Other Factors That Affect Passenger Ride Comfort

In addition to the four major factors that affect passenger ride comfort, there are many other factors that are also worthy of mention, among which are seating and vehicle layout. For example, seats must be designed to avoid resonance of the passenger on the seat. Since passengers vary in weight, the resonant frequencies vary greatly, and, therefore, care must be taken to ensure adequate vibration isolation between the mountings and the passenger. The seat must be designed to be comfortable to a wide range of passenger sizes and shapes and must be adequately soft and damped so that dynamic characteristics remain essentially unchanged in all working deflections. The width of the seats and the pitch (distance between seats) also play an important part in passenger comfort and should be maximized to the extent possible. Amtrak is currently using a seat width of 23 in with a pitch of 50 in for long-distance passenger car specifications.

Vehicle layout is also a very important factor in passenger comfort. Luggage space, space per passenger, luggage racks, aisle width, clear window visibility, and dining atmosphere are all considerations that must be properly specified for each particular passenger car procurement.

TESTING REQUIREMENTS

Testing requirements for thermal comfort, noise, and lighting are fairly straightforward. Testing requirements for thermal comfort, for example, must be conducted in an environmental chamber that can be accurately controlled for temperature and relative humidity. The passenger car is placed in the environmental chamber and exposed to all the specified ambient conditions while accurate measurements are taken of all the inside and operational characteristics of the car. In much the same way, lighting and noise levels of the vehicles can be easily and accurately measured by meters to ensure agreement with performance specifications.

The measurement of ride quality, however, is not such an easy task; there are many methods for gathering data to ascertain the ride quality of vehicles. These methods all result in numbers that only verify the engineering description of the vibration of a vehicle and that usually are not highly correlated with either the passenger's perceptions of the vibration or evaluation of the ride. In fact, there is not enough agreement between vertical and lateral vibration to define a region of maximum passenger sensitivity. Passenger sensitivity has been shown to be largely dependent on procedural differences in operating conditions, and, thus, available data give no clear-cut basis for choosing any one vibration comfort criteria in preference to another.

The criteria Amtrak utilizes to judge quality of vehicles are generally referred to as the "as good as" criteria. (The "as good as" criteria require specific instrumentation and test condition details be specified and met.) It has been our experience that no one person is satisfied all the time; however, if one can demonstrate that the ride of a new vehicle is as good or better than the vehicle that passengers consider your most comfortable riding one, then there is no room for further arguments.

Future Areas for Development

There are many areas in passenger car ride comfort that will need future work. The following areas will need special consideration:

1. In terms of thermal environment, there should be an emphasis on system efficiency and a large utilization of outside ambient air over a wider range of temperatures for energy conservation.
2. Environmental considerations also require a substitute for refrigerant 12 in air-conditioning systems.
3. Active suspension systems need to be investigated toward solving comfort problems with lateral accelerations and high-speed curving.
4. Seat designs and window visibility need much study and improvement and more work needs to be done on passenger car interiors.

In light of the influence of passenger comfort on the rail business, it is clear that improvement must continue to be made not only to improve maintainability of components and to eliminate known weaknesses, but also to raise passenger car standards in line with the expectations of the traveling public.

Methods for Ride Quality Evaluation of Off-Road Machines

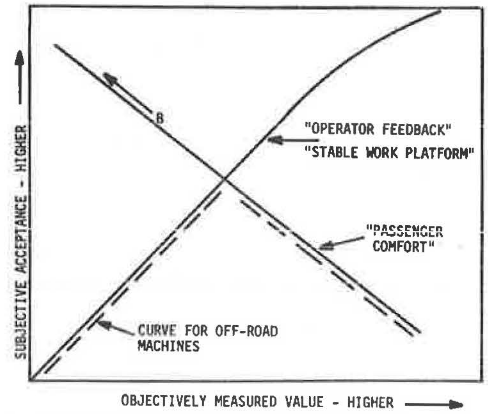
JAMES C. BARTON

This paper summarizes the state of the art of ride quality evaluation methods for off-road machines. The factors that affect ride quality for machine operators are identified. In addition, the application of vibration standards such as ISO 2631 and SAE J1013 is reviewed.

Off-road machines are machines that generally do not travel on public roads, streets, or highways, although they may operate on pavement (such as a lift truck in a warehouse) or on a prepared road (such as a haul road in a mine). Off-road machinery, therefore, includes agricultural, construction, industrial, forestry, underground, and earth-moving machinery, but excludes military and recreational vehicles (1). The term "machine" refers to a work tool with either a paid or self-employed operator and without passengers.

Ride quality is discussed only in terms of the dynamics of motion, in the sense of what is measured as vibration (including transients). The objective or criterion of interest for off-road machines is in terms of "operator preference" or "acceptability."

Figure 1. Balancing ride quality factors.



A = "OPTIMUM" FOR OFF-ROAD MACHINES

B = "OPTIMUM" FOR HIGHWAY VEHICLES AND PASSENGERS

RIDE QUALITY FACTORS

The factors that determine the ride quality of off-road machinery are very different from those that determine the ride quality of highway vehicles and mass transportation systems. An understanding of these factors is more important than, and therefore preliminary to, the details of evaluation techniques.

As an active part of a man-machine work system, the operator's opinion of the ride quality of his machine is his subjective summation of the following dynamic factors:

1. Whether the machine is a stable work platform,
2. Whether there is sufficient feedback of the machine's dynamics to provide the operator both the cues necessary for productive work and the information necessary for the operator's safety in precarious situation,
3. The nature and level of transients, and
4. The nature and level of random vibration.

The first three factors are of little or no consequence for passengers of mass transportation. The second and third factors are relevant to drivers of highway vehicles, but in a minor way compared with the level of random vibration felt by these drivers. A generalized ride quality model integrating the effects of these factors on ride quality rating is shown below:

RIDE QUALITY RATING = [(A x D) x STABLE WORK PLATFORM] + [(B x E) x DYNAMIC FEEDBACK] + [C x F) x TRANSIENTS] + [G x RANDOM VIBRATION]

Depending on whether the model is being applied to vehicle drivers, operators, or passengers, the following values are obtained

where

A = 1 FOR OPERATORS, 0 FOR HIGHWAY VEHICLE DRIVERS AND PASSENGERS,
B = 1 FOR OPERATORS, 0.1 (?) FOR HIGHWAY VEHICLE DRIVERS AND 0 FOR PASSENGERS,
C = 1 FOR OPERATORS, 0.1 (?) FOR HIGHWAY DRIVERS AND PASSENGERS, AND
D,E,F,G = MACHINE DEPENDENT VALUES.

Obviously, laboratory tests for human response to whole-body vibration are incapable of measuring the first two factors and only slightly capable of measuring the third. Hence laboratory results have a limited application to off-road machinery ride quality evaluation.

The provision of a stable work platform and of a sufficient feedback of the platform's dynamics necessarily contradict unrestricted reductions of the levels of transients and random vibration. One cannot provide vibration and transient inputs to the operator (the dynamic feedback he desires) and, at the same time, isolate him from vibration and transients. Therefore, ride quality evaluations have as an end point a proper balance of these factors, as opposed to a concentration on any one at the expense of the others. Figure 1 is a general model of this situation. The curve shown for off-road machines is not unlike that for illumination levels or radio volume levels; more dynamics are good only up to a point, and where that point is depends on how much dynamic feedback is desired.

Within the seven general categories of off-road machines (agricultural, forestry, industrial, earthmoving, etc.), there are 60 different types of commercially available machines (1). Each type of machine may have several design configurations. For example, SAE J1057a lists 9 design configurations for tractor-scrapers (2); this is only one of the 60 different types of off-road machines.

Any type of machine may have several distinct applications, and the various design configurations of each type are sometimes tailored for specific applications. Weight is often a factor in these applications since most types of machines have a wide range of weights. Small machines of a given type and configuration do not necessarily do the same type of work as the larger machines. Thus the realities of developing techniques or "ride quality models" for off-road machines take into account the following:

1. There are multiple dynamic factors, some interrelated and contradictory.
2. The results of laboratory tests for human response to vibration have limited applications.
3. Obviously, it is impossible to involve 30 or 40 subjects simultaneously as operators of a specific machine. Therefore, tests must be done consecutively.
4. Machines do not simply travel from point A to point B as a transportation vehicle does. Hence, actual work cycles appropriate for the machine must be used.
5. There are a great number of types and configurations of machines, and a variety of applications for each one also. Hence, the balance of dynamic factors necessary varies from machine to machine.

Ride quality evaluation techniques were by necessity developed empirically over a period of years after experience with the machine and its applications. Also, considering item 5 above, in particular, ride quality evaluation techniques are far too extensive to cover in detail here. Therefore, most of the following discussion will be general in form. It is clear, however, that the first requirement for doing meaningful research in this area is a thorough knowledge of both the machines and their respective applications.

EVALUATION OF STABLE WORK PLATFORM AND DYNAMIC FEEDBACK

The operator's opinion of the ride quality of his work machine may suffer under several circumstances:

1. If he is frustrated because of an insufficiently stable work platform to do the work he demands of it in a specific work situation, this is a situation independent of the machine's vibration levels and its influence on the operator's ability to operate manual controls.
2. If he feels unable to command the machine as he desires because there is insufficient dynamic feedback for him to make proper control decisions, this is a situation unrelated to the machine response to the operator's commands.
3. If he feels insecure because he is too isolated from the machine to accurately judge his safety or what should be done in precarious situations; conversely, the operator may have a false sense of security about his safety; unfortunately, the operator does not consider this in his judgment of ride quality until it is too late. Therefore, the evaluating engineer must consider both these situations, in addition to the operator's opinions.

Clearly, the criteria for these factors depend on the needs of the specific type of machine; for example, a machine that cuts earth must be a more stable work platform than a machine that only hauls earth.

Generally, design formulas and corresponding evaluation tests have been developed empirically by various off-road machinery manufacturers according to their needs. These are largely proprietary, hence very little literature exists on the subject specific to off-road machines. In more general terms, there is some excellent literature about the value of motion cues (dynamic feedback) and the ill feeling of experienced pilots in flight simulators when the visual field presented is not in harmony with the simulator motion, i.e., the dynamic feedback is unsatisfactory (3,4).

Current methods for the design and evaluation of the work platform stability and dynamic feedback are not a problem as is shown by the lack of operator complaints. To the contrary, methods have been sufficiently successful so that few people recognize these as "ride quality" factors until good practice in this regard is overlooked in pursuit of the narrow objective of reducing vibration.

TRANSIENTS

By definition, a transient is a deterministic nonperiodic event (5). It is not, therefore, one of the higher values that occur normally on a statistical basis in Gaussian random vibration. The fore-aft (x-axis) dynamics related to shifting transmission gears, for example, is a transient. By the very nature of off-road machines, the shifting of transmission gears and the operation of other controls may be frequency events, depending on the machine and the way it is being used. Such transients are perceived by the operator for what they are. A harsh shifting transmission, for example, is perceived by the operator as a harsh shifting transmission. Consequently such events are evaluated accordingly. Transients lend themselves well to treatment in the time domain with relatively simple instrumentation. For example, such an instrument is described for transmissions in SAE Paper No. 650465 (6). Variations of this type of evaluation method are used by off-road machine manufacturers for evaluating transmission shift and similar other transients.

Consistent with the definition of a transient as a deterministic nonperiodic event, computer models of the power train and machine are done in the time domain rather than the frequency domain. The model results are evaluated by the same time domain methods as those used in actual tests of the machine.

THE OPERATOR

The remainder of this paper will discuss the fourth ride quality factor--the dynamics that are measured as random vibration. In general, off-road machines are distinguished from other vehicles by the fact that the person on the machine is an operator and not a passenger. Machine operation, therefore, is distinguished by the following characteristics:

1. The machine operator, as distinguished from a passenger, has control over the speed and to some extent the terrain traversed, and therefore can control the vibration to a level acceptable to himself.
2. The operator knowingly and willfully causes much of what is measured as machine, or operator, vibration. Therefore, the operator has the advantage of anticipation, a powerful element in the psychology of ride vibration evaluation (7,8).
3. The operator is paid to operate the machine; hence, he has different expectations of the "ride quality" than does a paying passenger or an automobile buyer (9).
4. As a paid worker usually operating several hours per day, day after day, the machine operator becomes habituated to the ride of his machine (or type of machine). This does not mean he is oblivious to the ride; rather it means he has a different subjective response to it than does a layman. More importantly, this habituation forms the basis for his acceptance of a new machine.

Because ride quality evaluation really attempts to objectively quantify a psychological situation, the basis for evaluation of off-road machinery must take into account the important elements of operator habituation, expectations, anticipation, and control of the operating situation. This can be done by placing great weight on subjective opinions of operators in real operating conditions and less weight on laboratory objective tests and/or the volume of literature based on such tests. Laboratory subjects are passengers, not drivers or operators; hence, laboratory tests lack the important elements discussed above. For machines covered by the Occupational Safety and Health Administration (OSHA) Standards in particular, it is also reasonable to expect that the operator has been given sufficient training to know what to expect of the dynamics of the machine.

When looked at closely, objective measurements of ride quality attempt to replace the subjective opinions of one group of people (the operators of the machine of interest in the operating situation of interest) with the subjective opinions of another group of people (the subjects and circumstances used in the development of judging techniques and criteria). Therefore, it is considered essential that the baseline data be an accurate representation of that which they are later intended to represent.

CRITERIA TERMINOLOGY

The criteria for evaluating the dynamics (or ride quality) of off-road machinery is in terms of "acceptability" or "operator preference." These terms are consistent with the concept of off-road machines as capital tools in a competitive market where the machine operator often influences the purchase. However, available terminology for evaluating dynamics in ISO 2631 (10) and its Draft Addendum 2 (11), while useful, is not strictly applicable. In the field of earth-moving machinery, for example, there is no evidence of "motion sickness" (12). There is also no statistical association between prolonged years of operating heavy equipment (at the higher vibration levels of machines of an earlier era) and "health" problems (13,14), nor is there any demonstrated cause-effect mechanism to suggest that "health" problems could occur (7).

Heavy equipment operators have an unusually low incidence of the diseases associated with psychological or general stress (15). There is no connection between subjective "fatigue" and vibration in a demanding work situation (16), and no evidence of loss of productivity (as caused by "decreased proficiency" or reduced performance) from "fatigue" on machines with both higher vibration levels and the more demanding task requirements (17,18). For many types of machines and their respective applications, performance of work tasks is not concurrent in time with the high machine vibration levels that occur during other parts of the work cycle.

Thus, as can be seen in ISO 2631, there is left only the criteria of "comfort" to assess ride quality, a word that is both ambiguous as an absolute descriptor and misleading for work machines because "comfort" evokes the image of a luxury automobile. Draft Addendum 1 (19) to ISO 2631 recognizes that "comfort" is relative to the situation by setting forth acceptable values of vibration for different situations (such as those within homes, offices, workshops, etc.), all of which are different from the "comfort" guidelines of ISO 2631 itself. This is to be expected because the level of vibration at which pain is felt by humans is roughly one thousand times the level of perception of vibration. The references for ISO 2631, the general literature, and everyday experience show that within this 1000 to 1 range, what is "comfortable" or "acceptable" is psychological, i.e., it depends on what people expect in any specific situation.

As shown above, the appropriate descriptors for the ride quality, or dynamics, of off-road machinery are in terms of "acceptability" or "operator preference." Target values for new machines are not absolutes, but are established relative to the existing model or the comparable competitive model. In the same way, design targets for all aspects of new machines in a free, competitive market--including ride quality or dynamics--must be objectively measured by the standard "as good as or better than."

LITERATURE

The existing literature on measured levels of operator vibration for off-road machinery is particularly misleading and does not represent the true state of the art. The shortcomings in the literature range from measurements under test conditions inappropriate to the machine, through instrument problems and analysis program errors, and finally, to an obvious lack of understanding of random vibration.

In my opinion, a better method of determining the present state of the art may be to work closely with members of industry and follow the work of the appropriate SAE and ISO committees. The remainder of this discussion will draw heavily on this method. Basic measurement procedures, compatible with ISO 2631, were given in SAE J1013-1973 (20). SAE J1013 JAN 80 (21) and a working draft in ISO (22) were written to resolve many of the problems (as indicated by recent literature) of vibration measurement and analysis procedures. The use of these documents, adherence to good practices in instrumentation, and close consultation with engineers intimately familiar with machines and their applications should help correct the problem.

REVIEW OF CURRENT TECHNIQUES

For general purposes, such as evaluating model results, quantifying new machines compared with existing or competitive models, or quantifying improvements, both 1/3 octave rms acceleration and weighted overall rms acceleration are used, according to ISO 2631-1978.

Detailed techniques for measuring vibration are described in SAE J1013-1973 and have been further expanded on in SAE J1013 JAN 80. For some purposes, such as providing an economical instrument system for small manufacturers, SAE J1225-1978 (23) specifies the requirements for a portable meter to measure weighted overall rms acceleration.

Simultaneous with the methods of ISO 2631 as incorporated in the SAE documents, narrow constant bandwidth analysis is used. There is no real need to reduce the number of types of analyses since the major operating expense is the acquisition of data of FM tape and its transformation to the frequency domain by digital methods for use as engineering data (1/3 octave data and broadband data have little engineering value). The calculation of 1/3 octave rms acceleration values and weighted overall rms acceleration values are simple computer subroutines that entail insignificant added time and cost to the user.

The actual machine test conditions, i.e., what the machine is doing during the test, depend on the machine and on the objectives of the specific test. It is considered especially important for the data to be taken and analyzed in stationary segments to avoid the erroneous conclusions that can be drawn from nonstationary data.

Use of the analysis methods follows from experience and from the operator habituation discussed earlier. The narrow constant bandwidth analysis provides engineering data. The weighted overall rms acceleration provides a convenient "single number" for a given direction of vibration. In most cases these values will relate well to operator opinion. It is quite satisfactory to use three such "single numbers," one for each direction. There is no practical use for a combined multidirection single number for off-road machines, and those suggested in the literature correlate poorly with operator opinion. This is related to the difference between "operators" and "passengers" as discussed earlier.

In cases where the measure of weighted overall rms acceleration does not relate to operator opinion, quite often one of the 1/3 octave rms values will stand out relative to the corresponding value on an earlier model machine. This situation can be called "annoyance" vibration, and it is related to operator habituation. If a new machine has a "tone" (typically low level and above 10 Hz, hence with little influence on weighted overall rms values) under some operating conditions that was not present on an older similar machine, the operator's expectations that the new machine should be "better" in all ways than the older machine leads him to think that the "vibration" (or "tone") indicates the machine is faulty and that expensive repair will soon be necessary. In these cases, 1/3 octave rms values are better indicators than the weighted overall rms value that may, in fact, be contrary to operator opinion.

In such cases of "annoyance" vibration as described above, absolute values are meaningless because the situation is based on relative values and habituation. "Annoyance" vibration is more likely to be seen among test operators for a company where the habituation to specific characteristics of a given machine is strong and there is a high motivation to report observations about a new machine.

The lack of "recommended levels" in the SAE documents does not indicate disagreemnt with the recommendations of ISO 2631. In fact, careful study of

ISO 2631 shows that those recommendations are not fixed absolutes for all situations as they are sometimes portrayed by users of ISO 2631. Also, the lack of "recommended levels" in the SAE documents does not indicate SAE disagreement over what the levels should be. The SAE documents reflect the facts that the terminology for criteria in ISO 2631 is not strictly applicable, that absolute values are inappropriate in a situation where only relative values serve useful purposes, and that random vibration is only one factor in determining ride quality.

Figures 2 and 3 illustrate why the weighted overall rms value, as specified in ISO 2631, is used instead of the also popular "absorbed power" value (24-26).

Figure 2 includes a rearrangement of the equation for absorbed power and the related translation of the frequency coefficients. With the exceptions of a constant and a different frequency weighting, absorbed power is mathematically the square of the weighted overall rms of ISO 2631.

Figure 3 shows the results of 63 different data segments (80 statistical degrees of freedom in the spectrum analysis for each segment) for which both the absorbed power and the ISO 2631 weighted overall rms acceleration were calculated. The data segments include a variety of wheel-type and track-type machines, and test segments ranging from representative operating conditions to extremely severe special test conditions used for accelerated destructive testing of the machine. The linear relationship shown in Figure 3 illustrates that for these machines, the rather big difference in frequency weighting of Figure 2 plays a minor role in relative values, i.e., machine A versus machine B. Thus, the use of the ISO 2631 frequency weighting in the SAE documents is not so much an endorsement of ISO 2631 as it is a reflection of the fact that variation in frequency weightings are not of great importance for the purposes of the SAE documents. The maximum point variation from the regression line of Figure 3 is about 17 percent. This is not much larger than the variations in measured vibration that the operator creates through his own body movements, which may be 5 or 10 percent or more of the "vibration" signal recorded from the transducer on the disc on the seat cushion.

There is no point is searching for a "more correct" frequency weighting curve when in fact the signal processed is a mixture of vibration and the effects of the operator's own movements (i.e., the accelerometer motion arising from the force variations from operating pedals, levers, steering wheel, etc.)

It can be seen from Figure 2 that a unit value of rms acceleration is two times as "severe" at 4.5 Hz as it is at 1 Hz, when measured by both the ISO and SAE method. With the absorbed power method, the severity ratio is 22 to 1 yet the bulk of literature available supports a ratio much closer to 2 to 1. This indicates that values at the linear level (rms) are more realistic than values at the power level (mean square). Similar observations can be made about values within the 4 to 10 Hz range.

For the horizontal directions (x-axis and y-axis), similar data show less scatter than that of Figure 3; overall, there is less of a difference in the frequency weightings. Time has confirmed the notable pioneering achievements of Pradko and Lee (24-26) in general methodology, but has been less kind to the details.

Much of the literature suggests a 6 decibel/octave (dB/oct) frequency weighting in the 1 to 4 Hz range rather than the 3 dB/oct weighting specified in ISO 2631. Changing to 6 dB/oct would provide the bonus of simpler instrumentation, i.e., standard filters.

Finally, rms is a complete statistical descriptor of vibration levels for random vibration with similarly shaped probability density functions. For most off-road machines, the data are Gaussian and no descriptor beyond rms in needed. The exceptions are discussed below as potential new techniques.

Figure 2. Equations and weighting for ISO 2631 weighted overall RMS versus absorbed power.

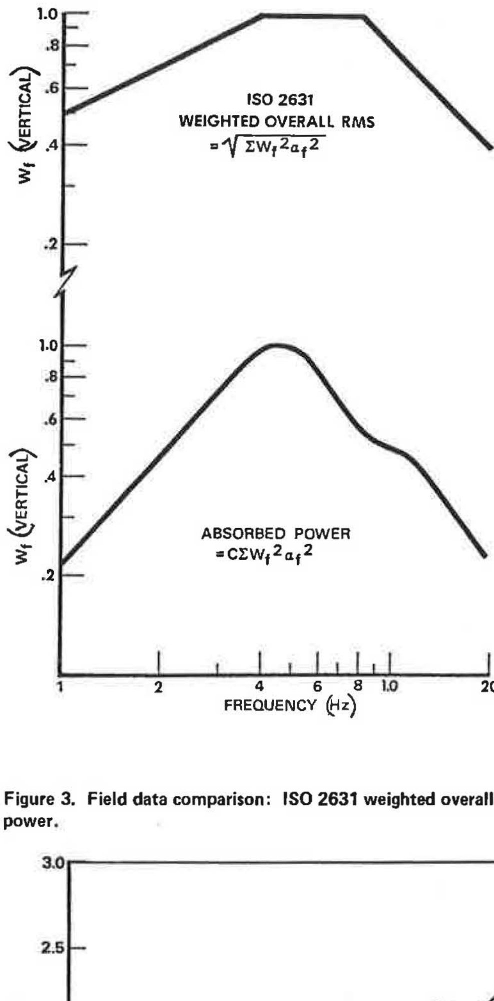
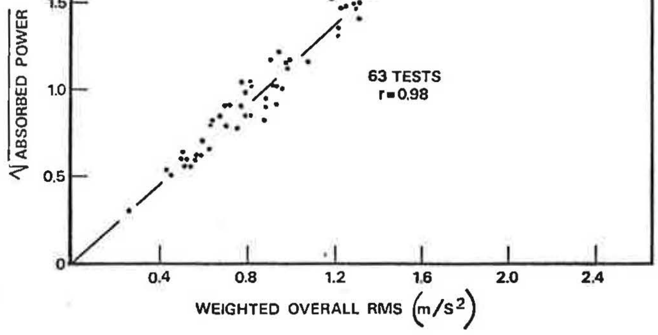


Figure 3. Field data comparison: ISO 2631 weighted overall RMS and absorbed power.



POTENTIAL NEW TECHNIQUES

The techniques described in SAE J1013 JAN 80 and ISO 2631-1978 are sufficient for measuring the random vibration of most off-road machines. For the few occasions when measured values do not correlate with operator opinion, use of the probability density function is useful. Most of the data, if properly taken, are Gaussian. On the few occasions when they are not, a few relatively high values in the time data have such a large effect on the rms value that the rms value overstates the severity of vibration. For example, adding time data points of eight times the rms value for 0.5 percent of the total data points in a Gaussian distribution increases the rms by 15 percent. In such cases, better correlation with operator opinion is achieved by deleting the unusually high values in the time data and recalculating the rms. This works because the vibration itself is Gaussian (as theory would predict) and the unusually high values are often a result of a discrete event that the operator identifies as such, and not as vibration or "ride."

Because of the large effect that a few unusual data points can have on the rms, extra care is taken to monitor data during the measurement and analysis procedures to ensure that any spurious electrical signals are identified and eliminated. A dummy transducer channel a oscillograph monitor are commonly used as part of good instrumentation practice.

It is also good practice to analyze data in segments expected to be stationary since the novice often can be misled by the high "crest factor" that occurs when two stationary Gaussian data segments of different rms are analyzed as a single longer segment. This high crest factor occurs even though there is nothing unusual in either data segment.

Although there are now several methods for determining how closely data approach a Gaussian distribution, it might be useful to have a method that could be incorporated into a device such as the meter described in SAE J1225. In its simplest form, the method would need to show only the data as sufficiently non-Gaussian, thereby indicating the rms value shown on the meter as most likely an overstatement of the actual vibration severity. One such method might be to consider the probability density function as an area and create a "form factor" from a ratio of different order moments, made dimensionless by the following equation:

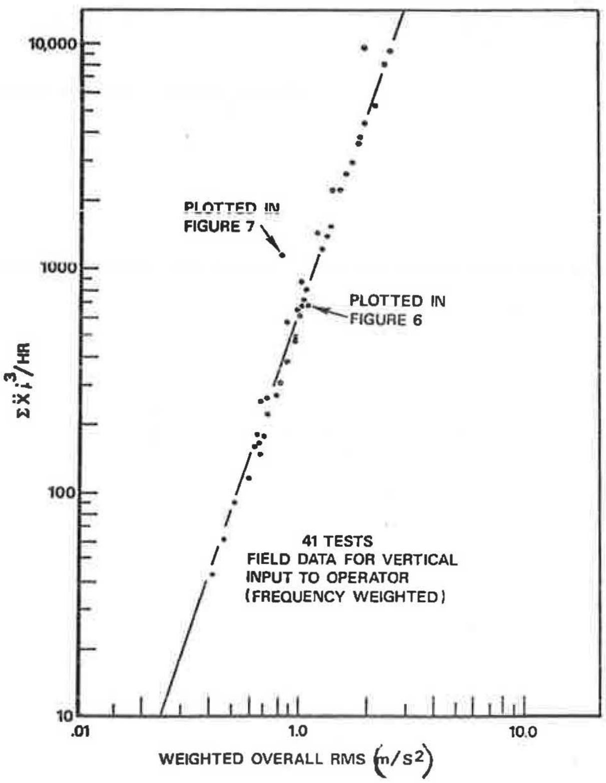
$$\text{Form factor} = (\Sigma a_i^4/n)/[(\Sigma a_i^2/n)]^2$$

The denominator is the square of the mean square value of the vibration; hence, it is not a complex additional calculation. The numerator is an additional summation of digital time data.

Figure 4 includes data from 41 independent test runs (from the 63 test runs of Figure 3). The data were calculated in a manner somewhat analogous to the form factor equation, but with different exponents instead, and were plotted as the function of two variables rather than as a ratio. As shown, only a few points deviate significantly from the line with the expected slope value of 3.

Figure 5 is the probability density function of a sample data point near the line shown in Figure 4. As can be seen, this function closely resembles a Gaussian curve. Figure 6 is the probability density function of the data point farthest away from the line of Figure 4. It departs from the Gaussian curve and suggests either a non-linear system or non-stationary data.

Figure 4. Test data processed through form factor analogy versus weighted overall RMS.



In Figure 4, most of the data points are near the line, thereby indicating a reasonably Gaussian distribution. This furthermore confirms the validity of using the rms as a complete discriptor, a current technique mentioned above.

The outlying points of Figure 4 are data which depart substantially from a Gaussian distribution (as shown in Figure 5). Hence this indicates that the form factor equation has potential as an added feature to indicate when the data are significantly non-Gaussian in rms "ridemeters."

FUTURE NEEDS

1. There is less of a need for new techniques to evaluate ride quality than for sorting out the variety of those being currently used and focusing on these techniques that already provide the desired information.

2. There is a need to recognize that the major improvements in vibration reduction preceded, hence were independent of, the sophisticated measurement and evaluation technologies and their associated design targets. Furthermore, it must be kept in mind that the powerful tools available for data analysis carry with them the danger of becoming an end in themselves at the expense of common sense, intuition, and the basics of vehicle dynamics that have led to so many machine improvements in the past.

3. The off-road industry has taken care of its own technical needs by way of proprietary methods and the appropriate technical societies. The best sources for identification or verification of unmet needs are the industry trade associations, the SAE, and the companies themselves.

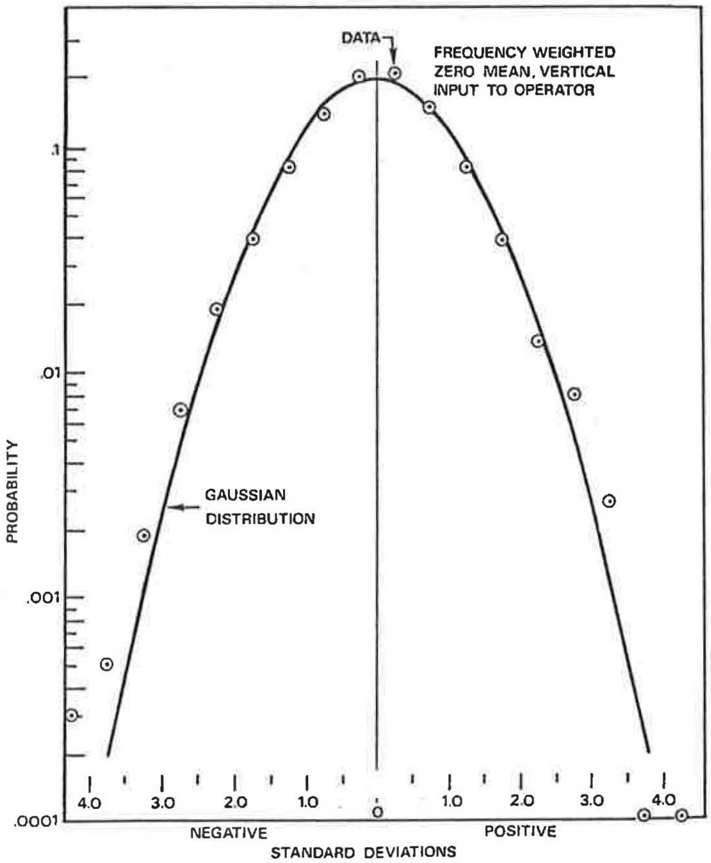


Figure 5. Probability density function for a sample data point from Figure 5: first point.

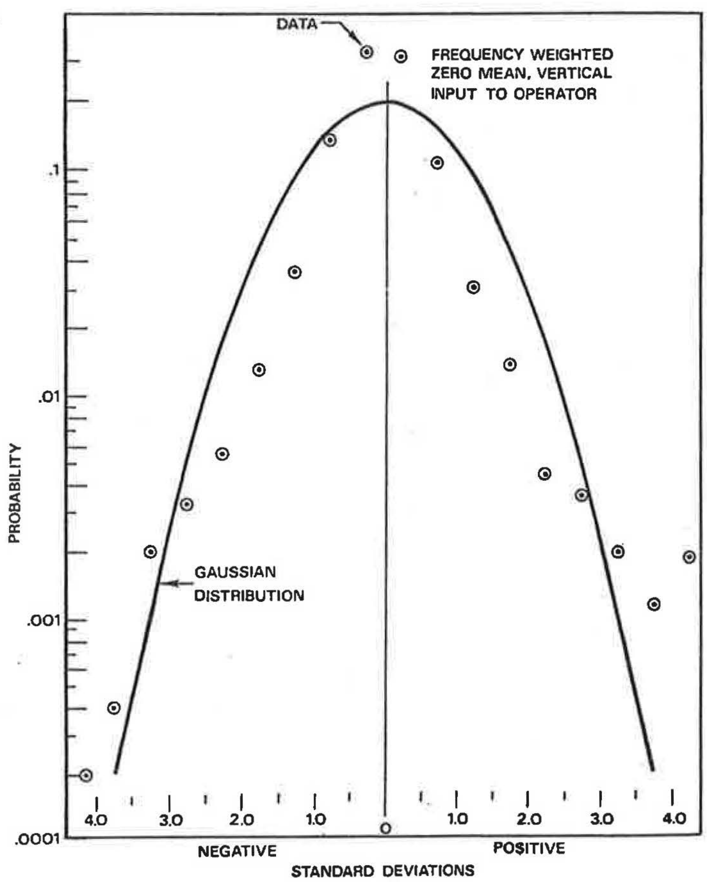


Figure 6. Probability density function for a sample data point from Figure 5: second point.

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Subjective Ride Quality Testing Procedures

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This paper describes the problems of obtaining passenger ratings of their subjective reactions to different vehicle environments. The rationale for assessing subjective reactions is discussed. Several methods of measuring passenger comfort are noted, and two common methods are described in detail, along with the base for choosing between them. Practical and psychometric considerations governing the use of rating scales are reviewed, and the importance of individual differences is noted. Finally, a standard sequence of steps is presented for analyzing subjective data and deriving comfort models.

Since the first National Aeronautics and Space Administration (NASA) symposium on ride quality in 1972 (1), there has been concern about the inclusion of subjective factors in ride quality research. Much of this concern has been expressed as suspicion about the legitimacy of subjective factors and the desire to eliminate them from studies in this area. Thus, there have been attempts to build ride quality meters and attempts to establish ride quality standards. Neither of these efforts have proven com-