is often difficult to remain close to the chased vehicle as it changes lanes or as other vehicles merge into the same lane. The problem of following vehicles in low-speed, heavy traffic results in a shift in the percentage of data taken in heavy traffic from speeds in the 0 to 25 mph range to higher speeds.

A.3 Trip Selection

The second problem area in the GM Chase-Car Study is the occurrence of certain biased trip types in the data sample. Information on trip occurrence is supplied by the DOT/TSC analysis of the GM data tapes. In their analysis, TSC excluded approximately 300 of the 2,500 trips used by GM due to velocity and acceleration errors caused by faulty clock information on the tapes. With this exclusion, TSC determined the breakdown of the 2,200 trips to be as follows:

78%	Unbiased, Partial Trips
17%	Biased, Partial Trips
4%	Unbiased, Full Trips
1%	Other Trips

The heavy reliance of the study on partial trips implies that the early portions of most trips have been truncated. Although the nature of these portions is not known, it is conceivable that the first portion of many trips involves driving which may be substantially different from other portions of the trip due to variables such as population density, road type, etc. This breakdown of trip occurrence also indicates that many biased trips were included. Biased trips refer to those which originated from locations such as the hotel at which the chase-car operator was staying. It should be noted that the most statistically valid trips, those which were unbiased and full, make up only 4 percent of the entire data set.

A.4 Definition of Acceleration

A third problem area is the definition of the acceleration and cruise operations. To discriminate acceleration modes from cruise, GM used an acceleration threshold of 0.05g, and labeled all accelerations less than this as part of the cruise mode. The utilization of such a threshold leads to the high occurrence of the cruise mode in the GM analysis. In their analysis of the GM data tapes, TSC used a much lower acceleration threshold, with the result that the relative frequency of occurrence of cruise and acceleration is radically changed, as shown in Figure A-2. It should be noted that an acceleration of 0.15g corresponds to a speed change of 11 mph in 10 seconds. The justification for using a lower threshold in acceleration is clear when it is recognized that there is a difference of between 2 to 8 dB between the sound level produced by an automobile at cruise and at an acceleration of 0.05g in the speed range up to 25 mph.

A.5 Determination of Acceleration

A further problem area dealing with acceleration concerns the ability of the chase car to simulate accurately the acceleration of the vehicle being chased. As acceleration has an added derivative of time, its instantaneous value is considerably more difficult to duplicate visually than is speed. For this reason, it is questionable whether the chase-car technique can accurately measure vehicle acceleration. Although some speed validation is presented by GM for the chase-car technique, none is given for instantaneous acceleration. Further, the provided speed-versus-time validation is too condensed in time to offer any substantial indication of the accuracy of acceleration simulation.

A.6 Isolation of Urban Data

The final problem area limiting the applicability of the GM study to noise impact assessment is its failure to isolate urban driving from all other driving. Due to their particularly high concentration of both population and vehicles, urban areas are of prime importance in assessing noise impact. Further, it is anticipated that rural and urban driving patterns are significantly different. Evidence of this difference is provided by the TSC analysis of the Chase-Car data. In their analysis, TSC successfully divided the

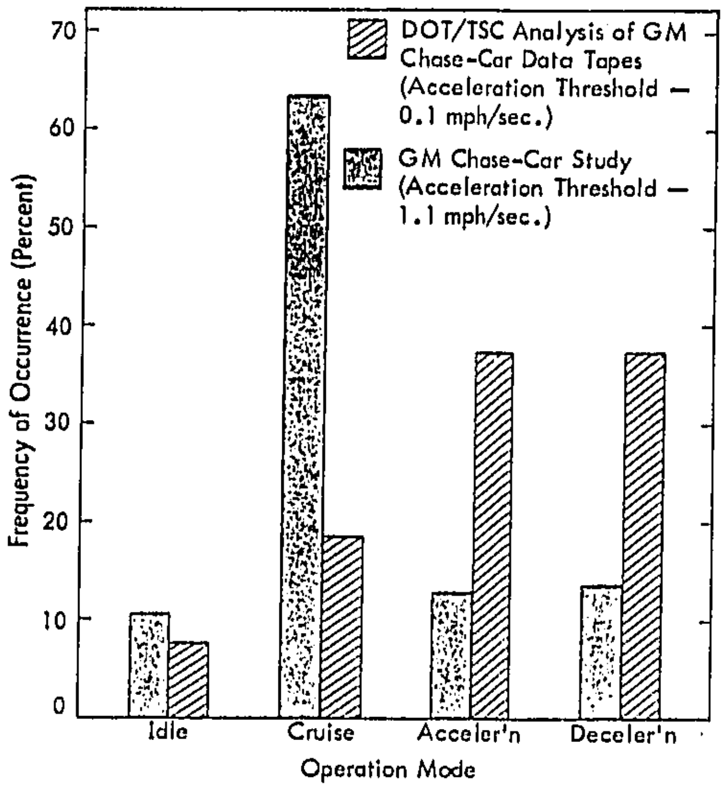

Figure A-2. Occurrence of Operating Modes — All Road Types.

road types into urban and rural. The occurrence of operating modes for these two classifications can be compared in Figure A-3. This comparison indicates that the occurrence of modes is substantially different for rural and urban driving. The GM study does classify roadways into highway and non-highway categories. However, the non-highway category cannot be considered synonymous with an urban area. The lack of correspondence is demonstrated by a comparison of the speed distributions given by GM and the EPA Urban Driving Cycle, as shown in Figure A-4. For this figure, the freeway portion of the EPA cycle has been eliminated to be consistent with the GM definition of non-highway driving. From this comparison, it will be noted that the GM non-highway category includes speeds up to 60 mph while the maximum of the EPA cycle is between 35 and 40 mph. Further, the GM non-highway road type includes more high-speed driving than does the urban driving specified in the EPA cycle.

A.7 Conclusions

Because of the potential limitations in each of the three studies discussed above, it is concluded that typical automobile operation for noise impact purposes is not well defined by the existing data. This indicates that further work in this area is necessary before the automobile noise impact can be determined and a measurement methodology developed.

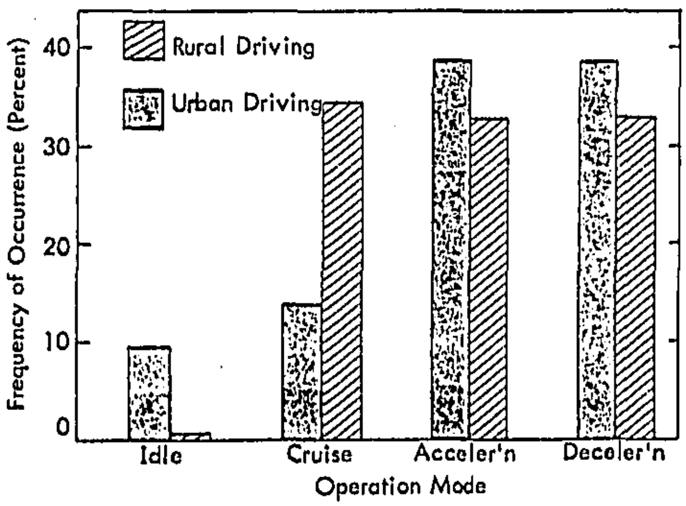

Figure A-3. Comparison of Urban and Rural Driving — DOT/TSC Analysis of GM Chase-Car Data Tapes.

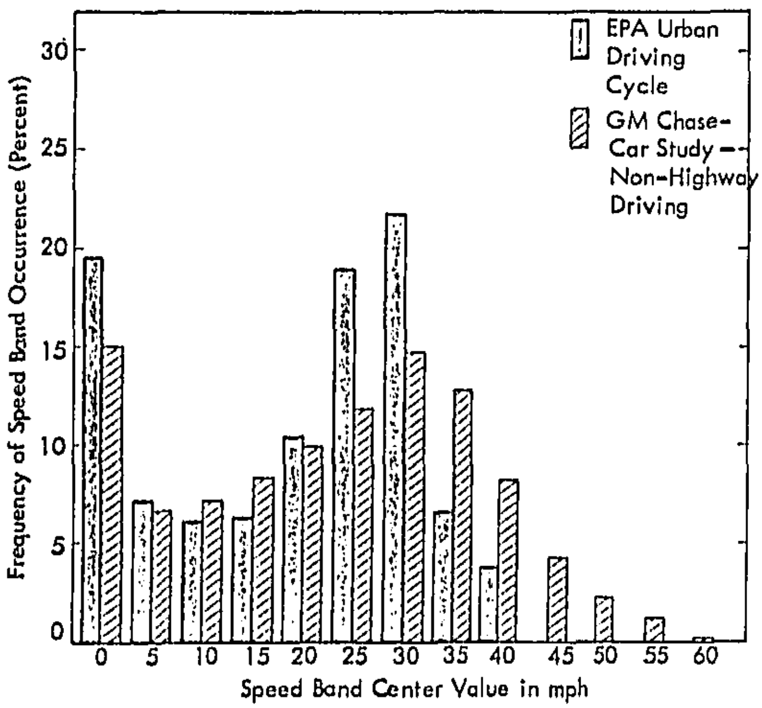

Figure A-4. Comparison of Speed Band Occurrence.

APPENDIX B

Photographic Measurements of Vehicle Operation

B.1 Introduction

Because of the inconsistencies and limitations of the existing automobile operation data, it was decided that some limited independent measurement of vehicle kinematics under uninfluenced operation was required. The purpose of this study was to provide a qualitative understanding of traffic behavior as well as to obtain velocity and acceleration data which could be used to compare to the existing operational data. A secondary objective of the study was the development of an effective data collection technique. The objective of these limited measurements was not to obtain a valid data base which would fully describe vehicle operations, but the data can be used to support conclusions drawn from other studies.

B.2 Approaches to Vehicle Operation Measurement

There are several methods by which automobile operations could be measured. The methods used in previous studies include the chase-car technique, the use of instrumented individual vehicles, or combinations and variations of these. The chase-car technique used in the CAPE-10 and GM studies has a number of serious limitations. If the "chase-car" technique is used to simulate other vehicles, although speed may be adequately simulated, there is considerable question as to how accurately acceleration can be determined. Since acceleration has an added derivative of time relative to velocity, its instantaneous value is extremely difficult to duplicate visually using another automobile. This limitations could be eliminated with the use of a radar unit and the sensing of chase vehicle velocity; however, unobscured contact with the chased vehicle is difficult to maintain at corners, intersections, and in those situations where vehicles are likely to become between the chase and chased vehicles. Another limitation of the chase-car technique is that it is not suited for either high or low traffic density conditions.

Another method used to collect vehicle operation data using instrumented vehicles is to install transducers directly in privately owned vehicles and record data as the operator drives normally. This method also has several limitations. With this technique data collection is limited to transducer output, and no information is obtained to relate recorded kinematic and performance data to the circumstance or location under which it was produced. Further, unless the instrumentation was installed without driver knowledge, driver patterns may be influenced by its presence. Also, statistically valid selection of the drivers to be studied is quite difficult.

Because of the limitations inherent with chase-car and instrumented-vehicle techniques of automobile operation measurement, a stationary, photographic technique utilizing motion pictures of traffic flow was selected. By observing the variation of position for individual vehicles in the traffic flow from one motion picture frame to the next, displacement as a function of time was determined for each automobile. This method of vehicle operation measurement has the following advantages:

- Explicit information on vehicle location at the time of specific operations.
- Increased accuracy in the determination of instantaneous velocity and acceleration.
- Unaffected by extremes of traffic density.
- No influence on individual drivers.
- The effect of one vehicle upon another can be observed.

A disadvantage, of course, is that engine speed cannot be monitored.

B.3 Vehicle Measurements

To utilize this method of kinematic measurement, it is convenient to break conceptually roadways into two major segments; namely, those between intersections where uncontrolled free flow exists, and those in the vicinity of an intersection where flow interruption occurs. With this breakdown, data can be collected for each type of segment independently.

With the existence of traffic flow models to deal with free flow, it was decided to measure vehicle kinematics at an intersection. The site chosen for the measurements was a traffic light-controlled intersection on State Route 7 in McLean, Virginia, near its junction with Interstate 495. At this site, Route 7 is a four-lane major arterial roadway that intersects with a two-lane roadway. In addition to four lanes, Route 7 also has left-turn lanes at this intersection. The left-turn lanes are controlled individually by the traffic lights. The neighborhood around the intersection is primarily residential; however, the houses are separated from Route 7 by frontage streets. The posted speed limit on this section of Route 7 is 45 miles per hour. A photograph of the site taken from the data film is presented in Figure B-1. It should be noted that this site was not selected to be necessarily representative of all intersections or even a class of intersection, but rather to be used to demonstrate the utility of the measurement technique and obtain some preliminary automobile operation data.

The data films of vehicle operations at the intersection were taken from the top floor of a nearby hotel. From this vantage point over 280 feet of the roadway could be photographed. Motion pictures of the traffic of Route 7 were taken using a 16mm camera at a frame rate of 24 frames per second. The camera was operated such that the complete acceleration of the automobile waiting at the light was recorded when the light changed to green. This afforded data on the acceleration of individual automobiles in a line starting from rest in response to a traffic light change.

As part of the data collection, motion pictures were also taken to establish accurate time and displacement information. The camera framing rate was used as the time base for data reduction; however, to verify the frame rate, a stopwatch was photographed for 30 seconds at the beginning and end of each reel of film. Displacement along each lane of the roadway was determined as part of the data reduction by photographing a reference vehicle with a distance scale affixed to its side as it passed through the intersection in the appropriate lane.

Reduction of the data films was accomplished with the console editing device pictured in Figure B-2. The editor displayed the film frame by frame and provided accurate frame count. To obtain the kinematic data from the traffic flow, the camera frame rate was first verified with the photographed stopwatch. The film rate was found to be accurate for all three reels of data film. Distance along the roadway was then determined using the motion pictures of the reference vehicle. To accomplish this scaling, the vehicle was allowed to move 10 feet as indicated by its markings. Then, the 10-foot distance was transferred to a transparent overlay on the editor screen. Proceeding in this

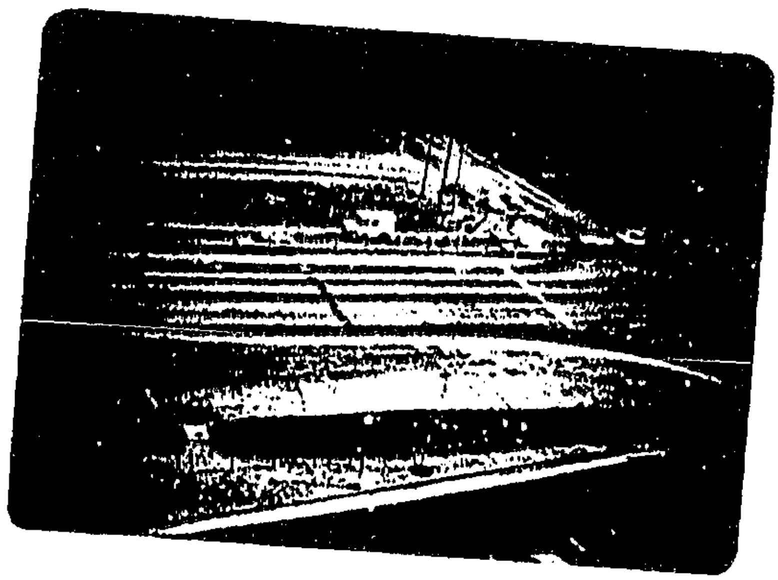

Figure B-1. Site of Automobile Operation Measurements

Figure B-2. Data Film Analysis With Console Editor manner, 10-foot increments were established along the entire vehicle path corresponding to one lane of travel. The 10-foot increments obtained in this manner are displayed in the photograph of Figure B-1.

With the establishment of the film rate as an accurate time base and with the determination of distance along the roadway, the displacement of individual automobiles in the traffic flow was readily obtained as a function of time. To obtain this information, a point on each vehicle was noted and followed as it passed each 10-foot increment. Parallax error was minimized by using the distance determined for the lane corresponding to vehicle travel and by using a point on the vehicle similar in location to the markings on the reference vehicle used originally to establish distance. The frame count as the point passed the increment marker was also noted. Due to the discrete nature of the film framing, the point on the vehicle could not always be lined up with the distance increment marker. This introduced an error of about 5 percent in the distance measurement. Continuing with this data reduction, displacement as a function of time from the initiation of acceleration was determined for the vehicles filmed.

Vehicle velocity at each increment along the roadway was calculated by computer using a difference equation for velocity. This equation is given by:

$$v_i = \frac{\frac{\Delta s_i}{\Delta t_i} \Delta t_{i+1} + \frac{\Delta s_{i+1}}{\Delta t_{i+1}} \Delta t_i}{\Delta t_i + \Delta t_{i+1}}$$

where v_i is the velocity at the i'th distance marker, Δt_i is time taken to move from the i'th-1 to the i'th marker, and Δs_i is the distance increment between these same two markers. For purposes of reducing the film data, Δs_i was a constant 10 feet and Δt_i was the number of frames taken between markers divided by 24 frames/sec. With this information, the velocity equation becomes:

$$v_i = 0.42 \frac{\frac{\Delta n_{i+1}}{\Delta n_i} + \frac{\Delta n_i}{\Delta n_{i+1}}}{\Delta n_i + \Delta n_{i+1}} \quad , \text{ft/sec}$$

where Δn_i is the number of frames elapsed between the i'th-1 and i'th increments.

Using the equation described above, speed-versus-time profiles were obtained for 34 automobiles corresponding to 14 traffic light changes. An example of these speed profiles is presented in Figure B-3 for a range of accelerations observed. As evidenced by this figure, there was indication that the profiles could be fitted reasonably well with straight lines. The coefficients of determination calculated for these linear approximations were quite high and are also indicated in the figure. Linear approximation to the data was selected both due to the nature of the results and to the accuracy of the measurements; however, it could not be established if automobiles actually accelerated in a truly linear manner. As indicated in the figure, there is some variation in the data about the linear mean acceleration rate. As the velocity information is only accurate within about 1 mph, the variations cannot be attributed decisively to either data limitations or actual vehicle operation. An indication of error in the data reduction process was obtained by an independent determination of displacement as a function of time for one vehicle in two different data reductions. The resulting speed profiles are indicated in Figure B-4. From this comparison, it will be observed that agreement of the two data reductions is within 1 mph for all the velocity data.

Another example of automobile speed profiles is afforded in Figure B-5. In this figure, profiles are presented for the first, second, and third automobiles in a line as they accelerate after the light change. A feature demonstrated by this figure which was also indicated by the rest of the data set is that the lead vehicle in a line accelerates at a higher rate than the second and that the second vehicle accelerates faster than the third. This trend is further evidenced in Table B-1 which presents the linearly approximated accelerations of the first through fourth automobiles in a line for the 14 light changes observed. The values presented in Table B-1 have been averaged using several different groupings of the results. These expected values of linearly approximated accelerations are presented in Table B-2 along with the corresponding standard deviations.

Because of the very limited nature of this study, the average acceleration values presented in Table B-2 cannot be used to arrive at any general conclusions. However, the results can be compared to existing vehicle operation data. Of the three existing vehicle operation studies only the CAPE-10 Study and EPA Urban Driving Cycle supply data in a format which can be used for comparison. The CAPE-10 presents an average

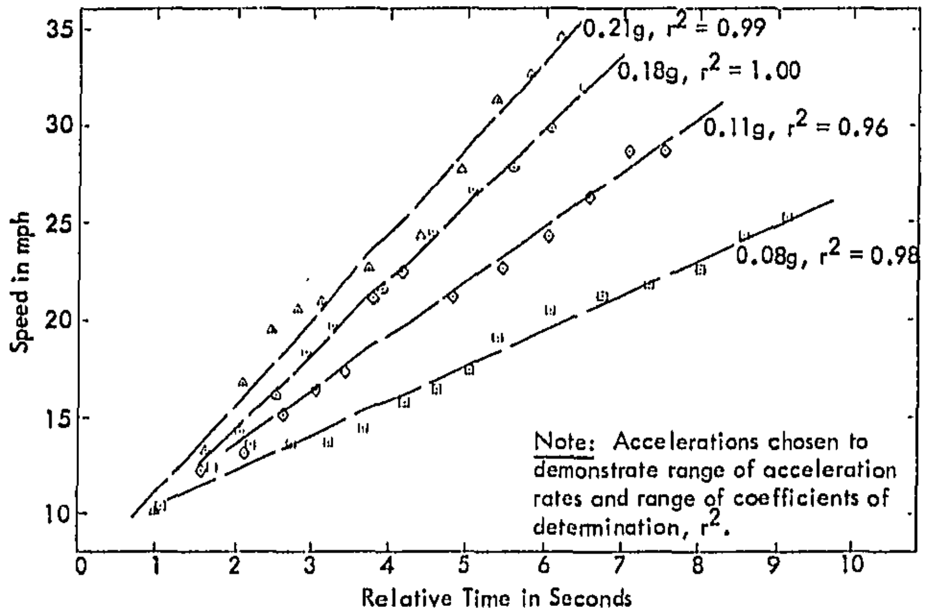

Figure B-3. Speed Versus Time — Application of Linear Approximation.

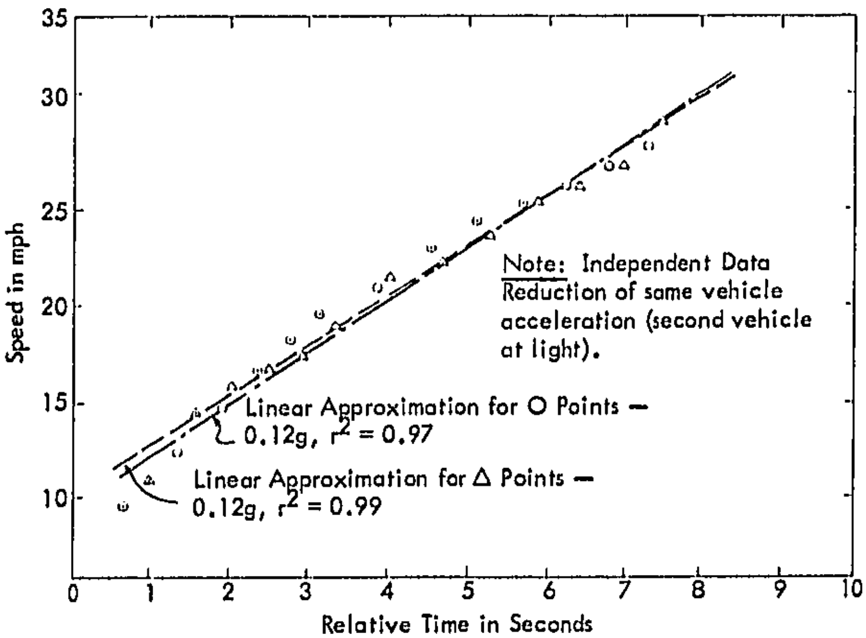

Figure B-4. Speed Versus Time — Data Reduction Technique Reproducibility.

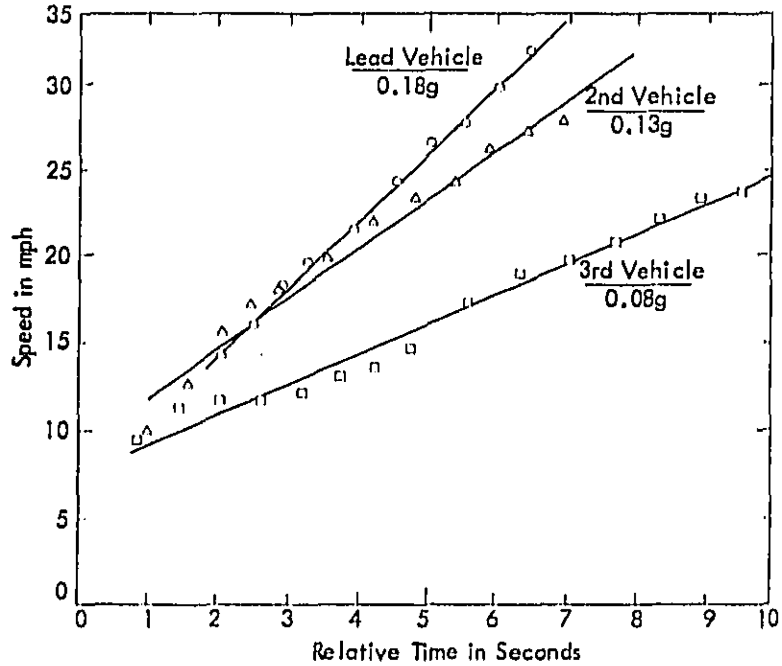

Figure B-5. Speed Versus Time — Adjacent Vehicles in Same Line.

Table B-1

Automobile Accelerations: Linear Approximations

Light Change No.	1st Automobile		2nd Automobile		3rd Automobile		4th Automobile	
	Acceleration (in g's)	Coeff. of Determin.	Acceleration (in g's)	Coeff. of Determin.	Acceleration (in g's)	Coeff. of Determin.	Acceleration (in g's)	Coeff. of Determin.
1	0.15	0.99	--	--	--	--	0.11	1.00
2	--	--	0.12	0.98	0.14	0.96	--	--
3	0.16	1.00	0.13	0.96	0.08	0.98	--	--
4	0.15	0.99	0.14	0.97	0.12	0.99	0.10	0.99
5	0.16	0.99	0.11	0.98	0.12	0.99	--	--
6	0.19	0.99	--	--	--	--	--	--
7	0.17	0.98	0.12	0.99	--	--	--	--
8	--	--	0.11	0.98	--	--	--	--
9	0.24	0.97	0.21	0.99	0.15	0.95	--	--
10	0.21	0.96	0.17	0.98	0.18	0.98	--	--
11	0.13	0.95	0.11	0.96	0.11	0.96	--	--
12	0.13	0.97	0.13	0.96	0.10	0.99	--	--
13	--	--	0.11	0.93	--	--	--	--
14	0.18	1.00	0.13	0.98	0.08	0.98	--	--

Table B-2

Vehicle Accelerations:
Average Linearly Approximated Acceleration Rate

	Expected Value in g's	Standard Deviation σ
All Observed Automobiles	0.140	0.037
All Observed Automobiles Less First of Line	0.125	0.029
First Automobiles of Line Only	0.170	0.032
Second Automobiles of Line Only	0.133	0.029
Third Automobiles of Line Only	0.120	0.031

acceleration for each of the five cities included in that study. These profiles are shown in Figure B-6. For comparison purposes, the profiles were fitted with an average linear approximation between the speeds of 5 and 25 mph. This approximation resulted in an acceleration rate of 0.14g which compares well with that determined in the Wyle measurements. The speed-versus-time information of the EPA Urban Driving Cycle for starts from zero miles/hour was also used to construct acceleration profiles. These profiles indicated that acceleration ranged from about 0.07g to 0.15g. The range of these accelerations agrees well with that observed in the Wyle study; however, it should be remembered that accelerations greater than 0.15g were eliminated from the Cycle to allow simulation with a dynamometer.

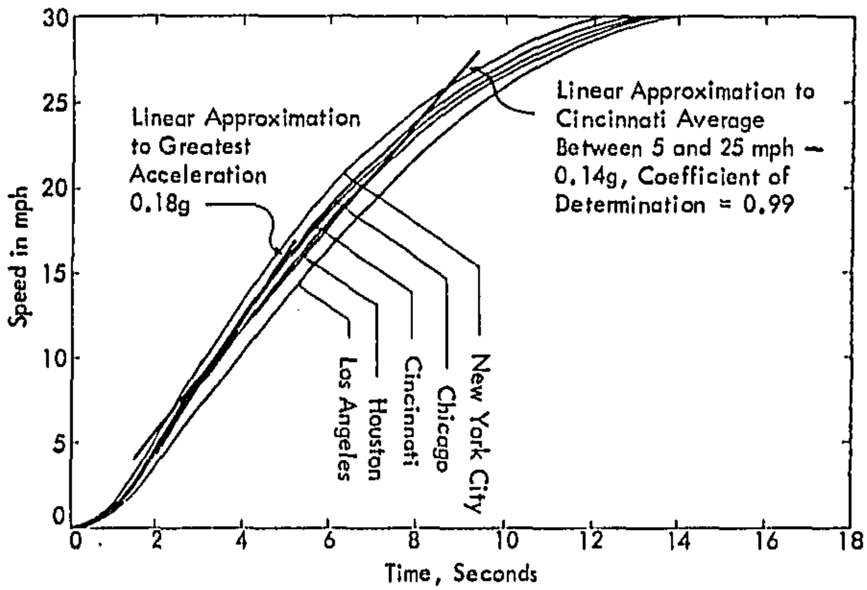

Figure B-6. Average Acceleration Profile From CAPE-10 Study.

APPENDIX C

Instrumentation System

C.1 Introduction

The data acquisition system for the noise tests discussed in Section 5.0 consisted of instrumentation to measure and record simultaneously both sound levels and vehicle operating parameters. The equipment was located along the test section, where the vehicle operated, on board the vehicle, and in a trailer located 300 feet from the test track. A block diagram of the complete data acquisition and recording system is shown in Figure C-1. The details of each element of the system are given in the following sections.

C.2 Acoustic Data

Measurements of the sound level produced as the vehicle passed over the test section were made at eight locations beside the test track and one location inside the vehicle. All measurements were made with B&K ½-inch Type 4134 microphones mounted on B&K 2619 preamplifiers. The microphones were placed on tripods at a height of 4 feet above the asphalt surface with a diaphragm parallel to the ground. This orientation results in a flat frequency response (±1 dB) up to 10 kHz for all noise sources in the horizontal plane. Eight microphones were placed at a distance of 50 feet from the vehicle path centerline spaced every 25 feet beside the 200-foot-long test section — see Section 5.3. Polyurethane foam windscreens were installed on each microphone.

The microphone preamplifiers, powered by B&K 2801 power supplies, were placed near the tripods and coaxial lines carried the signals to the instrumentation trailer where they were input to GR 1933 sound level meters. A broad band, unweighted signal was passed from the sound level meters to a second bank of GR 1551 sound level meters where the signal was amplified and recorded on FM tape using a Honeywell 5600C tape recorder. The bandwidth of the recording was DC to 10 kHz, controlled by the 30 ips tape speed of the recorder. An IRIG B time code was also recorded on the FM tape.

The signal from the microphone was filtered in the GR 1933 sound level meters using an A-weighting network, and then detected using the "fast" response characteristic.

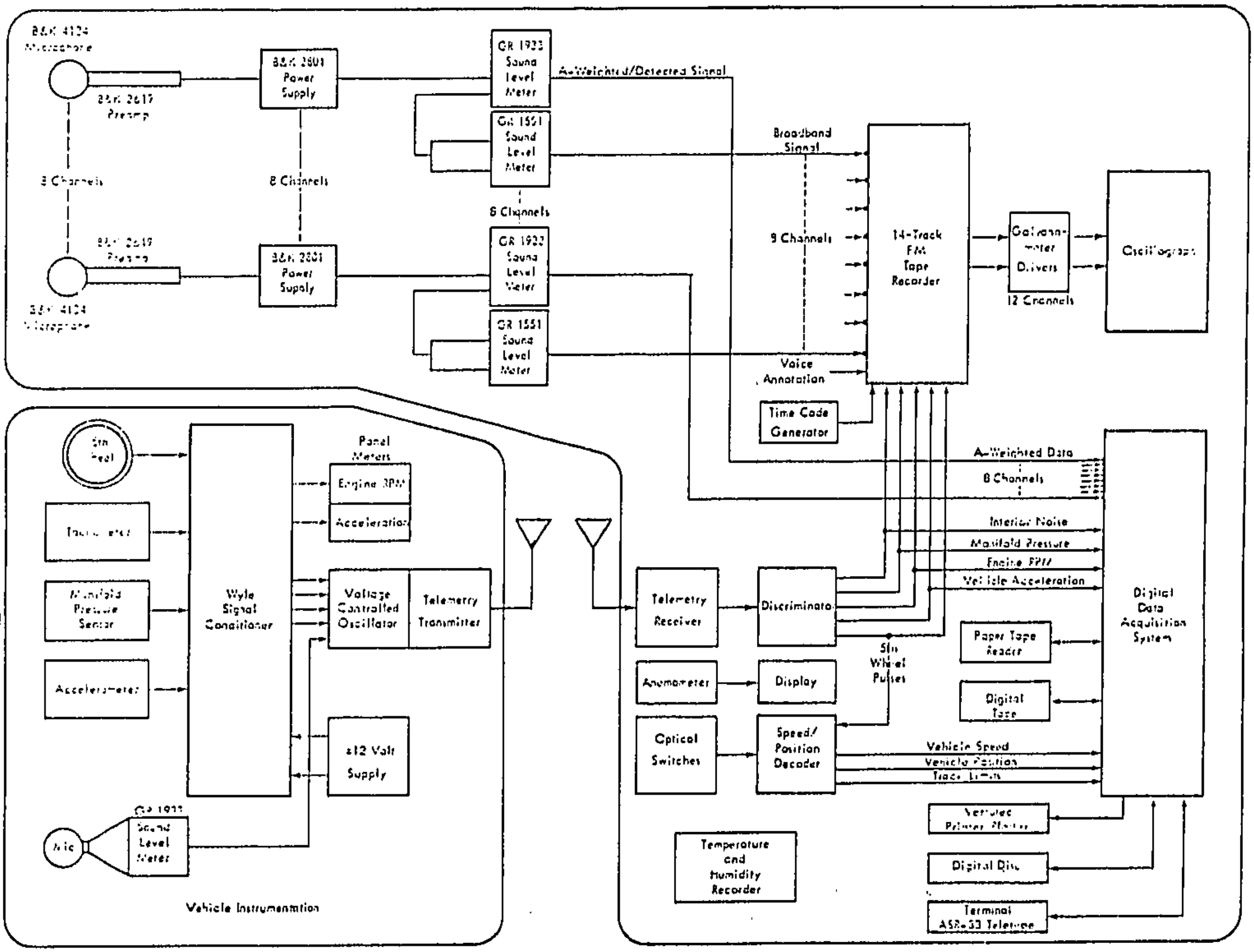

Figure C.1. Data Acquisition and Reduction Instrumentation -- EPA Light Vehicle Test Facility

This corresponds to a detection time constant of approximately 100 msec. In the GR 1933, the signal was converted to a DC voltage proportional to the A-weighted sound level in decibels and was input to the computer for storage on digital tape and printout. The A-weighted levels from each microphone channel were also recorded on an oscillograph recorder fed from the output of the FM tape recorder, and monitored during each run.

Sound levels were measured in the vehicle during all tests, the data being telemetered to the control trailer. The microphone was positioned approximately 6 inches from the driver's right ear using the guidelines in SAE Procedure 336a. A B&K 4134 microphone was used, mounted on a B&K 2619 preamplifier powered by a B&K 2804 power supply.

C.3 Vehicle Parameters

Vehicle parameters that were used included engine speed, vehicle speed, acceleration, manifold pressure, and position on the test track. The data were transmitted from the vehicle via a telemetry system to the recorders in the instrumentation trailer.

Engine Speed

Engine speed was sensed by means of a capacitative pickup attached to the secondary wire of the ignition coil for vehicles equipped with spark-ignition engines. The signal was conditioned to provide a single square pulse for each ignition firing pulse, and fed to a frequency-to-voltage converter to provide a DC signal proportional to the engine speed. For vehicles equipped with diesel engines, a magnetic pickup was used to sense the rotational speed of the crankshaft pulley.

Vehicle Speed

Vehicle speed was measured by a fifth wheel attached to the rear bumper of the vehicle. A standard Nucleus, Inc., fifth wheel assembly was used with a Disc Instrument Model 885 optical encoder installed in place of the standard unit to provide an extremely stable and consistent pulse output of 100 pulses per revolution. The standard unit produces pulses of irregular duration with evidence of frequency modulation for constant rotation speeds. The fifth wheel circumference is 7 feet so that one pulse was generated for each 0.07 foot of linear travel. This is equivalent to 628 pulses per second at 30 mph. The pulses were transmitted via the telemetry system and conditioned in the trailer.

The speed decoder in the ground station accepts the pulse input from the discriminator and converts it to a 0 to 10v DC signal proportional to frequency. The pulse train is also divided down by a factor of 10 to give one pulse per 0.7 foot of travel. This signal is input to the computer which provides a cumulative total of distance travelled.

Acceleration

The vehicle acceleration was measured by a Statham LOD-1-180 strain-gage accelerometer hard mounted to a bracket on the floor of the vehicle. The mounting plate was adjustable for attitude in two axes to allow the accelerometer zero to be set with the vehicle in its tested configuration. The low level signal output from the accelerometer is amplified to a level of 0 to 5v for telemetering and the output is filtered to remove vibration and noise outputs from the signal.

Manifold Pressure

The manifold pressure was measured by a strain-gage pressure transducer with an internal amplifier. This transducer is connected into one of the vacuum lines to the engine intake manifold. The measured pressures range from about 3 to 15 psia and produce an output of 0 to 5v. A filter in the signal conditioner removes high-frequency fluctuations caused by temporary local pressure changes in the manifold.

Interior Noise

Interior sound levels were measured by a General Radio Model 1933 Type I precision sound level meter set to A-weighting network and fast response. The 0 to 4.5v output was fed directly to the telemetry system.

The signals from each transducer (except the interior microphone) were filtered to eliminate high frequencies, using filters with a time constant of 100 msecs. which is approximately equal to the time constant in the ground acoustic system. In this way, the measured acoustic and vehicle parameter data were time compatible.

The transducer inputs were connected to a vehicle signal conditioner operating from a battery power supply that generated regulated voltages for transducer excitation and operation of the electronics. Inputs for calibration signals and outputs for driver display were provided on the unit. Filtering and signal conditioning required to interface the transducers to the telemetry system are performed in this unit. The signals for acceleration, engine RPM, interior noise, and manifold pressure were available at the signal conditioner for display on analog or digital voltmeters and oscilloscopes, as required by the driver.

C.4 Computer System

The computer system is based on a Varian Data Machine Model 620, 16-bit minicomputer. The computer has 12K of on-line memory and a variety of peripherals for use in a data acquisition mode. Input/output devices include a paper tape reader/punch, digital incremental tape recorder, a cartridge-type disc, teletype and printer/plotter. Acquisition of analog data is through a 16-channel differential multiplexer to an analog-to-digital converter which converts the ±10v inputs to 12-bit digital formats. The multiplexer is capable of sequentially scanning the inputs at rates of up to 50,000 channels per second but in this application is used only to about 500 channels per second. Also included in the system is a clock, which allows the measurement of elapsed time concurrently with the data.

In test operation the data was acquired, digitized, and stored on the disc as it was received. At the completion of each test, the data was run through various analysis or plot programs and the results displayed on the printer/plotter within two minutes. Upon examination, the data was stored on magnetic tape for further analysis or file purposes.

In addition to data storage, the disc is used to store all active programs. These programs can then be called out by the operator via the teletype.

C.5 Telemetry System

The telemetry system is designed to transfer the data from the moving vehicle to the instrumentation trailer in an accurate and reliable manner. The vehicle parameters, after processing by the signal conditioner, are input to the system in the vehicle containing the VCOs (voltage-controlled oscillators) and transmitter. The VCOs convert each 0 to 5v DC input signal to a sine wave with a frequency which is controlled by the input signal. The sine wave outputs from all VCOs (operating at different frequencies) are combined and modulate a 256 MHz carrier in the transmitter.

The transmitter output was fed to an antenna mounted on the roof of the vehicle by a magnetic base. The modulation containing the data was removed by the receiver in the control trailer and fed in parallel to the inputs of all the subcarrier discriminators. These units separate out the individual signals and output a ±10v DC level. The signals that were input to the VCOs as 0 to 5v level are thus reproduced as an equivalent ±10v level for input to the recorders and computer.

C.6 Calibration

Calibration of the system and its various components were performed first in the laboratory and subsequently in the field.

Laboratory Calibrations

The equipment was calibrated in the Wyle test facilities at Hampton, Virginia, before being used in the field. These calibrations checked the sensitivity, linearity, and response of the components before they were assembled into a system. All laboratory calibrations were performed using equipment with standards traceable to the National Bureau of Standards.

Field Calibrations

Field calibrations were performed to maintain system accuracy as described below:

- Manifold Pressure — A daily calibration of manifold pressure was performed using a pressure pump and gauge connected directly to the pressure transducer input. The pressure was set to 5 psia and then the ambient value (about 14.3 psia) and the discriminator output adjusted for the proper range and zero.
- Engine Speed — Engine speed and calibrations were performed using a function generator to simulate the pulses from the ignition. For each engine type the pulse frequency corresponding to a fixed RPM was input to the signal conditioning assembly, and the telemetry discriminators adjusted to yield an output level of ±10v corresponding to the required range of engine speed.
- Acoustics — A pistonphone calibrator was used at the start of each day and at the completion of each vehicle test series.

- Telemetry System — Calibrations for range and linearity were performed for the entire system with each test vehicle. Precision voltages were input to the VCOs in the vehicle and the discriminator outputs checked and adjusted to the required accuracy.

- Vehicle Speed — Daily calibration for vehicle speed was performed by inserting a square wave from a function generator at a frequency of 628 Hz into the speed decoder module at the ground station. This frequency was monitored by a frequency counter and is equivalent to a vehicle speed of 30 mph. Calibration of the fifth wheel was achieved by moving the wheel a measured distance (200 feet) and counting the total number of pulses generated. The accuracy of the vehicle speed was found to be better than ±0.5 percent.

- Acceleration — Calibration of the accelerometer was performed prior to testing each vehicle and periodically during the testing. The zero level was set by parking the vehicle on the test pad with all equipment installed and the platform leveled by means of a bubble level adjacent to the accelerometer. The driver monitored the output with a digital voltmeter and adjusted the zero on the transducer amplifier to 0.0v ±1 mv. He then rotated the accelerometer 90° to a vertical orientation and set the output (1.0g) to 5v ±1 mv. The ground station operator, in radio contact with the driver set the telemetry discriminator outputs to ±10v corresponding to 0 to 1.0g. The settings were checked at 30-minute intervals.

C.7 System Accuracy

The accuracy of the system during the test program was maintained at a high level by following rigid procedures of calibration and adjustment before each test series. Detailed records of signal levels set before tests and levels measured after tests were also maintained and demonstrated a high degree of instrument stability during the tests.

Estimates of the accuracy of each parameter have been made based upon expected calibration errors and upon actual performance during testing. Table C-1 lists the parameters measured and the associated accuracy of the measurement.

Table C-1

System Measurement Accuracy

Parameter	Measurement Accuracy
Pass-by Acoustic Levels	±0.5 dB
Interior Noise Levels	±1 dB
Vehicle Speed	±0.1 mph
Acceleration	±0.002g
Engine Speed	±25 RPM at 3000 RPM
Distance	±0.2%