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INSTRUMENTATION METHODOLOGY FOR AUTOMOBILE CRASH TESTING

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INTERIM REPORT

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16. Abstract

Principal characteristics of existing data acquisition practices and instrumentation methodologies have been reviewed to identify differences which are responsible for difficulties in comparing and interpreting structural crash test data. Recommendations are made for standardizing these differences which include non-uniform practices in transducer location, data acquisition and presentation of plotted data. The general nature of current filtering specifications used in structural data acquisition also adversely affects data interpretation and comparison. Examples emphasizing the importance of low frequency data content of occupant compartment accelerometer data are presented and a possible analysis criterion for specifying suitable filtering characteristics for this parameter, is described. A method which has the potential to analytically describe and "filter" test results by fitting a polynomial curve having limited frequency reproduction capability to digitized crash test data is also proposed.

Recommendations for standardized structural data acquisition parameters have been made to establish a structural performance base and evaluation criteria for application to full scale production vehicle crash test results.

The role of structural crash test data for use in computer simulation model development is also reviewed and its role in current and advanced simulation models is defined based on model input/output characteristics.

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PREFACE

The work described herein has been prepared at the Transportation Systems Center, Cambridge, Massachusetts, and was sponsored by the National Highway Traffic Safety Administration under Project Plan Agreement No. HS-412 entitled "Instrumentation Methodology for Automobile Crash Testing." This work is directed towards the development of a standardized instrumentation methodology for the purpose of defining and obtaining maximum useful structural data from automobile crash testing.

Program direction was administered by the sponsor Program Manager, Mr. Glen Brammeier of the Reasearch Institute's Office of Vehicle Structures Research. The TSC Task Manager was Dr. Herbert Weinstock of the Office of Engineering.

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1.0 INTRODUCTION

1.1 BACKGROUND

The evolvement of full scale production vehicle crash testing methodologies among various test organizations, and the wide spectrum of test objectives pursued, has resulted in non-uniform instrumentation methodologies and data acquisition practices. Although structural data acquisition filtering practices are somewhat standardized, there is evidence which suggests that the data acquisition bandwidth is too high, resulting in major difficulties in comparing and interpreting test data. As a result of these differences, there is no clear definition of required data acquisition practices necessary for structural evaluation of the vehicle based on an established relationship between the acquired data and affording protection to occupants. Difficulties exist, therefore, in data comparison and interpretation for similar tests conducted by different test organizations.

The trend toward smaller vehicle sizes and the inherent mass disadvantage of these vehicles in collisions with larger vehicles in a non-homogeneous vehicle size traffic mixture has given rise to concern about occupant protection afforded by small cars in such collisions. A related concern is the aggressiveness characteristics of structurally modified vehicles in collisions with unmodified vehicles and the relative protection afforded to the occupants of each vehicle for this situation. To consider these problems, it is necessary to incorporate appropriate measurements into a standardized instrumentation methodology to quantify these problems by providing a data base on occupant protection and structural parameters for the range of vehicles tested. This baseline data will aid in proposing and evaluating future vehicle structural modifications for optimizing occupant protection, over the entire vehicle configuration traffic mixture.

Simulation model development for prediction of occupant and vehicle dynamic response represents a major evaluation tool for future use by the NHTSA. The development of these models, of course, will require verification by crash test data. In order to attain maximum usefulness of available crach test data, it is necessary that simulation models predict, as a minimum, those parameters which are defined as basic to occupant protection and structural performance evaluation. Also, in the interest of model development, it is necessary to review model development needs to determine if crash test data would facilitate model development.

1.2 OBJECTIVES

The objectives of this program are to:

a. Review current instrumentation methodologies and data acquisition practices and identify differences which are responsible for difficulties in data comparison and interpretation,

b. Make recommendations for standardizing practices as these needs are defined,

c. Specify standardized data acquisition parameters suitable for characterizing vehicle structural performance considering existing and projected vehicle size-configuration traffic mixture, and,

d. Evaluate the usefulness of crash test data in simulation model development, and define minimum requirements for model prediction capability, to be compatible with and for full utilization of standardized crash test data.

1.3 SUMMARY OF PRINCIPAL FINDINGS AND RECOMMENDATIONS

a. Principal differences in current methodologies, responsible for difficulties in comparing and interpreting data from different test organizations, are identified as:

(1) Non-uniform transducer location practices,

(2) Non-uniform filtering practices (i.e., variances are allowed by SAE filtering guidelines of J211a),

(3) Structural data acquisition frequency content (per J211a) is too high, and

(4) Non-uniform data plot scaling and formatting.

b. Recommendations are made to standardize the above described practices, and an analysis required to specify suitable filter characteristics for structural data acquisition is described. Examples illustrating the importance of low frequency data content and the effects of variances in filtering characteristics are presented.

c. A method to analytically describe test results by means of fitting a polynomial curve to experimental data is proposed, and is currently under development at TSC.

d. Recommendations are made for standardized structural data acquisition parameters which include consideration of vehicle aggressiveness and compatibility measurements.

e. The role of crash test data for use in advanced simulation model development is discussed. The status of current model formulations is such that specific data acquisition cannot be specified at this time, although the general nature of useful data is known. The recommendation is made that requirements for specific physical test data for use in advanced model development should await the formulation of such models. Specifying data acquisition parameters at this time would require anticipation of the specific needs of advanced formulations.

1.4 REPORT CONTENT

In Section 2.0, the dynamic characteristics of the crash ride-down deceleration pulse are discussed, and parameters necessary to characterize structural performance in terms of occupant loading during ride-down, vehicle compatibility and aggressiveness characteristics are defined. Structural energy dissipation and dynamic stiffness measurements are defined, and recommendations are made for standardized structural data acquisition practices.

The second consideration in developing standardized data acquisition practices was to review instrumentation methodologies and data acquisition practices existing at major crash testing organizations, to the extent possible with available information. This was done for the purpose of identifying differences in practices which are responsible for difficulties in comparing and evaluating crash test data, and identifying common data acquisition practices suitable for standardization. Information pertaining to current practices is contained in the appendix.

In Section 3.0, the nature and sophistication of simulation models, their development needs, and typical input/output parameters are reviewed and discussed. This information, together with a review of existing and recommended practices for structural data acquisition parameters, has been used to evaluate the role of crash test data in the development and verification of simulation models.

2. REVIEW OF CURRENT AND FUTURE REQUIREMENTS FOR CRASH TESTING DATA ACQUISITION PRACTICES

2.1 PRINCIPAL CHARACTERISTICS OF AUTOMOBILE CRASH DYNAMICS AS RELATED TO OCCUPANT SURVIVABILITY

In an impact event, the occupants must be decelerated to a stop within the available deceleration distance (basically the sum of structural crush deformation and interior clearance space between occupants and interior structure), while maintaining occupant restraint forces and accelerations below acceptable levels. These conditions, together with maintaining the occupant compartment perimeter, are necessary to prevent injuries resulting from gross collisions between the occupant and vehicle perimeter, and from imposing excessive restraint forces on the occupant.

Basic parameters which characterize the impact event are: vehicle crush deformation characteristics; forces and accelerations experienced by occupants and the manner in which they are applied (i.e., magnitude and onset rate associated with crash pulse); the duration of the crash event; and occupant compartment intrusion measurements. The crash ride-down pulse shape (best represented by acceleration measurements at the occupant locations) dominates the crash dynamics. For example, for a given velocity change and impact duration (i.e., a given deceleration distance) the maximum loads and/or acceleration, as well as the onset rate of these parameters, applied to the occupants can vary by significant factors depending on the pulse shape. The most efficient pulse shape in terms of minimizing acceleration levels for a given duration and deceleration distance is the rectangular shaped pulse.[1] The acceleration onset rate for this pulse shape however is very high (theoretically infinite) indicating that abrupt restraint system load changes would be experienced by the occupant and that a more gradual application of loads associated with a longer rise time is desirable. The acceleration-time history of the structure at each occupant location is an important parameter, in tailoring restraint systems to the crash dynamics.

The limiting factor in the crash ride-down situation is the quantity of available crush distance. This is particularly important in collisions between vehicles having significant mass differences (i.e., the compatibility problem), where the smaller vehicle has less crush deformation capability and must undergo a more severe velocity change. Utilization of available crush distance is therefore a primary structural evaluation parameter. The vehicle structure must absorb the vehicle's kinetic energy in the process of deformation, while maintaining occupant loading and rate of loading at safe levels. A convenient form for visualizing how the structure's crush capability is utilized is to plot load and acceleration data vs crush distance. In this format, over or under-utilization of crush capability, and determination of occupant loading and acceleration levels, can be determined.

Characterization of the structural dynamic stiffness and the structure's energy absorption capability are therefore primary structural evaluation parameters. These parameters may be evaluated in instrumented barrier tests, where the deformation is restricted to the structure between the point of impact and the occupant locations.

The parameters discussed above are basic indicators or figures of merit which provide valuable structural performance data, useful for estimating probable occupant survivability based on structural characteristics of the vehicle. These characteristic measurements should be made in the testing of all vehicle structure types for all test modes and impact speeds, until a complete matrix of structural performance characteristics for all structural configurations is generated. This matrix of data may provide a major information source for a vehicle crashworthiness rating system, but as a minimum, will begin to collect standardized structural performance data for each vehicle structural configuration subjected to impact tests.

Recommendations for specific data acquisition parameters are discussed in Section 2.4.

The motion characteristics of the occupant compartment (and specifically at each occupant location) obtained by integrating accelerometer data are of prime importance in evaluating the structural characteristics of the vehicle as discussed above. Because of the general usefulness of this data, it is also potentially valuable as a basic comparison parameter between full scale crash tests of vehicle of different structural configurations and between full scale crash tests and simulation model predictions. It is also expected that the occupant compartment acceleration pulse shape will be particularly useful in the development of crashworthiness rating indices which are currently under development for production automobiles, as part of Title II of Public Law 92-513, Automobile Consumer Information Study.

Using current filtering practices, however, high frequency oscillations and/or short duration, moderate amplitude spikes, appear in the data. These "perturbations" appear randomly in the data and have a gross effect on the acceleration magnitude at any instant in time. Comparison and interpretation of the data between similar impact tests is, therefore, made very difficult, especially when emphasis is placed on the maximum acceleration levels developed. The meaningfulness of these "perturbations" as related to possible injurious effects on occupants must be quantified, if this potentially valuable source of evaluation data is to be effectively utilized as a basic evaluation parameter.

While these events have some importance in characterizing the collapse mode of the vehicle, it is important to consider the effect of these "perturbations" on the occupants. The acceleration magnitudes of these short duration pulses and/or high frequency oscillations are often of the same order of magnitude as the average deceleration value associated with the overall pulse. The changes in displacement associated with such motions however are very small, especially when compared with the total crush distance. In addition, the occupants are basically decoupled with the vehicle for most of the crash duration (until restraint forces take effect), and are unaffected by small displacement changes during the overall crash ride-down distance. If these spurious motions can be shown to be relatively harmless, they should be removed using appropriate filtering characteristics. More generally, it is necessary to define the (occupant compartment) acceleration data bandwidth, necessary to characterize the impact event, based on an understanding of the frequency content of acquired data. Information of this nature was solicited from all test organizations contacted. While the need for such information was acknowledged, none of the organizations contacted have initiated such an investigation. Typical problems in interpreting the data are addressed in Section 2.2.

2.2 PROBLEMS IN INTERPRETING ACCELEROMETER DATA BASED ON EXISTING PRACTICES

A primary concern in acceleration data acquisition is to eliminate high frequency, high acceleration amplitude mechanical resonances associated with localized vehicle structural resonances or in accelerometer package mounting. These resonances may mask the acceleration characteristics of the crash test and create an undesirable acceleration signal/localized structural acceleration, noise ratio which might influence the required range, the selected transducer, the scaling of recording instrumentation such that the resolution of the desired data is reduced and most importantly, the overall vehicle crash ride-down characteristics, may be obscured. The question becomes one of analyzing the data to distinguish between mechanical noise sources and the general acceleration characteristics of the crash event. Filtering characteristics which have an important effect on the data are intimately related to this question and must be specified such that maximum information is obtained based on an understanding of the frequency content of the crash event.

An acceleration signal of significant magnitude having a frequency content greater than the filter cutoff frequency, often appears within the acceleration time history, the higher frequency signals normally being suspect as mechanical noise. The most common cutoff frequency used in vehicle structural acceleration data filtering is 60 Hz as specified in SAE recommendation J211a (Ref. 2), although 50 Hz is also a common approximation to the "class 60" filter.

The SAE recommended filtering classes have evolved from experience in testing and are primarily based on judgement. While the objective of providing a recommended practice to standardize filtering practices has been accomplished to a large degree, a side effect of issuing the standard seems to have been to dampen research efforts aimed at better understanding of the frequency content of the crash event. This is not to say the filtering classes set forth in J211 are inadequate, but rather that they have not been validated by analysis of crash test data. It is significant in reviewing the literature that a void exists in the areas of definition of mechanical signal vs. noise content and comparison of inter-laboratory crash test data.

The following examples are intended to illustrate the problem:

Example 1: Figure 1 is a plot of the (Martin-Graham) digital filter transfer function, used by Calspan, to approximate an SAE J211 Class 60 Filter.[3] The rolloff characteristics are very good above 150 Hz, however, below 150 Hz, the filter provides little signal attenuation. This effect can be seen in the filtered data presented in Figure 2 which shows a typical piece of passenger compartment accelerometer data, filtered using a range of cutoff frequencies. As can be seen in Figure 2c, a strong signal of approximately 125 Hz appears in the data filtered at 50 Hz. Examination of the filter characteristics for the "50 Hz filter" shows an attenuation of approximately 2 db (20%) at 125 Hz. Clearly, if the role of this filter is to eliminate signal content above 50 Hz, the characteristics of the filter chosen by Calspan (and in turn, specified by J211a) are very poor. The filter described in Figure 1 would be more appropriate for use as, for example, a 150 Hz (3 db down point) filter.

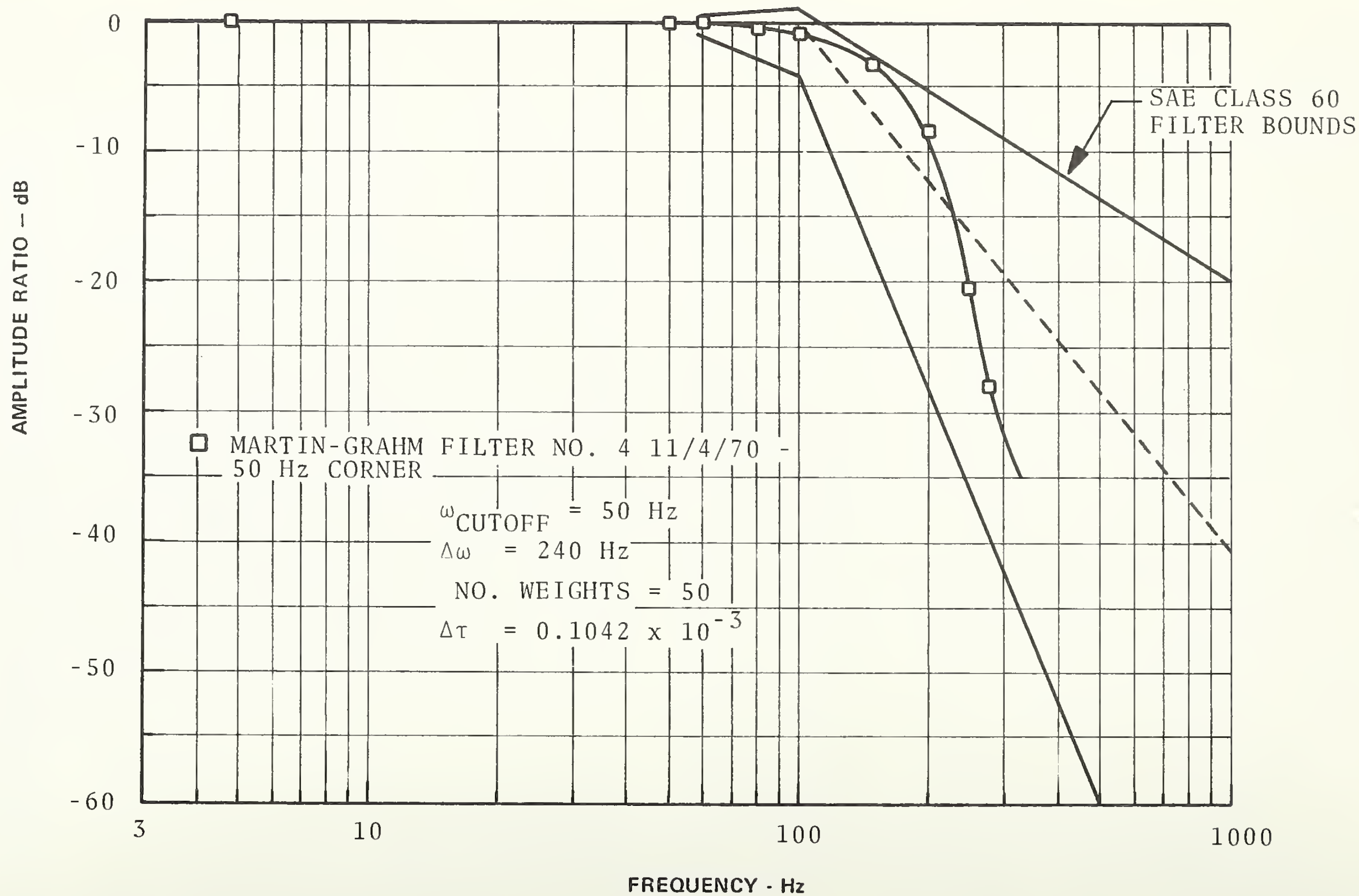

Figure 1. Plot of SAE Class 60 Filter Envelope and Calspan Digital Filter Frequency Response

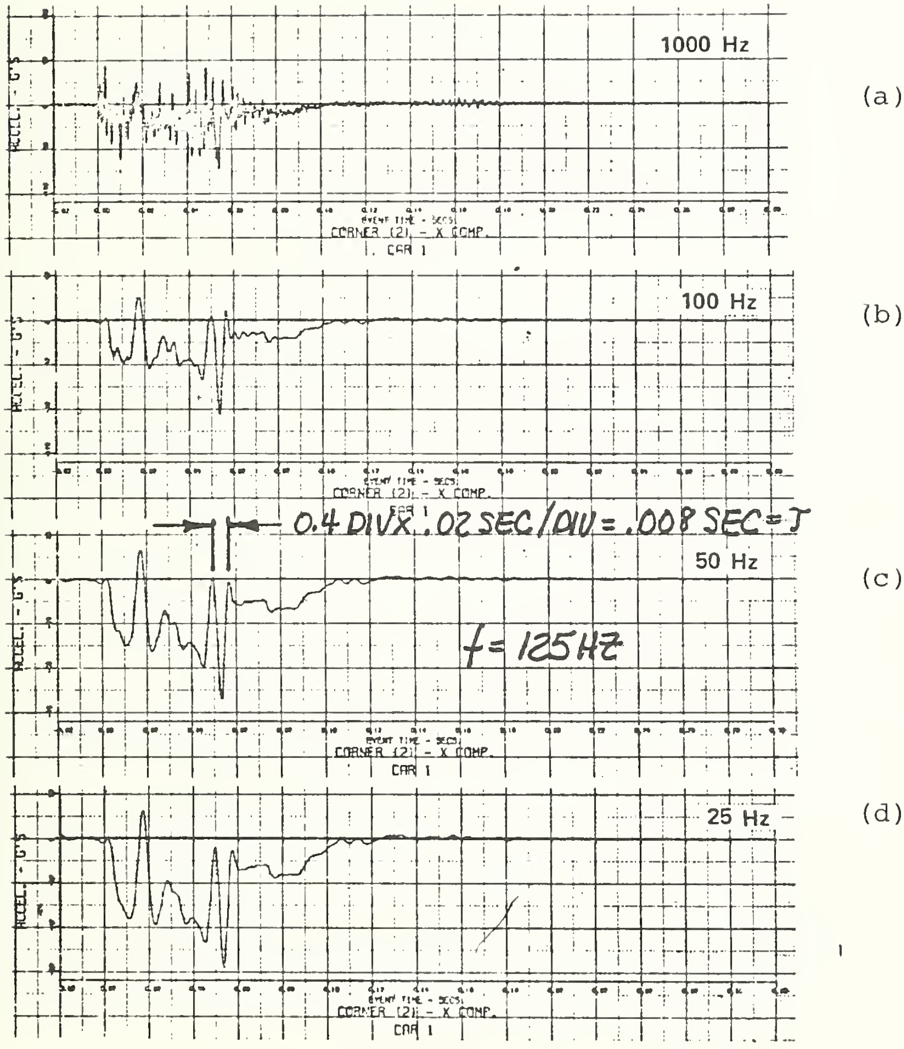

Figure 2. Filtered Occupant Compartment Acceleration Data

The above example illustrates a characteristic approach to filtering among contractors; that is, filtering efficiency is compromised in order that the filter conform to the specified street width of SAE Recommended Practice, J211a. The net result of this practice is that "unusually" high frequency signal content commonly appears in the data. This example may also serve to illustrate the importance of understanding the dynamic characteristics of the crash event, specifically, noise vs. signal frequency content, before selecting or tailoring the filter bandpass characteristics.

Example 2: Figure 3a shows an example of filtered passenger compartment acceleration data (Ref. 3), which for the purpose of cursory analysis, has been separated into a basic low frequency component approximated by straight line segments (Figure 3b) and a residual high frequency oscillatory component (Figure 3c). The latter component, although not discrete in frequency has the character of a damped quasi-sinusoidal response. The first few cycles of this signal are highest in magnitude and most nearly sinusoidal. To interpret the importance of each component, the following calculations are made for each component:

a. Displacement associated with low frequency component (Figure 3b) s = 5.8 ft; (ΔV = 81 ft/sec or 55 mph)

b. Sinusoidally decaying displacement corresponding to the acceleration amplitude of 65 g's (p-p) at a frequency of 71 Hz as shown in Figure 3c, s = .125 in (p-p), maximum, i.e., an oscillatory motion of about $\pm 1/16$ in. Maximum velocity occurs between $0 \leq \tau \leq .02$ sec, and is approximately 2 ft/sec.

The value of the damping ratio for the residual sinusoidal component is calculated from the approximated envelope (dashed lines) of Figure 3c, and the following equation relating amplitude ratios of any two displacement peaks separated by n complete cycles of free vibration:

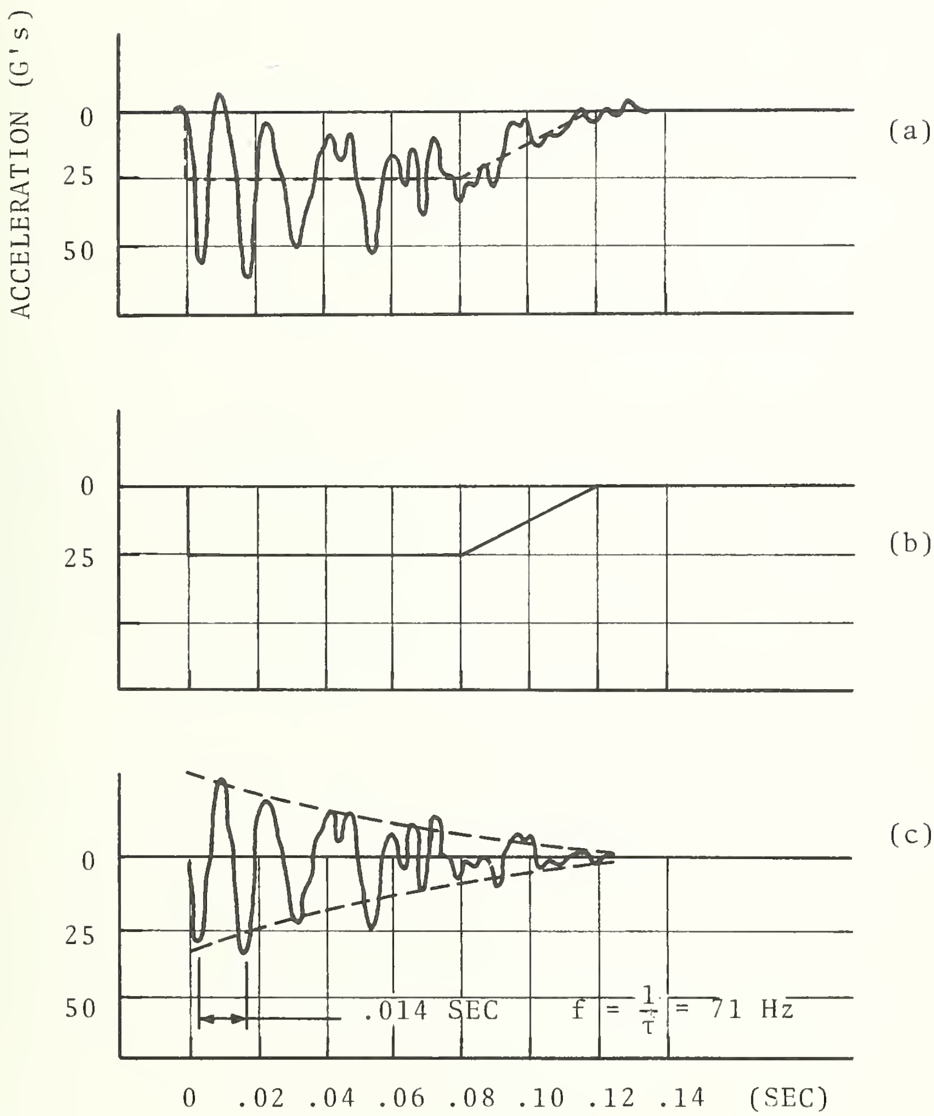

Figure 3. Displacement Analysis of Occupant Compartment Acceleration Data

$$\frac{X(n_o + n)}{X(n_o)} = e\left[\frac{-2\pi n\xi}{\sqrt{1 - \xi^2}}\right]$$

where

$X(n_o)$ = initial amplitude

$X(n_o + n)$ = amplitude n cycles later

ξ = damping ratio, c/C_c

The amplitude at t_0 is approximately 32 g's

The amplitude 8 cycles later, i.e., t = 8 (.014 sec) = .112 sec, is approximately 3.2 g's

The corresponding damping ratio is found to be: $\xi = .045$

This example serves to illustrate the relative importance of the two frequency components. Although it does not specify a desireable cutoff frequency, it does, however, show the need for weighting low frequency data content, since displacement information, critical to the crash ride-down characteristics, is contained largely in the low frequency content of the crash dynamics.

A second way of overviewing the filtering question is to consider the effects of higher frequency content on occupant loading. The dynamics of the typical frontal crash event, where the restraint system consists of standard lap and shoulder belts or an air bag system, in an unmodified production vehicle, is such that the structure will have nearly completed its deformation (deceleration) before the occupant begins his deceleration.

Essentially, this means that the occupant must be decelerated in the distance corresponding to the available space between the occupant and instrument panel which is nearly at zero velocity when the occupant begins deceleration (that is to say, very little of the crush deformation which the vehicle has undergone is actually used to decelerate the occupant). Since the occupant is not directly coupled to the vehicle structure during the greater part of its deformation history, high frequency loads are not transmitted to the occupant and it can be argued that for this reason, high frequency, low displacement amplitude motions of the occupant compartment are not of interest and only serve to confuse the interpretation of the data.

It is logical to expect however, that future developments in restraint systems will lead to systems which will sense an impact event, and activate a belt system which will automatically tighten and remove belt slack, having the effect of beginning occupant deceleration earlier in the crash event and increasing the effective occupant deceleration distance by utilizing a significant part of the vehicle crush deformation as well as occupant compartment clearance. In this situation the restraint system would most probably be integrated into the seat and since seat cushions are characterized by resonant frequencies below 5 Hz, the occupant would again be isolated from high frequency, low amplitude motions.

The natural isolation of the occupant, either by characteristics of the crash event or restraint system/seat characteristics (not withstanding occupant impact with interior parts of the vehicle), coupled with the importance of the large displacement amplitude content associated with passenger compartment accelerometer data as discussed above, weights the importance of the lower frequency content of the data.

The problem remains however, one of identifying various events in acceleration time history data with corresponding physical events in the structure. Based on the above discussion, the intent of acceleration measurements is to measure acceleration magnitudes corresponding to the gross plastic deformation of the structure and to extract displacement data by integrations. High frequency, low displacement amplitude motions associated with elastic behavior of the structure in the area of the accelerometer package mounting (which could be excited simply by the presence of the accelerometer package) are undesirable, and should be considered mechanical noise.

In examining several pieces of typical acceleration time data, for a symmetrical frontal impact condition with respect to the vehicle longitudinal axis where data is available from the four corners of the occupant compartment (Calspan data) the acceleration time history data on either side of the vehicle, at a particular station, exhibit very similar overall pulse shape characteristics; peak accelerations occuring at the same instant in time, but with varying magnitudes. It would appear from examining the data that the difference is due to a moderate amplitude, high frequency vibration content, superimposed with a phase difference on a basic lower frequency content signal.

Resonances in the area of the accelerometer package mounting location would easily explain this behavior. Differences in structural stiffnesses of the vehicle (from side-to-side), and the random manner in which the resonant motions of the structure are excited, would account for these observed phase differences. This in turn, would account for differences in peak magnitudes observed from accelerometers located at points on the vehicle structure which are symmetrical with respect to the crash mode (e.g., the four corner locations as discussed above).

A good practice is to monitor acceleration at each of the four occupant locations as practiced by Calspan and General Motors, thereby obtaining two sets of symmetrical data at the two most important stations of the structure. Another benefit of this technique is that four pieces of data are available for analysis, provided that the data is not averaged prior to recording. In frontal impacts where the passenger compartment is not grossly deformed, similar pulse shapes and peak acceleration magnitudes should be expected from side-to-side, for data gathered at similar stations provided the high frequency content discussed above, is eliminated by proper filtering.

In an effort to relate occupant compartment accelerometer data frequency content with physical events such as resonances and structural contacts, appropriate test data is being obtained for analysis. This data will be primarily acceleration time history data, preferably from the four occupant locations.

Corresponding event sequence tables and determination of accelerometer package/mounting location resonant frequency data (to the extent permitted by the condition of the crashed vehicle) have also been requested.

This data will ideally be obtained for a symmetrical frontal impact test of an unmodified production vehicle, impacting a barrier at a test speed of approximately 30 mph. This will typically limit large plastic deformations to the vehicle structure between the point of impact and the front occupant accelerometer locations, and maintain the integrity of the occupant compartment. For this situation, plastic deformations will occur primarily in the front structure, and primarily elastic motions will occur in the occupant locations. The data will be analyized using spectrum analysis techniques, to determine if local structural resonances exist within the filtering bandwidth and are responsible for large undesirable accelerations which degrade the overall acceleration measurement.

The test configuration selected has been chosen to facilitate the analysis, and to allow some direct interpretations to be made. The dynamic response information which will result, however, is characteristic of the structure and conclusions based on the results will apply equally to more severe test configurations such as higher speeds and different impact modes.

The data obtained from contractors will be transformed into the frequency domain using a spectrum analyzer, and the acceleration spectral density function will then be examined to determine if high amplitude acceleration inputs at discrete frequencies, exist. This information will be compared with accelerometer package/structural mounting, resonance data which will be obtained from the structural locations from which the accelerometer data was acquired. Peaks in the spectral content which correspond to observed natural modes of the accelerometer package and its mounting would be a definite indication that a source of mechanical noise has been identified, and would allow meaningful criterion (at least in part) for specifying the necessary filtering characteristics to eliminate such resonances from the data.

The accelerometer data will also be used to quantify the effects of ensemble averaging of signals from locations where similar inputs exist by spectrum analysis of the averaged signal. Spectrum analysis of integrated velocity and displacement frequency contents will be examined to establish the vehicle crush magnitude frequency distribution. This information might also provide a useful basis for establishing a filtering criterion.

2.3 RECOMMENDATIONS FOR STANDARDIZING DATA ACQUISITION PRACTICES

A review of the literature and correspondance with various test organizations indicated that a wide variety of test programs have been undertaken and are in progress, for a wide variety of objectives in automobile crash testing. Initial efforts in development of a standardized instrumentation methodology attempted to segregate various related research activities into categories and define separate methodologies for each. The difficulties with this approach are discussed in the appendix, however the categories identified and the cumulative list of data acquisition parameters obtained by various test organizations are of interest.

Table I lists the broad objective categories of automobile crash testing and the various research activities pursued to accomplish each objective. For each research activity defined the corresponding data acquisition parameters commonly acquired by the various test organizations were defined. These are listed in Table II along with the general usefulness of the data as related to evaluating the test objective. Table III is an abbreviated listing of principal test modes utilized in crash testing and is included here as a basic consideration in the development of instrumentation methodology development.

TABLE I OBJECTIVES IN AUTOMOBILE CRASH TESTING

I Reduce Probable Injury to Occupants, Using Anthropomorphic Dummies to Approximate Human Injury -

This objective is accomplished by:

(a) Vehicle structural development - to define passenger compartment intrusion and develop interior and exterior designs to reduce injury to occupants by controlling or limiting structural collapse. Work is being performed on front and side structure development of compacts and sub-compacts to define levels of compatibility in frontal and side crashes with full size and luxury size cars. Tests are then performed to define relative probable injury levels associated with combinations of larger, structurally modified or unmodified vehicles striking smaller modified or unmodified vehicles. These tests are referred to as aggressiveness tests.

(b) Restraint system development - define injury to occupants by evaluating occupant motions and forces on the occupant during collision.

(c) Development of improved dummy occupants - obtain data to improve human dynamic simulation capabilities and evaluate human tolerance to the impact environment.

(d) Development of improved dummy occupant injury criteria - obtain data to provide improved information on human vulnerability to impact and other bodily damages.

II Development of Improved Vehicle Safety Systems

Objective is accomplished by design, development and testing of new developments in automotive safety, incorporated in a complete functional vehicle (ESV) which is designed, fabricated and tested as a total system.

III Development of a Crashworthiness Rating System for Production Vehicles

Objective is accomplished by:

(a) Full scale production vehicle crash test (past and future) data.

TABLE I OBJECTIVES IN AUTOMOBILE CRASH TESTING - CONTINUED

(b) Development of a crashworthiness rating system.

IV Predicting Occupant Injury and Vehicle Structural Performance thru Extrapolation of Experimental/Analytical Results, to Modified Collision Configurations.

Objective is accomplished by:

(a) Extracting appropriate test data from full scale (and/or component) vehicle crash testing for use as input to, or verification of, the analytical models. Development of cursory vehicle and occupant analytical models with the aid of experimental crush data to estimate the overall effects of various test parameters in the crash event.

(b) Development of detailed vehicle and occupant response models to simulate in detail, the crash dynamics, and provide a wide range of predictive capability without the necessity of experimental crush data.

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
I-a	1. Acceleration measurements of occupant compartment (four corners), frame, various structural components such as torquebox, firewall, rear deck, engine (1, 2, or 3 axes)	Obtain acceleration/time history and maximum acceleration levels of various points on structure and integration to obtain velocities and displacements. Accelerometer data is often examined to determine duration, average value, rise time and maximum value data. Also used for constructing deceleration vs displacement plots. Integrated accelerometer data is often cross-checked with filmed data.
	2. Filmed data of side, overhead and underside views	To observe collapse mechanisms of key structural components and collapse sequence. Used to construct event sequencing tables for analysis. Also, extract velocity and displacement/time histories, cross-check with integrated accelerometer velocities and displacements.
	3. Component and/or complete vehicle crush testing	Extract load deflection and collapse mode data. Used as design aid in developing and evaluating structural modifications prior to crash testing, and static resistances are determined for use in lumped mass simulation models.
	4. Basic crash test conditions such as: impact velocity, angle of impact, point of impact, gross vehicle weight, test mode, and vehicle modification (if applicable)	Define test condition, test mode and severity of test. Describe vehicle modifications if any

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
I-a (Cont'd)	5. Post-test measurements of crush and rebound distances, intrusion into occupant compartment, fuel loss, door functionability	- Crush distance and occupant compartment intrusion are basic measures of the effectiveness of the structure to protect occupant - Rebound distance is relatable to elastic energy stored by the structure at the maximum crush deformation. Also used as a data cross-check with filmed data and integrated accelerometer displacements. - Fuel loss has implications on fuel tank design and mounting, related to fire hazard. - Door functionability is a measure of post test egress capability of structure
	6. Pre-test gross analytical modeling of structure	Simplified lumped spring mass simulation models are used (together with resistance data from component crush testing) as a further design aid to development of structural modifications
	7. Barrier Load Cell Data and Barrier Acceleration	Used to assess aggressiveness characteristics of structure. Acceleration measurement is necessary to assess barrier inertia effects
	8. Strain gage measurements	Used to determine loads developed in specific structural members, usually during crush testing. Data is used in assessing failure modes and in developing structural modications. This is a specialized measurement in the sense that it cannot be identified with a specific structural element

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
I-a (Cont'd)	9. Dynamic displacement measurements such as steering column displacement, or dummy displacement	Obtained by using linear string potentiometers between a point on the vehicle which is not expected to undergo deformation, and a member (usually associated with occupant compartment perimeter or the dummy) which will deform or displace. This is a specialized measurement in the sense that it cannot be identified with specific points on the vehicle (except for steering column and dummy displacements).
I-b	1. Lap and shoulder belt loads (each side of the belt system)	Used to determine magnitude and rate of onset of forces to the occupant for comparison with estimated injurious levels
	2. Filmed data of dummy occupants.	Used to record dynamic motions of dummies such as displacements and velocity (linear and rotational) time histories, impacting velocity and definition of impact surfaces. Photographic data is correlated with integrated dummy acceleration data.
	3. IORS deployment time.	Monitor initiation of bag inflation - measure of sensor reaction time.
	4. IORS pressure/time history.	Assess system performance, monitor effects of and time of head impact.
	5. Passenger compartment noise and pressure levels.	Compare data with estimated or known ear damage thresholds.

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
I-c	1. Head acceleration (translational) using triaxial accelerometer package.	Integrate to obtain velocity and displacement data, cross-check with filmed data of dummies. Calculate (resultant) injury indices: (a) Head Severity Index (b) Head Injury Criteria Compare with present estimated tolerance levels. Analyze acceleration time history to obtain: pulse shape, rate of acceleration onset, pulse duration, and peak magnitude
	2. Chest acceleration.	Integrate accelerometer data to obtain velocity and displacement data, cross-check with filmed data. Analyze acceleration time history to obtain pulse shape, rate of onset, duration and peak magnitude. Compare chest loading and deflection to estimated or known tolerance levels
	3. Pelvis acceleration.	Information may be useful in development of restraint systems
	4. Femur load measurement (each leg).	Compare with present estimates of upper-leg damage thresholds
	5. Head Laceration Index using Laceration Severity Index procedure.	Used to ascertain potential head laceration damage

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
(See Table I) I-c (Cont'd)	6. Head Injury Criteria, Severity Indices, Head & Chest Accelerations, peak, mean, range and standard deviations of these parameters. Tests involve various restraint configurations and test modes.	Used in statistical evaluation of dummy systems to establish dummy repeatability and reliability standards of performance
	7. Results of dummy occupant analytic model, parametric studies, and limited human expose to impact test, data.	Used as design aid in development of dummy human dynamic response, simulation characteristics
II	1. Structural Data - Basically as listed in I-a, Items 1, 2, 4, 5, 7, and 9.	Refer to corresponding descriptions, I-a
	2. Restraint System Data - Same as I-b, Items 3, 4, and 5	Refer to corresponding descriptions, I-b
	3. Dummy Data - Same as I-c, Items 1 through 5.	Refer to corresponding descriptions, I-c
	In addition to the above,	
	4. Rebound Velocity.	Calculated from initial velocity, barrier force and vehicle mass measurements. Cross-checked with integrated accelerometer data and photographic data
	5. Force vs Distance Response.	Barrier force cross-plotted with integrated accelerometer data. Provide vehicle dynamic stiffness characteristics

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
II (Cont'd)	6. Vehicle rebound resistance.	Used to approximate the amount of post impact kinetic energy expended during rebound by measuring friction or drag forces acting through the rebound distance
	7. Vehicle rebound acceleration.	Used to assess post impact vehicle motions. This is separated from pass. compartment accelerations etc., because the range of the accelerometer is chosen such that it best measures lower acceleration magnitude associated with rebound
	8. IORS mounting force and motions.	Provide additional information on the performance characteristics of the IORS as pertaining to mounting adequacy. Changes in mounting geometry prior to or during inflation may degrade airbag performance
	9. Rebound velocity.	Determine total vehicle velocity change. Cross-check with accelerometer data
	10, Vehicle attitude during impact.	Integrated accelerometer data at known locations and analysis of photographic data used to calculate pitch yaw and roll vehicle angular displacements
	11. Angular accelerations, velocities and displacements of dummy head.	Differential analysis and subsequent integrations of accelerometer data

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
III-a	1. Structural data - basically the structural data contained in Category I-a, Items 1 through 5.	Refer to corresponding descriptions in I-a
	2. Restraint System Data - Same as listed in I-b, Items 1 through 5.	Refer to corresponding descriptions in I-b
	3. Dummy Data - Same as listed in I-c, Items 1 through 6.	Refer to corresponding descriptions in I-c
III-b	1. Algorithm for Rating System (suitable for rating a model within its own model class and within the entire passenger car population), considering most common crash test modes and the corresponding injury potentials, no. of tests to establish a statistical significance and use of best known injury indices.	To permit determination of a crash survivability rating system to evaluate the relative effectiveness of various passenger car products in protecting its occupants
IV-a	Basic structural data acquisition consists of structural resistance (stiffness) characteristics associated with discrete or multiple vehicle components from a crush test representative of vehicle deformation mode, principal lumped mass characterization of the vehicle and determination of dynamic structural resistance correction factor. Predicted outputs which are compared with crash test data are primarily accelerations, displacements associated with lumped masses, and energy absorption associated with structural resistances.	Currently useable analytical models are primarily of the hybrid type. These require static structural crush test data as input to a lumped mass vehicle representation. Extrapolation capability is limited to interpolated response predictions at different speeds and to a limited extent, for vehicle modifications. It is not possible to extrapolate to modified vehicle crash modes. Advanced formulation models are required to achieve this capability

TABLE II - COMMON DATA ACQUISITION PARAMETERS AND CORRESPONDING DATA REDUCTION AND/OR USEFULNESS OF DATA REQUIRED TO MEET CRASH TESTING OBJECTIVES - CONTINUED

Objective (See Table I)	Common Data Acquisition Parameters	Corresponding Data Reduction and/or Usefulness
IV-a (Cont'd)	Data acquisition for verification of dummy dynamics consists of acceleration pulse shape, dummy head and chest accelerations and restraint system loads, and contact locations including geometry changes and forces corresponding to dummy/interior impacts. Photographic details of dummy dynamic displacements and contact events are also collected.	Predictive capability includes body segment motion descriptions, restraint system forces, forces developed in dummy/interior interaction, and injury criteria calculations
IV-b	Required crash test data to develop advanced simulation models is currently undefined, and awaits the formulation of such a model. The character of data required will be load transmission data, forces, movements and corresponding stresses, and deformations associated with structural elements simulated by the model. Predicted outputs of such models should be identical to a standardized battery of data acquisition parameters obtained in full scale crash tests.	Principal problems in the development of advanced simulation models involve modeling problems and not the need for crash test data. Data from such tests will be necessary to guide the development of these models when they are formulated

TABLE III PRINCIPAL TEST MODES UTILIZED IN CRASH TESTING

T1 Frontal Rigid Barrier*

- (a) Perpendicular impacts
- (b) Inclined impacts, up to 30° with barrier

T2 Frontal, Car-to-Car

- (a) Aligned axes
- (b) Offset axes
- (c) Oblique

T3 Frontal Pole Test

T4 Side Impact, Car-to-Car

T5 Side, Pole Impact

T6 Moving Rigid Barrier Tests*

- (a) Side
- (b) Rear

T7 Rear, Car-to-Car

T8 Rollover

T9 Sled Testing

T10 Crush Testing (Mode corresponds to collision mode)

- (a) Structural component testing
- (b) Whole vehicle testing

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*Variable rigidity barrier development is underway and is expected to eventually replace rigid barrier testing as a more representative collision mode.

Preliminary review of data acquisition practices (refer to the appendix for details) indicates that contractors have an adequate expertise in instrumentation and photographic technology although basic differences in methodologies exist which are responsible for difficulties in comparing data. These differences noted exist primarily in structural data acquisition practices. Differences in methodologies exist in the following areas:

(a) Transducer location selection,

(b) Transducer installation techniques,

(c) Disagreement on the number of accelerometers required to measure a signal,

(d) Variations in filtering data (i.e., the street width of SAE J211a is too wide), and

(e) Uncertainty regarding the structural information frequency threshold required (i.e., the optimum filter cutoff frequency).

(f) Scaling and formatting of data plots.

As outlined in the appendix, a consideration of principal characteristics of the methodologies reviewed indicates a number of fairly common practices in use. These include:

- Acquisition and reduction of photometric data - including common camera equipment, film type, film speed, use of targets, and similar field coverages,
- Generally signal conditioning and amplification is done on-board the test vehicle for better signal/noise transmission characteristics,
- Telemetry is most commonly accomplished using an umbilical cable,
- Generally data is not multiplexed unless the number of available storage channels is exceeded, in which case data is stored in multiplexed format,

- Permanent data recording is generally accomplished using 1 inch, IRIG format, 14 channel FM tape recorders,
- Data reduction and plotting is accomplished using analog to digital signal conversion and digital computer processing and plotting,
- Synchronization signals and a signal representing exact time of vehicle contact are typically recorded on all filmed and magnetic tape data for precise time synchronization of all data parameters, and
- Filtering is in accordance with SAE recommended practice, J211a (which allows substantial differences to exist because of a large rolloff street width).

The need exists for common transducer location criteria, and for reporting requirements to assure adequate location description. This is particularly necessary in accelerometer measurements where high acceleration amplitude, high frequency elastic vibrations are likely to occur, especially if the transducer is mounted on a "soft" structural element (i.e., a natural mounting resonance within the filter bandwidth). Questions related to transducer location selection are:

(a) Single vs multiple transducer measurements

(b) Signal averaging vs signal filtering

From a review of the filtering characteristics used by various organizations and the typical frequency content observed in the accelerometer data, there are strong indications that the data is influenced by differences in filtering characteristics and that structural data frequency bandwidth is too wide. This was discussed in Section 2.2. As mentioned previously an attempt will be made during the Fourth Quarter to quantify this statement, however if this cannot be done with retrofit data, serious consideration should be given to an experimental program.

In considering single vs multiple transducer measurements, it has been argued that a single acceleration measurement taken in a relatively remote location (e.g., rear deck in a frontal crash) will provide a better representation of the crash environment than one or several measurements taken within the occupant compartment where the accelerometer package is subject to structural elastic motions and sometimes plastic deformations. While this has not been quantified, one way or the other, this technique seems appealing when structural acceleration data having frequency content in excess of 100 Hz for example, is examined.

An elastic motion of the structure of $\pm$0.1 inches at 100 Hz which could never be thought of as a threat to occupant survivability, would cause an acceleration of $\pm$100 g's to be developed. If it can be shown that these high amplitude acceleration levels are in fact due to structural resonances, this would present a strong case for arguing that occupant compartment accelerations should be filtered at lower frequencies. Similar arguments could be made for other structural data. For example, a filter which is 3 db down at 40 Hz, with a 24 db/oct rolloff rate, for the same resonance motion, would reduce the acceleration "noise" signal by 35 db to $\pm$1.8 g as shown in Figure 4 by the nominal J211 Class 60 filter transfer function and a hypothetical filter with a 40 Hz corner. It is appropriate to re-mention that while the J211 filter is labeled as a 60 Hz filter, it nominally has a 3 db down point of, and will essentially pass all frequencies up to 115 Hz. In some cases, it is possible to program a filter which will conform to SAE specifications which will have a 3 db down point at even higher frequencies (Calspan's Class 60 Hz filter has been shown to be 3 db down at approximately 150 Hz). The effect of this "higher than expected" frequency content is to allow high acceleration amplitude, high frequency signals to confuse the interpretation of the data by allowing these signals to override the importance of the low frequency signal containing high displacement amplitude information which is critical to occupant ridedown. In effect, the spectrum analysis of occupant compartment accelerometer data should be based on a displacement amplitude criterion, to permit assessment and eventually partitioning of

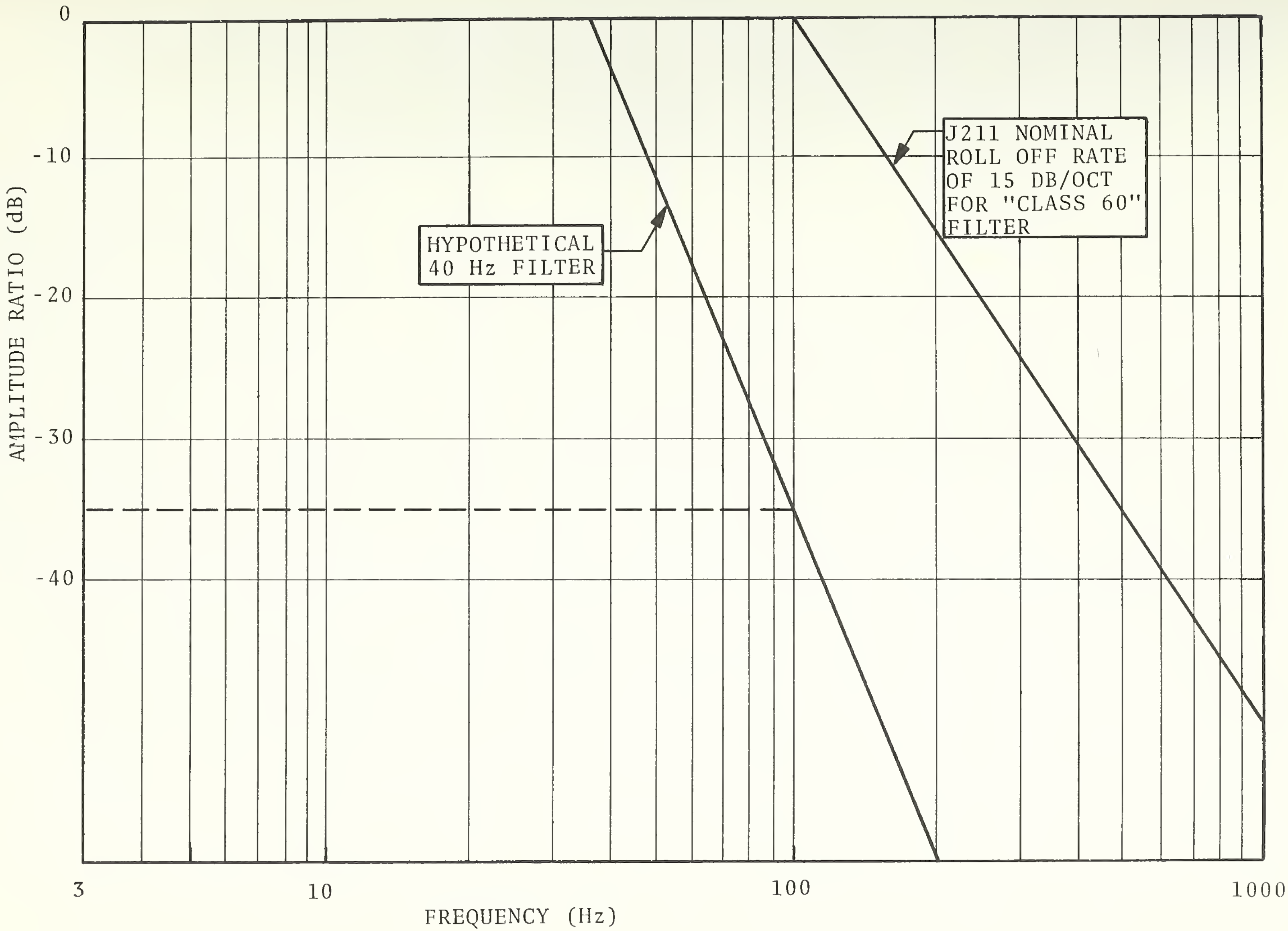

Figure 4. Suggested Filter Characteristics With Reduced Filter Cutoff Frequency

the frequency content of elastic motion due to resonances, vs plastic deformation of the structure. Information of this nature was requested by each test organization contacted, however, while the need for such research was generally accepted, it is appropriate to emphasize that none of the organizations contacted have initiated such an investigation.

The displacement amplitude criteria mentioned above will have to be resolved in the analysis program. If resonances can be shown to influence the data on a regular basis, the frequency band identified and the corresponding acceleration levels of the resonant motions will yield a range of displacement amplitudes which will be judged to be significant for inclusion in the data if its amplitude is greater than some pre-specified level. For an initial criterion, this level will be taken as 0.2 inches peak-to-peak. The acceleration produced by this displacement amplitude as it varies with frequency is shown in Figure 5.

The argument for remote location measurements will become much less attractive if lower structural data acquisition cutoff frequencies are adapted, and results will be more consistent and interpretable if uniform filtering guidelines (i.e., one specific filter frequency response for use in filtering occupant compartment acceleration) are adapted. Since most contractors have a digital data reduction capability and most filtering is done on digitized data because of the zero phase shift advantage, the emphasis should be on digital filtering.

The question of filtering vs averaging is again related to the level of filtering specified. Averaging (in lieu of filtering) will again be less attractive, if lower structural data acquisition cutoff frequencies are implemented. Another factor concerning averaging is that it is only valid when the basic low frequency content associated with plastic deformations does not occur in the transducer location area, or is identical, which is difficult to ascertain. Averaging is effective in eliminating noise sources, if the above condition is met, however, the noise is reduced by a ratio which is inversely proportional to the square root of the number of

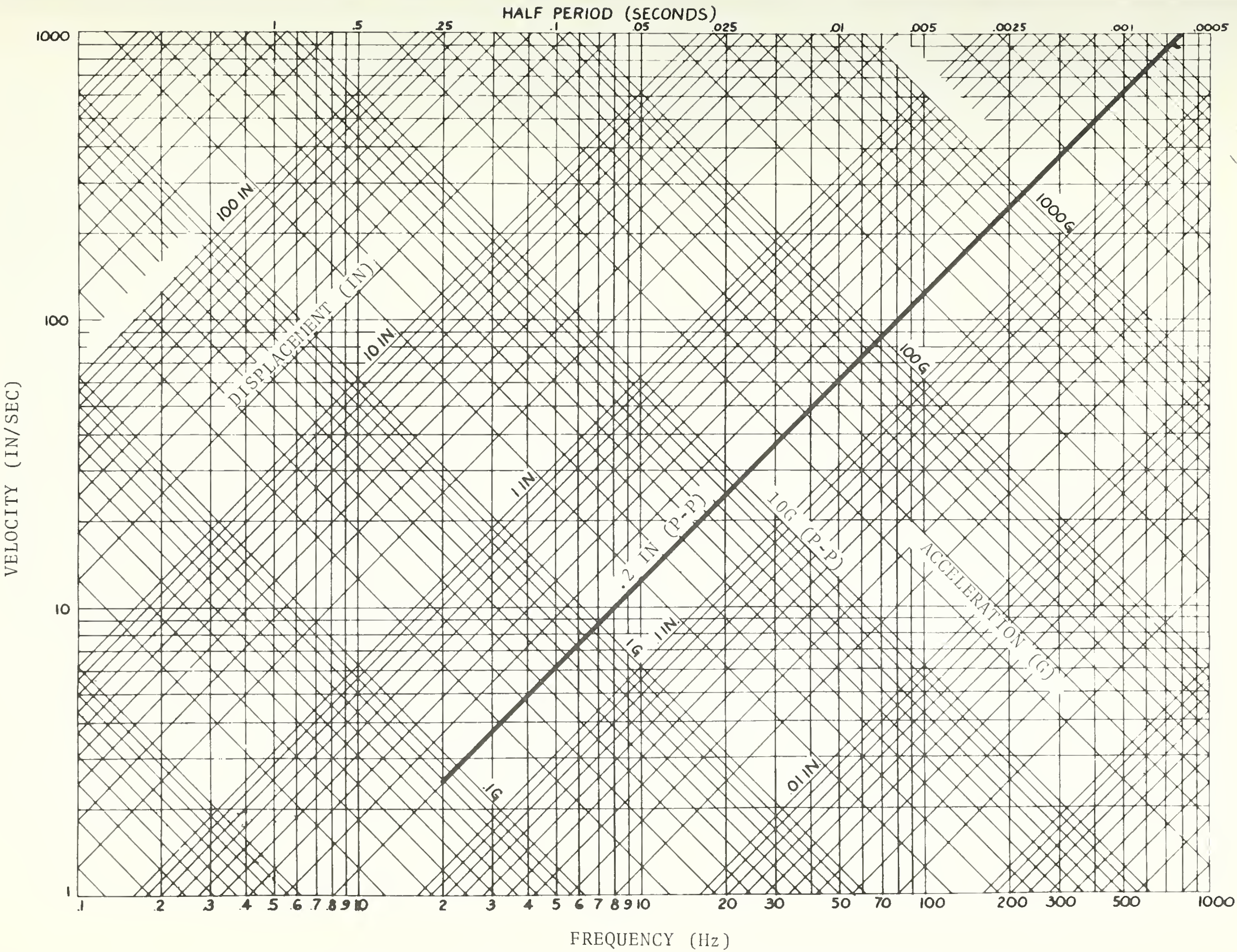

Figure 5. Acceleration Amplitude Versus Frequency of A Small ($\pm$ 0.1 inch) Oscillatory Displacement

signals averaged. It is evident that a prohibitively large number of transducers would be required to provide the same attenuation which is provided by the (hypothetical) 40 Hz filter discussed above.

Multiple acceleration measurements within the occupant compartment, such as the four corner measurements as practiced by Calspan (floor pan location) and General Motors (rocker panel location), are desirable and recommended as standard practice as opposed to single "C.G.", tunnel, or rear deck measurements, as representative of passenger compartment acceleration. It is further recommended that the signals be recorded on separate data channels in raw, unfiltered form, and should not be averaged. This practice will provide:

(a) Acceleration, velocity and displacement descriptions at the principal occupant locations which is critical information necessary to analyze vehicle ride-down characteristics,

(b) Dynamic force-deflection and energy absorption characteristics of the structure (in combination with barrier force data) between point of impact and each occupant location,

(c) Increased data for dynamic analysis (refer to Section 2.2),

(d) Data redundancy for severe impact situations which may cause occupant compartment deformations in the location nearest the vehicle impacting surface.

Standardized data plot scaling and grid size for presenting structural data is another basic need. A review of many structural data plots presented in reports by various contractors has led to a recommended guideline for reproducing data for report presentation. This guideline in combination with standardized filtering practices will provide the capacity for direct comparison of data presented in reports from various contractors, by providing common abscissa and ordinate size and grid spacing as a function of the maximum amplitudes of the parameters being plotted. Refer to Table I. Nominal abscissa and ordinate size and grid recommendations have been specified, so as to provide for improved resolution of the data and for direct overlaying of plots (within equal amplitude bands). Nominal abscissa length has been scaled to be approximately 4 inches and nominal ordinate length, approximately 1.5 inches. Amplitude ranges have been chosen to partition the range of test conditions such that most of the amplitudes will fall into the moderate or mid-level range and should envelope the majority of moderate velocity-moderate vehicle size, structural response parameters.

Labeling of data as currently reproduced in reports is often illegible due to character printing which is too fine, or due to printing of characters on the grid portion of the plot. Plot labeling, accordingly, should be off-grid and of sufficient size to be legible when reproduced in report format.

Analytical Description of Test Results

An analysis is in progress which is looking into the feasibility of fitting the data with a polynomial curve, which will adequately describe the data. The data could then be reported in both graphical form and also represented by the coefficients and the order of the polynomial fit of the data. It would not be difficult to supply each contractor with the computer software to implement the curve fitting and re-construction routine on his own computer. Each contractor would then have the capability to describe his own data by using the polynomial curve fitting routine, and to take the data description (i.e., coefficients and order number) of other contractors and reproduce the data in his own computer system.

This technique has much potential. It could, for example, provide the capability to:

(a) Describe and analyze the deceleration-dynamic displacement characteristics, and in general, increase the quantity of data available on this important vehicle performance indicator,

TABLE IV STRUCTURAL DATA PLOTTING SCALE FACTORS

Abscissa Parameter Time (Min – Max)	Abscissa Scale Factor	Grid Resolution	Grid Spacing	Abscissa Length (Max)
0 - 50 ms	80 in/sec	.0005 sec	.04 in	4 in
50 - 150 ms	40 in/sec	.001 sec	.04 in	6 in
150 - 300 ms	20 in/sec	.002 sec	.04 in	6 in
Displacement				
0 - 20 in	.2 in/in	.2 in	.04 in	4 in
20 - 50 in	.1 in/in	.4 in	.04 in	5 in
50 - 100 in	.05 in/in	.8 in	.04 in	5 in

Ordinate Parameter Acceleration (Min – Max)	Ordinate Scale Factor	Grid Resolution	Grid Spacing	Ordinate Length (Max)
0 - 20 g	.1 in/g	.4 g	.04 in	2 in
20 - 100 g	.02 in/g	2g	.04 in	2 in
100 - 200 g	.01 in/g	4 g	.04 in	2 in
Velocity				
0 - 50 mph	.04 in/mph	1 mph	.04 in	2 in
50 mph - up	.02 in/mph	2 mph	.04 in	2 in
Displacement				
0 - 20 in	.1 in/in	.4 in	.04 in	2 in
20 - 50 in	.04 in/in	1 in	.04 in	2 in
50 - 100 in	.02 in/in	2 in	.04 in	2 in
Force (Barrier)				
0 - 100K lb	.02 in/Klb	2Klb	.04 in	2 in
100K-250K lb	.008 in/Klb	5Klb	.04 in	2 in
250K-800K lb	.0025 in/Klb	16Klb	.04 in	2 in

(b) Greatly facilitate and increase the exchange of test data between test organizations,

(c) Provide a means for quantifying the similarity of the data,

(d) Provide a means for describing test results for comparison with predicted results of analytical models, and

(e) Such analytical curve fitting routines have the potential to act as filters, in the sense that the maximum number of data peaks (which is relatable to frequency) which the fit will reproduce is dependent upon the order of the polynomial fit.

Other recommendations for structural data acquisition are as follows:

(a) The use of a mechanical filter (i.e., an accelerometer package mounted in a C.G. vibration isolation system) should be evaluated in an experimental program, in parallel with standard accelerometer mounting/filtering practices. Such a configuration could, for example, attenuate vibratory motions above some preselected frequency, at the rate of 12 db/octave. The accelerometer mounting system would isolate low displacement motions typically in the order of ± 0.1 inch. For motions greater than ± 0.1 inch, the isolation system stiffness should increase (perhaps by using a snubbing action, or a non-linear load-deflection curve), and the accelerometer would track the larger displacement motions. This approach offers the possibility of eliminating electronic (or digital) filtering altogether. The development of such a mechanical filter would require a moderately low investment. The consequence of the mechanical resonance of the filter would have to be investigated, however, the known relationship between the input/output characteristics of the filter at resonance may be adequate to offset this disadvantage.

(b) Accelerometer packages should have minimum mass and profile. Large mass, due to either support bracketing or addition of protective covers, and high profile packaging, have the effect of inducing inertia forces and generating rocking-mode resonances of the structure.

(c) The use of damping material added to the structure in the area of the transducer mounting location should be considered in an experimental program. Depending on the filtering characteristics which are acceptable (as determined by the test objective) it may be possible to filter out a potential resonance, or to relocate a transducer to an area which has a better frequency response. In general, the use of damping material causes transients to die-out much faster and damping materials therefore have a potentially useful function in crash testing. It is recommended that this technique be evaluated and its usefulness quantified in an experimental program.

(d) Obtaining pre-test structural response characteristics of the occupant compartment accelerometer package mounting to the structure (i.e., structural resonances) would be useful in identifying the corresponding high frequency content in the data and would also provide structural stiffness information which is useful in selecting transducer mounting locations. The recommended method of exciting the structure is by installation of a small inertia force generating device (i.e., small electrodynamic shaker) at each normal accelerometer mounting location, and sweeping frequency until resonances are detected and noted. It may also be possible to excite the structure by mildly impacting the structure as follows:

(1) Vertically - one inch vertical drop of vehicle frame onto solid metal block (with plywood facing).

(2) Longitudinally - subject bumper to 5 mph pendulum test. Alternate method would be to use an adapter fixture to excite the frame.

(3) Laterally - subject frame to 5 mph pendulum test using an adapter fixture to reach frame.

Although several organizations cite the importance of a resonance-free mounting and location configuration, this requirement has not been integrated in a normal test plan or test procedure, and is never mentioned in any detail, in test reports.

(e) At least one contractor has subjected his on-board instrumentation equipment to shock and vibration levels actually experienced in crash testing, to insure that spurious signals are not generated by subjecting the support electronics to mechanical shock. The level of acceleration which the support electronics experiences, depends on its location in the vehicle and whether or not shock isolation mounting of the equipment is provided. It is therefore recommended that each contractor be required to certify that the crash dynamics does not affect the performance of the on-board signal support electronics.

(f) Until an analysis or experimental program has been performed to resolve the requirements for filtering occupant compartment data, the emphasis on peak acceleration levels should be removed.

(g) Correlation of accelerometer data and integrated velocity and displacement data is typically cross-checked with photographic data, and event-sequence tables describing major structural collapse and contact events from filmed data are commonly constructed and correlated with accelerometer data. The continued use of these practices is recommended.

Recommendations for Occupant Compartment Accelerometer Mounting and Location

A criterion for locating accelerometers within the occupant compartment is needed, along with a method of describing the chosen locations. This criterion should also consider differences in automobile size and construction techniques. A method similar to Calspan's technique of describing the transducer locations is recommended. The accelerometer packages are mounted to flat steel plates which are welded to the structure. The flat plates are located on laterally stiffened cross-members (front and rear) if the structure contains such cross-members, otherwise judgment is used to locate the plates. Location is described using a plan view of the occupant compartment and the following dimensions (refer to Figure 6):

(a) Lateral distance from vehicle centerline to right front and rear accelerometers - (dim A),

(b) Lateral distance from left-side accelerometers to right-side accelerometers - (dim B),

(c) Longitudinal distances between lateral crossbeams (and accelerometers mounted thereon) and A and B pillars at floor location -(dims C, D, and E),

(d) Lateral distance, vehicle centerline to B post -(dim F),

(e) Longitudinal location of tunnel accelerometer - (dim G) (if not located at C.G. of the four "corner" accelerometers) and

(f) Lateral and longitudinal dimensions to accelerometer packages, if not located on lateral crossbeams.

Recommendations for locating and mounting accelerometer packages within the occupant compartment are as follows:

(a) Longitudinal transducer mounting should be located on or near lateral stiffener cross members, to the extent possible. The area forward of the seating position or under the seat bench is preferred, depending on the location of the lateral stiffeners.

(b) Lateral location should be as close to passenger centerline positions without compromising longitudinal positioning on structural cross members.

(c) Data should be taken at two locations, symmetrical with respect to vehicle longitudinal axis both front and rear (four locations total), for reasons previously discussed.

(d) Mounting location should typically accept a flat, 5 x 5 in. steel plate with tapped holes, and welded to the structure. This represents a fairly common practice among test organizations. The accelerometer package may be fitted for uniaxial, biaxial or triaxial measurements, and is mounted using the tapped holes in the plate. Mounting should be secure to the extent that new (or lower) resonances are not introduced.

(e) The selected location should be described using a diagram (plan view) of the occupant compartment similar to that of Figure 6, and the dimensions listed above.

Resonant frequencies associated with selected locations should be higher than the filter cutoff frequency by a factor of at least two. Although this may not be physically possible (depending upon required filter characteristics definition), resonant frequencies associated with transducer mounting should be identified using techniques previously recommended. This information will be useful in data analysis and/or better location selection. The use of damping material in the area of the accelerometer package mounting and the use of low mass, low profile accelerometer packages, as previously described, will reduce the problems caused by structural resonances.

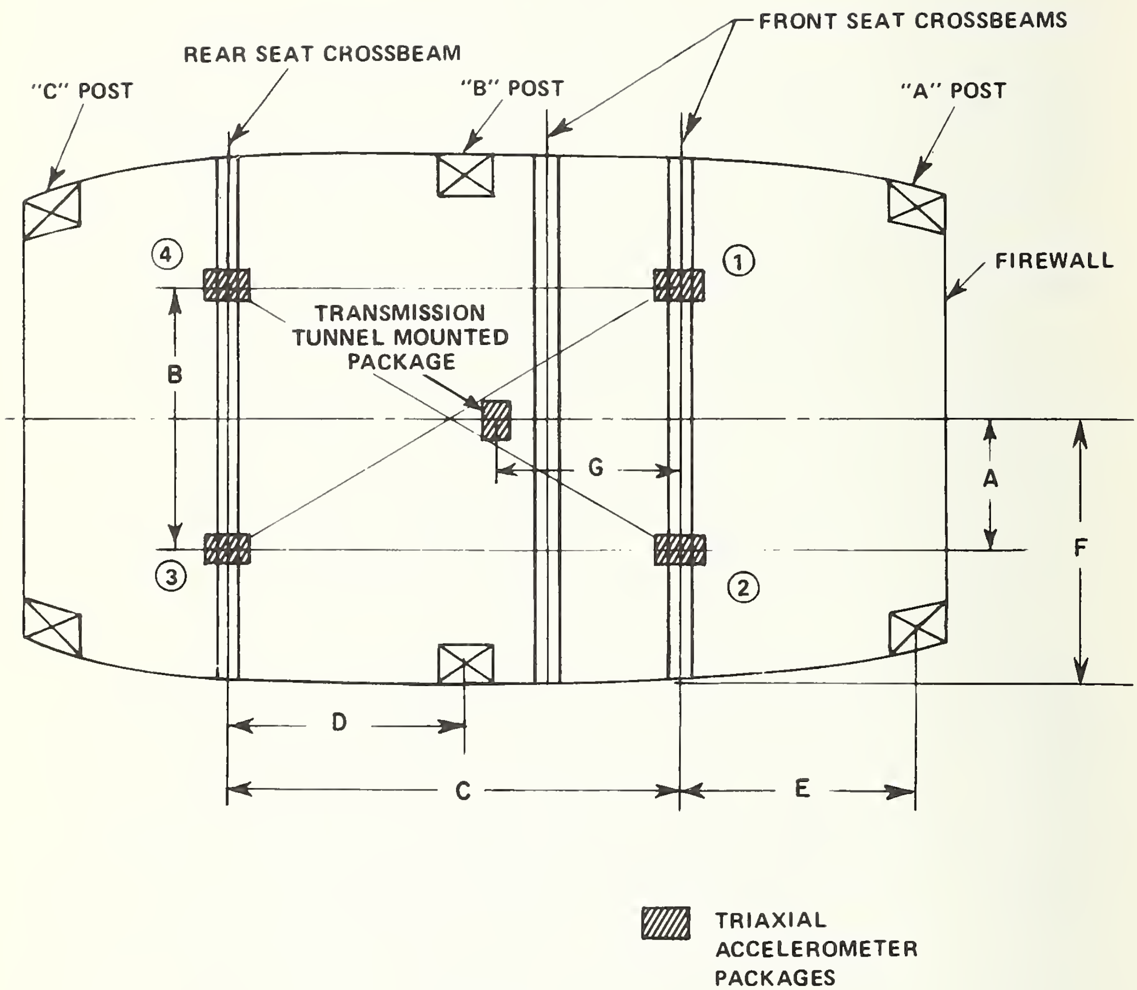

Figure 6. Schematic of Passenger Compartment Showing Accelerometer Locations

2.4 RECOMMENDATIONS FOR STANDARDIZED DATA ACQUISITION PARAMETERS (FIGURES OF MERIT AS RELATED TO OCCUPANT SURVIVABILITY)

I. Structural Data

a. Occupant Compartment Acceleration and Related Parameters

This parameter is required to provide motion descriptions of the structure as near as possible to the occupants for use in evaluating structural energy management and dynamic stiffness characteristics, the manner in which the vehicle structure provides ride down forces on the occupants and in describing the acceleration environment to which the occupant is subjected. This parameter has the potential form of a vehicle performance standard, and has been used as a design specification (for frontal barrier tests) in the ESV program.

To illustrate how the vehicle structure provides transmission of impact forces to the occupant as the structure undergoes deformation, passenger compartment acceleration and restraint system parameters such as seat belt load data, plotted against vehicle crush displacement (integrated acceleration data) provides a useful tool. Occupant loading levels, over or under-utilization of available vehicle crush distance and the application of restraint system load vs acceleration magnitude information, are illustrated in these plots.

To provide energy dissipation data and structural dynamic stiffness information, the force-displacement history between the occupant compartment and impacting surface should be measured. This is obtained by plotting synchronized occupant compartment displacement (integrated acceleration data) with barrier load-cell data. Dynamic crush characteristics of the structure (front, side, rear) is anticipated to be a major future evaluation parameter, if large cars are to be designed with compatible crush characteristics to afford some protection to small cars.

This parameter should also provide valuable information for the development of simulation models.

The integrated product of displacement and barrier force data would provide a direct measurement of energy dissipated by the structure between the impact point and occupant compartment.

The acceleration pulse shape and characteristics (rise time, duration, average value) are important parameters in restraint system design, and also for reproducing the crash pulse on sled test devices.

The acceleration magnitude vs vehicle crush displacement also contains data on front end compliance characteristics which are relative to vehicle agressiveness in impacts with other vehicles for non-perimeter framed vehicles (in perimeter framed vehicles, the frame acceleration measurement is a more direct indicator).

Because of the general usefulness and importance of occupant compartment accelerations as discussed above, it is also useful as a basic comparison parameter between full scale crash tests and simulation models, and also between full scale crash tests of vehicles of different structural configurations.

b. Engine Acceleration. This measurement is important because the large concentrated mass is a major energy dissipation element as well as a major threat to passenger compartment integrity. The product of engine mass and acceleration yields a large inertia force which must be managed by the structure to keep the engine from penetrating the occupant compartment. Engine displacement (from integrated accelerometer data) multiplied by engine inertia force and integrated over time should be acquired to provide a measurement of energy dissipation associated with engine decelerations.

c. Intrusion/Deformation Measurements. Passenger compartment intrusion measurements such as steering column and compartment perimeter elements dynamic deflections, and post crash static measurements of interior geometry changes and total vehicle crush distance, should be standard measurements. Also, post test assessment of door functionability, restraint system and fuel system integrity should be standardized reporting items.

II. Dummy Data Acquisition and Restraint System

Dummies are used primarily in evaluating interior impact protection, and restraint system performance evaluation. From reports reviewed, dummies are used in a small percentage of full scale crash tests and are used much more extensively in sled testing.

In the recent past, different dummies have been used to evaluate different types of restraint systems in full scale crash and sled tests, and test results have been confused by problems associated with repeatability and reliability and the use of more than one standarized dummy. Data acquisition practices, however, principally because of FMVSS 208, are basically standardized, although continued efforts to develope a standarized, all-purpose dummy remains a priority research area. These measurements are of ultimate importance of course but their use in structural crash testing should probably remain limited, awaiting the development of universally accepted dummy and the development of structures capable of increasing occupant survivability space for high speed (i.e., greater than 40 mph) impact testing, before they are used on a regular basis in crash testing. These are necessary conditions if the data is to be meaningful and to avoid subjecting expensive dummies to crash test damage. The existing practice of reproducing the crash pulse on a laboratory sled test should continue.

More detailed evaluation of occupant survivability of course, awaits new developments in the biomechanics area which will allow more exact assessment of human injury based on physical measurements of anthropomorphic dummies.

Occupant deceleration forces in the form of seat and lap belt loads, steering column axial loads and IORS bag internal pressure, are principal data acquisition parameters, which go hand in hand with dummy data acquisition practices where dummies are used.

III. Basic Test Conditions and Reporting Data

A summary sheet containing the following information pertaining to each crash test, should be acquired:

a. Vehicle impact velocity(ies)

b. Test mode description

c. Vehicle total test weight and individual engine/transmission and body weights

d. Vehicle modification description (if applicable)

e. Description of test objectives

f. List of data plots presented

g. Ambient temperature and conditions

h. Post test measurements of deformation, intrusion, fuel leakage, door functionability etc.

i. Total time of impact event

j. Total velocity change (car to car impact), of each vehicle

A summary of recommended data acquisition parameters for evaluating full scale production vehicle crash testing are listed in Table V.

TABLE V SUMMARY OF RECOMMENDED DATA ACQUISITION PARAMETERS FOR EVALUATION OF FULL SCALE PRODUCTION VEHICLE CRASH TESTING

Parameter	Principal Evaluation Usefulness
1. Occupant Compartment Acceleration vs. Time History (Four Corners)	Determine Pulse Shape, Rise Time, Average Value and Duration. These characteristics can be optimized for the available crush distance of a certain vehicle. These parameters are also used in tailoring restraint system characteristics, to the crash ride-down pulse. Motion characteristics of the occupant compartment are also used in other evaluation parameters listed below, and as a basic comparison parameter.
2. Occupant Compartment Acceleration vs. Crush Deformation	Determine Pulse Shape, Leading Edge Rise Distance, Peak and Average Value, and Total Crush. The pulse leading edge rise distance (slope) is a measure of the amount of vehicle crush used for building up deceleration forces on the occupant compartment. The ratio of peak to average acceleration values is a measure of pulse "squareness" or efficiency in decelerating the occupant.
3. Occupant Compartment Displacement vs. Barrier Force	Determine Slope of Load Deflection Curve (Vehicle Dynamic Stiffness). The dynamic load deflection curve describes the deformation resistance of the structure. The leading edge of this curve contains the information necessary to characterize vehicle aggressiveness based on the dynamic stiffness of the vehicle structure.* Dynamic stiffness data is useful to simulation model development and verification

*For perimeter framed vehicles, frame displacement vs. barrier force should be used for this measurement.

TABLE V SUMMARY OF RECOMMENDED DATA ACQUISITION PARAMETERS FOR EVALUATION OF FULL SCALE PRODUCTION VEHICLE CRASH TESTING (CONTINUED)

Parameter	Principal Evaluation Usefulness
4. Vehicle Energy Dissipation vs. Crush (Displacement)	Determine Integrated Product of Vehicle Displacement and Barrier Force Data; Plot vs. Crush Deformation (i.e., Vehicle Displacement). Indicates magnitude of energy dissipated by vehicle structure as it undergoes crush deformation, and total energy absorption and crush characteristics of vehicle structure.
5. Engine/Transmission Acceleration vs. Time	Determine Motion Characteristics of Engine Mass (two translational directions and one rotational to determine motion within a plane perpendicular to impact direction; total of three translational accelerometers required).
6. Energy Associated with Engine/Transmission Decelerations	Determine Product of Engine Inertia Force (determined from mass and acceleration data) and Engine Displacement (from integrated accelerometer data) and Integrate with Respect to Engine Displacement. Indicates structural energy associated with engine decelerations.
7. Vehicle Intrusion/Deformation Measurements	Change in geometry of the occupant compartment perimeter is a threat to occupant survivability, and should be quantified. Deformation (crush) measurements are taken and compared with integrated accelerometer data as a data cross check.

TABLE V SUMMARY OF RECOMMENDED DATA ACQUISITION PARAMETERS FOR EVALUATION OF FULL SCALE PRODUCTION VEHICLE CRASH TESTING (CONTINUED)

	Parameter	Principal Evaluation Usefulness
8.	Acceleration Measurements at "Intermediate Location" of the Structure	Acceleration measurements at intermediate locations on the structure between point of impact and location of occupants should be obtained to provide motion description useful in simulation model development and verification. Front frame engine cross-member, B post, and rear deck locations are recommended corresponding to front, side and rear impacts.
9.	Dummy Data Acquisition Parameters	Standard dummy data acquisition including head chest and pelvic accelerations and femur loads for assessing occupant injury as defined by FMVSS 208.
10.	Restraint System Loads vs Time and vs Crush	Lap and shoulder belt loads - used to determine magnitude and rate of onset of forces on occupants. For IORS measurements deployment time, pressure/time history and occupant compartment noise and pressure levels are necessary evaluation measurements.
11.	Construction of Event-Sequence Tables and Photographic Sequences	Constructed from photographic data reduction, this table describes details of the collapse sequence, major contact events and failures and failure mode description, of principal structural elements. A still photograph sequence showing the development of structural collapse (e.g., every 10 ms) is recommended to compliment the tables.

TABLE V SUMMARY OF RECOMMENDED DATA ACQUISITION PARAMETERS FOR EVALUATION OF FULL SCALE PRODUCTION VEHICLE CRASH TESTING (CONTINUED)

Parameter	Principal Evaluation Usefulness
12. Basic Test Condition and Reporting Data	Identify basic test conditions, test mode and properties of vehicles. These include: vehicle impact velocity, point and angle of impact, test mode description; vehicle test weight, individual weight of body and engine/transmission masses, description of modifications to vehicle (if applicable); description of test objectives; list of data plots presented; impact velocities; assessment of door functionability and fuel leakage; duration of impact event

3. THE ROLE OF CRASH TEST DATA IN MODEL DEVELOPMENT AND DATA ACQUISITION RECOMMENDATIONS FOR VERIFICATION OF SIMULATION MODELS

3.1 THE STATUS OF MODEL DEVELOPMENT

Basic parameters which are necessary to evaluate vehicle crashworthiness and agressivity were identified in Section 2.1 to be those associated with crash ride down characteristics. These basic evaluation parameters include vehicle crush distance, loads and accelerations to which the occupant is subjected, and maintenance of the occupant compartment perimeter as measured for a particular collision mode and impact speed. Characteristic measures of vehicle energy absorption efficiency between points of impact (front, side and rear) and occupant locations, and energy associated with engine/transmission decelerations have also been recommended as standardized data acquisition parameters.

The same characteristic measurements should ideally be predicted by simulation models, however, the various techniques and levels of sophistication and development of models preclude this situation based on the current state-of-the-art of simulation modeling. A review of the current state-of-the-art of computer simulation, defining: the spectrum of simulation model sophistication (i.e., the familiar five levels of simulation); current modeling concepts, their difficulties, limitations and potential for advanced development; and recommendations for advanced modeling formulation, are discussed in reference 4.

Basically, the results of this study indicates that to date the less sophisticated, hybrid, lumped mass models have provided greater quantitative prediction success than the more analytically sophisticated frame models. This is explained by the basic problem that frame models must necessarily choose cross sectional properties such that a beam element is made equivalent to several structural components or members. Another basic problem area is the treatment of structural joints.

Better methods of modeling joint efficiency and behavior are required. Other problems associated with frame model development are those associated with stress modeling of the "equivalent" beam structure undergoing large plastic deformations (i.e., changes in beam cross section and lengths as well as their time rate of change), and the assignment of lumped masses to mode points based on judgement by the user. In contrast to the frame models, the hybrid lumped mass models use of experimental crush data accounts for these effects.

The development and simulation capabilities of hybrid models, however, have or have nearly reached their maximum potential as an overall vehicle simulation (Ref. 4). This is because the problems involved with determination of a dynamic correction factor to use with static crush data and the necessity to exactly reproduce the dynamic mode of deformation with a static test for use in reproducing a unidirectional, translational test mode, become much more difficult for any type of unsymmetrical loading. Defining resistances such that net forces and moments acting on the lumped masses are representative, definition of a series of experimental crush tests to accomplish this and insuring the appropriate deformation mode, are reasons cited for the difficulties in extending the system to generalized unsymmetric loading.

Frame model, however, have demonstrated significant potential for advanced development and together with finite element models and other mechanical models, each representing a modular simulation of a vehicle segment, represents the best potential for achieving higher levels of simulation sophistication. Similar conclusions have been reached recently in Reference 5. Tables VI and VII of Reference 4 define the above mentioned simulation spectrum (i.e., levels 1 through 5) and a summary of major simulation techniques and the qualified and potential levels of simulation of each.

In addition to the development of a modular simulation approach, the following major development needs have been identified for additional investigation to advance modeling developments, (Ref. 4):

TABLE VI. SIMULATION SPECTRUM

Simulation Level	Degrees of Freedom	Modeling Detail	Nature of Loading and Response	Confidence Level	Applications
1	10	Overall Vehicle Stiffness	Each Model Specialized for Particular Load, Gross Vehicle Deformation and Acceleration	Qualitative	Parameter and Sensitivity Studies
2	20	Limited Parameters for Gross Modeling of Component Force-Deformation	Model Specialized for Loading Relative Displacements for Limited Variables, Rigid Body Accelerations	Qualitative	Identify Basic Phenomenon, Parameter and Sensitivity Studies, Component Compatibility
3	20	Detailed Modeling of Major Components by Approximate Methods or Experiments	Model Specialized for Loading Relative Displacements for Limited Variables, Rigid Body Accelerations	Accurate Relative Displacements of Major Components and Average Rigid Body Accelerations	Predict Occupant Compartment Behavior, Identify Basic Phenomenon, Interpret Exp. Data, Component Compatibility
4	100-200	Accurate Modeling of Major Components Approximate Modeling of Sub-Components	General Loading Three-Dimensional Response-Limited Detail Occupant Compartment Acceleration	Accurate Displacements and Accelerations of Model Variables	Predict Occupant Compartment Behavior, Identify Basic Phenomenon, Interpret Exp. Data, Component Compatibility
5	Greater Than 1000	Detailed Modeling from Geometry and Material Behavior Including Joints and Local Effects	General Loading Pointwise Response	Accurate Displacement and Accelerations for All Points	Predict Occupant Compartment Behavior, Interpret Exp. Data, Compliance Verification

TABLE VII. SUMMARY OF CURRENT SIMULATION PROGRAMS

Program	Type	Qualified Simulation Level	Restrictions	Potential Simulation Level	Needed Development
Simplified Models	Spring-Mass	Level 1	Specialized Conditions, Qualitative	--	--
BCL	Spring - Mass, General Configuration	Level 2 Level 3	Colinear Qualitative, Limited Verification Exp. Crush Data	--	--
KAMAL	Spring - Mass	Level 3	Colinear Experimental Crush Data	--	--
KRASH	3D Frame Experimental Stiffness Reduction	Level 2	Limited Validity of Reduction Factor, Qualitative	--	--
SHIEH	Planar Frame Plastic Hinge	--	Plane Motion, Ideal Plastic Hinge	Level 4 Module	Generalization to 3D
CRASH	3D Frame Plastic Finite Elements	--	Ideal Frame Elements	Level 5 Module	Account for Local Deformation and Joint Behavior
THOMPSON	3D Frame Finite Element with Reduction Factor	--	Ideal Frame Elements, Reduction Factor	Level 5 Module	Local Deformation and Joint Behavior, Generalize Reduction Factor

a. Characterization of joint behavior is required under various loading conditions.

b. Characterization of the effects of local deformation on load transmission and energy absorption are needed

c. Development and incorporation of realistic material strain-rate effects and behavior is needed and,

d. Numerical error control methods are required for appropriate selection of time steps and assessing effects of local error bounds on overall accuracy and efficiency.

The above mentioned development areas necessary for the development of advanced simulation models are primarily analytical in nature and it is doubtful that current data acquisition practices could conveniently be utilized for developing these needs. Load transmission data between impacting point, through primary structural members, to structural interfaces with the occupant compartment (i.e., load transmission measurements at intermediate points in the structure) would provide some important data but its usefulness is very limited without additional detailed information, such as a description of local deformation mode and magnitude and deformation rate history, a quantifiable description of joint behavior and accurate detailed accounts of relative displacements and their time histories. These pieces of information strongly suggest the use of photographic data interpretation and specialized instrumentation development. The regular accumulation and quantification of the behavior of individual structural members in the manner is much too complicated and ambiguous to include such measurements in a standardized methodology.

3.2 CHARACTERISTICS INPUT/OUTPUT QUANTITIES FOR TYPICAL LUMPED MASS, FRAME AND FINITE ELEMENT MODELS

Most model input data is particular to the nature and sophistication of the model. Typical input/output quantities of principal model types are characterized by the following (Refs. 6, 7, 8 and 9):

a. Lumped spring-mass (hybrid) models (e.g., the Battelle Model)

Input:

1. Identify and describe principal masses (engine/transmission, occupant compartment, rear axle, bumpers, suspension, etc.).

2. Identify and describe structural resistances (stiffness) with specific vehicle components or subassemblies and define their corresponding static load deflection curve, using a static collapse mode which is identical to the dynamic mode,

3. Determine a suitable dynamic correction factor for static load deflection data.

Outputs:

1. Forces, deflections, deflection rates and energy dissipation associated with each structural resistance (i.e., vehicle component), accurate values of overall crush,

2. Mass position, velocities and accelerations.

b. Frame Models (e.g., the two dimensional Shieh Model)

Inputs:

1. Frame geometry, arrangement and orientation,

2. Mass sizing and location for addition to frame,

3. Computation instructions (integration time steps, control logic)

4. Binding and extensional stiffness vectors of frame elements,

5. Plastic moments and axial yield forces for each frame element, and

6. Initial conditions necessary to excite (drive) the model

Outputs:

1. Displacements, velocities and accelerations of frame modes,
2. Internal forces and bending moments developed in each element

c. Finite Element Models (e.g., the Crash Model)

Input:

1. Selection of three dimensional mesh of points (joints) estimating a structures load carrying characteristics.
2. Selection of structural member connections between mesh joints and assigning corresponding codes relating to material and structural properties,
3. Define member cross-section (load carrying and stress distribution) properties,
4. Define material stress-strain properties,
5. Define (distributed) mass located at each joint, and
6. Define initial conditions and control and integration logic.

Output:

1. Joint positions velocities and accelerations,
2. Stresses at selected locations in members

A review of the input data necessary for frame and finite element modeling of a structure indicates an emphasis on: calculations (e.g., structural stiffness vectors) modeling approximations (grid sizing and location and mass distribution) and individual component testing to establish plastic moment and axial yield levels, and stress-strain properties.

The usefulness of crash test data as an aid in preparation of input data is minimal. Photographic data reduction, however, has advantages in providing a detailed account of the collapse mode and a standardized method of including summarized photographic descriptions would be desirable.

3.3 THE ROLE OF CRASH TEST DATA IN ADVANCED SIMULATION MODEL DEVELOPMENT

The role of crash test data in the development of advanced simulation will play a verification role as opposed to a development role at best until models of adequate sophistication to describe the entire vehicle response in detail are formulated. Current estimates of the availability of more sophisticated model development is approximately two years for level 4 simulation and five years for level 5 simulation (Ref. 4). Requirements for specific physical test data necessary for simulation development should be defined and identified when such a model has been formulated and should be done so in conjunction with the developers of the model. Specifying data acquisition parameters for use in model development at this time would require anticipation of the specific needs of advanced formulations, although the general character of the finite element and frame models which will be used in the future indicates that data of the following character would be desirable:

a. Load transmission data at intermediate points between point of impact and the occupant compartment.

b. Forces, moments and corresponding stresses and deformation histories developed in the intermediate members and in the frame assembly, and

c. Location of plastic hinges.

3.4 RECOMMENDED DATA ACQUISITION FOR VERIFICATION OF SIMULATION MODELS

Principal data acquisition parameters monitored in a crash test which sould be predicted by and used for verification of the higher levels of simulations (i.e., levels 4 and 5) are:

a. Occupant compartment accelerations, velocities and displacement time histories,

b. Occupant compartment acceleration vs. crush time history,

c. Vehicle dynamic stiffness characteristics (barrier force vs. crush distance history) from point of impact to occupant location closest to impact,

d. Energy absorption characteristics of the structure between point of impact and occupant location vs. time and also vs. crush history,

e. Maintenance of occupant compartment perimeter,

f. Engine/transmission acceleration, velocity and displacement time histories.

g. Energy absorption characteristics associated with engine/transmission deceleration vs. time and also crush history,

h. Weights of major engine/transmission, body, rear axle.

Secondary "intermediate" structural crash test data useful in model verification and development would be integrated (from accelerometer) displacement data taken from a point on the structure between the point of impact and occupant locations, to afford some additional detail on the primary structure collapse mode. Recommended locations are:

i. Frontal impacts: front frame engine crossmember (torque-box) acceleration

j. Side impact: "B" post acceleration,

k. Rear impact: rear deck (i.e., over rear axle) acceleration,

Photographic data provides much detail of the collapse mechanism in terms of "contact" events and structural modes of deformation. The results of photographic analysis can be summarized in event-time histories, to characterized structural collapse. This is recommended as a standard practice.

1. Construction of event-sequence tables describing: collapse sequence (especially engine and frame details), failures and/or collapse modes and description of key structural elements (i.e., buckling, bowing, cracking, twisting, etc.) maximum crash

amplitudes of various structural elements, door openings, identification of structural hinge points, etc.

m. Photographic sequences showing the development of the structural collapse mechanism at discrete time intervals (e.g., every 10 ms) and at principal contact event times would compliment the descriptions given in the event sequence tables.

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APPENDIX

PRELIMINARY REVIEW OF CURRENT INSTRUMENTATION METHODOLOGIES AND DATA ACQUISITION PRACTICES

AI.1 APPROACH

Initial efforts at development of a standardized methodology for automobile crash testing attempted to define separate methodologies for various object-categories of testing. Such categories would include: full scale production (structural) vehicle testing; restraint system development testing; dummy development tests; component and vehicle crush testing procedures; ESV and RSV testing, etc. Principal test modes would be defined, and accounted for in the methodologies developed for each objective category.

For each category identified, the development of an instrumentation methodology must consider as a minimum the following: test objective; required measurements to achieve objective; details of the instrumentation methodology; quantification of the effects of variations in instrumentation practices (such as transducer location and mounting, filtering, telemetry, calibration and recording techniques, measurement of system immunity to shock and vibration environment, etc.) used by different contractors to meet test objectives; range of impact speed; and, principal vehicle crash test modes which must be considered. This data must be collected and analyzed to identify candidate parameters for standardization for each objective category.

An attempt has been made to collect the required data for the development of separate instrumentation methodologies, by reviewing a number of test reports and by soliciting information from crash test organizations, by use of a questionnaire. This approach to the problem was ambitious and assummed that information regarding detailed test methodologies was easily obtainable. The information supplied by the various crash test organizations contacted, although very helpful in the preparation of this report, fell far short of the anticipated level of detail necessary to develop the separate methodologies discussed above. This report therefore makes recommendations for that part of the instrumentation methodology, for which an adequate information base has been prepared. These recommendations, fortunately, have been made for structural characteristics of full scale production vehicle crash testing, which is the primary objective of this program.

The following sections define the required data necessary for development of the various methodologies, information solicited from contractors to complete the required data, and a tabulation and discussion of information supplied by various contractors. Tables were prepared which outline principal objectives in crash testing (i.e. the objective categories) and principal data acquisition parameters associated with each category, based on report literature and contractor supplied information.

Generally, the information provided by various contractors was sufficient to outline the principal characteristics of the instrumentation methodology, particularly for structural testing. If the original concept of developing separate methodologies as discussed above is pursued however, it will probably be necessary to let small contracts (one to two man-months) to each test organization, to supply the required detail on various test methodologies, since little detail is available in the form of reports, and experience in soliciting data for this program indicates that a significant level of effort is necessary on behalf of the contractors to supply such information.

AI.2 DISCUSSION OF REQUIRED DATA TO CHARACTERIZE INSTRUMENTATION METHODOLOGY

The literature was reviewed and discussions with test organizations have been held for the purpose of constructing a comprehensive tabulation of test organization instrumentation methodologies, which would provide the required data for evaluation of various practices and for identifying candidate parameters for standardization, and to establish recommendations for standardized practices among contractors.

The "required data" is data which defines the elements of the instrumentation methodology necessary to meet the evaluation requirements of a particular development or research objective. These elements include: the test objective; data acquisition parameters; the purpose or usefulness of the acquired data in evaluating test results or its relationship to meeting the stated objective; details of the instrumentation methodology including transducer location and mounting practices; and, specifics of data reduction, filtering techniques and presentation of the data in report format. This represents the minimum information required from each contractor participating in crash testing development and/or research programs in order to review current practices with emphasis on identifying or specifying standardized instrumentation methodologies for the various categories of test objectives, considering:

(a) the usefulness of the data acquisition parameter in assessing such measures as occupant injury, vehicle crashworthiness and aggressiveness (i.e. does it qualify in importance?)

(b) the need for standardization based on a comparative review of various measurement and reporting practices presently employed (i.e. do variations in existing practices affect results?),

(c) the possible identification of more suitable evaluation parameters for use in various test objective categories, and

(d) identification or specification of data acquisition parameters which are suited to the development of advanced simulation models.

Table I is a listing of the broad objective categories of automobile crash testing and the various research activities pursued to accomplish each objective, as identified by performing a literature search and by reviewing many test reports. For each research activity, data acquisition parameters which are common to various contractors and which have a particular significance for evaluation purposes were identified to the extent possible, for the eventual purpose of formulating standardized data acquisition practices for each research activity.

In addition to defining significant data acquisition parameters for each category, the literature was also reviewed to identify the stated usefulness of the data, and data reduction practices (if applicable). This information is contained in Table II, and organized such that each data acquisition parameter is tabulated corresponding to a research activity identified in Table I. Tables I and II serve to partition the spectrum of research and development activities and to identify significant data acquisition parameters common to each. Table III is a listing of principal test modes utilized in crash testing, and is discussed here, as another basic consideration necessary for instrumentation methodology development. (Refer to Section 2.3 for Tables I,II, and III.

The next requirement was to identify details of the measurement systems used by various contractors for each data acquisition parameter identified in Table II, and the usefulness of each parameter in evaluating test results. Information pertaining to the evolvement of the instrumentation system would provide valuable background on the rational for the existing methodologies and would illuminate practical considerations which may not otherwise be considered. Unfortunately, very little information on instrumentation practices, or requirements was found in the literature. A discussion of principal characteristics of contractor data acquisition practices, based on available literature and information provided by contractors, is presented in Section 2.4.

A review of this data indicates that the level of detail as such that principal characteristics of the methodologies are described, with respect to structural data acquisition practices, but relatively little detail has been collected for the other objective categories outlined in Table II. This situation is fortunate however, since definition of the structural characteristics of full scale production vehicles is a primary objective of this program. It is also appropriate to note that the primary difficulty in interpreting structural data is the high frequency content observed in structural acceleration data, and that there is no clear definition or understanding of the dynamic structural response characteristics, which is a necessity prerequisite for defining filter characteristics, and to meaningful interpretation of test results. In this respect, it appears that presently employed methodologies have "evolved" rather than having been developed based on a systematic program aimed at a clear definition of the crash dynamics. This is not to fault the contractors whose development of techniques is weighted heavily by expediency, but to point out a technology void, which needs some attention.

AI.3 DATA SOLICITED FROM CONTRACTORS

A description of "required data", necessary for definition and evaluation of instrumentation practices among test organizations, and to establish an information base for the development of recommendations for standardized instrumentation practices, was discussed in Section 2.2. The gathering of information from report literature, into organized tables (i.e. Tables I through III), was also discussed. Because information gathered from reports and tabulated in Tables I thru III, contained only partial descriptions of the complete test methodology (as defined by the "required data" definition of Section 2.2), and because the information is tabulated in composite form and may not be entirely accurate in meaning from one organization to another, these tables were submitted to the major contractors for their review. A letter was composed and sent to each of nine crash test organizations contacted. Letter content included: a description of program objectives; identification of program sponsor; and the above described tables (I thru III) with some background information on the construction and content of the tabulated data. The letter also served, of course, to formally notify the various organizations that such an activity was being pursued by TSC and to seek suggestions which might facilitate the development of recommended practices. Organizations contacted here: American Machine and Foundary; Minicars; University of Mighigan's Highway Safety Research Institute; Transportation Research Center of Ohio; Agbabian Associates; General Motors Corporation (Automotive Safety Engineering); Ford Motor Company; Calspan; and Dynamic Science.

Information solicited included:

(a) A review of tabulated data presented in Tables I thru III, for accuracy and completeness as applicable to each organization's practices.

(b) Principal details of instrumentation specifications (i.e. manufacturer, model, range, accuracy and bandwidth) required to monitor each measure and listed in Table II. Background information such as the derivation or evolution of these specifications was also requested, if available, and

(c) A short description which characterizes methods of telemetry, data recording, filtering, and calibration

The gathering of the above described data, in tabulated form together with report material and supplemental information determined as the need arose, provided the information base to answer questions listed below with regard to structural data acquisition practices:

- What data is being acquired?
- What is the usefulness of this data in meeting a particular objective in crash testing?
- Do major differences exist in instrumentation methodologies for similar measurements?
- What data acquisition practices are common to most contractors, and what are the candidate parameters for standardization?
- What data acquisition parameters are suitable for use in the development of simulation models?

Table A-I was constructed as an aid to gethering the above described data, and was included with the letter sent to each crash testing organization.

AI.4 PRELIMINARY REVIEW OF CONTRACTOR DATA ACQUISITION PRACTICES

The available report literature and material supplied by contractors in response to the questionnaire is reviewed in this section to identify principal characteristics of the measurement system necessary to accurate measurement and interpretation of data. Basic elements of selecting and implementing a measurement system are listed below. A comprehensive description of each contractors techniques would permit these evaluations and comparisons, and to be made, however, only partial information is available and partial evaluations are made.

(a) basic understanding of the quantity to be measured in order to make necessary decisions regarding instrumentation specifications

(b) selection of transducer type such that the simplest device, considering the associated signal support equipment required, which will provide adequate performance, is selected

(c) definition of transducer range, frequency response, and accuracy requirements

(d) environmental effects, mainly temperature sensitivity and sensitivity to shock and vibration inputs

(e) methods of mounting locating and installation configuration, and

(f) methods of filtering, telemetry, calibration and recording

AI.4.1 Principal Characteristics of Calspan Methodology

Calspan has prepared a report on the development of their instrumentation and data handling technique utilized in the Crashworthiness II program (Ref. 3). As described in this report, Calspan's techniques were developed by information obtained through the literature, by making field trips and by utilizing past instrumentation experience.

Calspan's methodology is characterized by the following: (Refer to Figure A-1)

1. On-board location of the complete data acquisition system (transducer, signal conditioning and amplification electronics, and power supplies) and repackaging of signals prior to transmission thru umbilical cable, yielded improved signal/noise ratio when compared to remote amplification.

2. Shock and vibration qualification testing of onboard signal support electronics packages to levels experienced during impact to establish effects of shock induced errors in the measurement system. Overall signal recording error was estimated to be $\pm 5\%$ of nominal crash signal levels.

3. Transmission of amplified signals via trailing umbilical cables to recording system. Data is not multiplexed, but is transmitted via individual wires in the cable.

4. Recording system consists of 14 channel FM record, in tape IRIG format, tape recorders, for direct analog recording. (Location is off-board.)

5. Photographic coverage using high speed (1000 fps) cameras from side, overhead and underside locations. Pre and post-test still photographic coverage.

6. Data processing accomplished using analog to digital converter and digital processing and print outouts. Digital sampling rate used in 9600 s/s using a time extension factor of 32 with tape slow-down. Basic data reduction consists of the following data parameters and computations:

   (a) vehicle accelerations and integrated velocity and displacements,

   (b) resultant vehicle acceleration magnitude,

   (c) vehicle acceleration averaging,

   (d) dummy accelerations,

   (e) dummy resultant acceleration magnitude,

   (f) dummy severity index time history and total severity index,

(g) load quantities: femur, pole and belt, and

(h) summation and/or averaging of loads.

All parameters may be digitally filtered and plotted. The plotting subroutine allows selection of plot size, scale, title, parameter dimensions, overplotting, and time-history and acceleration vs. displacement plots.

7. The importance of vehicle compartment acceleration data and for multiple location measurements therein, is cited. This rationale is common among various contractors. A "standardized" location scheme was used as shown in Figure A-2

8. Filtering is accomplished digitally, using a Martin-Graham filter, programmed to satisfy SAE J211 filtering specifications. Characteristics of the Martin-Graham digital filter used, are:

   (a) unity gain within $\pm 1\%$ to filter cutoff frequency

   (b) rolloff characteristics are approximated by a $(\cos)^2$ function

   (c) zero phase shift introduced by filter

It is appropriate to note that, although the report acknowledges that structural resonances usually mask the characteristics sought, and makes final recommendations, that studies be made to define the nature of filtering which should be allowed, and to define the principal characteristics of the crash impulse, Calspan (nor any other contractor) has not attempted an answer to these questions. (An attempt to deal with this question within the scope of this study has been discussed in Section 2.2.)

Because of uncertainties regarding required number and location of measurements and analytical operations required (e.g. filtering vs. averaging), and because of convenience and reliability factors, a standardized location and mounting configuration was developed for occupant compartment accelerometer data. (Figure A-2) The procedure for locating accelerometers is to locate the lateral stiffener-members (crossbeams), front and rear, and mount the accelerometers at the centerlines of each (outboard) passenger location. The fifth accelerometer (i.e. tunnel or C.G. location) is normally located on the diagonals constructed from locations 1 and 3 and 2 and 4. If the vehicle body does not have lateral crossmembers, or if the fifth accelerometer cannot be mounted at the diagonals, judgment is required in selecting the mounting locations. The locations are then dimensioned from the vehicle centerline and to the A, B and C posts.

This is a good practice and conforms closely to the recommendations made in Section 2.3.

Table A-II is a summation of principal data acquisition parameters and the corresponding instrumentation characteristics used by Calspan. This is not a complete list as it contains only those parameters for which an adequate description is available in the report literature. Acceleration, displacement and strain measurements taken at various structural locations in the course of, for example a structural development effort, which are poorly defined in the report literature, are not included. Other standard test information includes pre and post test measurements, diagrams for cursory description of vehicle mounted sensor and target locations, and test site location of sensors and cameras (Figures A-3, A-4 and A-5 respectively).

AI.4.2 Review of ESV Instrumentation Methodology Recommendations

Of the literature reviewed, Reference 10 has been found to be a significant piece of literature, describing the recommended instrumentation methodology for use in testing the crashworthiness performance of the Experimental Safety Vehicle prototypes (i.e. the basis for the instrumentation methodology utilized by Dynamic Science in testing the AMF and Fairchild ESVs). This report addresses aspects of the test plan, data acquisition requirements, identifies candidate transducers and electronic support equipment, the corresponding principal instrument specifications, and many other details of test methodology. The added value of this report is that it includes a discussion of the usefulness of each recommended data acquisition parameter, as described in Table II.

The practices recommended in this report which are applicable to this discussion, are characterized by the following:

(1) A comprehensive list of data acquisition parameters has been generated, based on meeting selection criteria which considered a parameter's importance in indicating occupant injury, usefulness for defining test conditions or for data correlation purposes, and, usefulness in assessing structural performance and its effect on the input to the occupant. This list is reproduced in the Appendix as Table A-III.

(2) A list of candidate electronic equipment for making the above measurements was generated, including two levels of redundant measurement systems. Key instrument specifications are also listed. These lists are reproduced in the Appendix as Tables A-IV and A-V, respectively.

(3) Major problems associated with standardizing test procedures to facilitate data comparision between laboratories are identified as: the need for uniform filtering practices; the need for uniform transducer location criteria; and, elimination of the practice of accepting only one or two accelerometer measurements as representative of the entire occupant compartment motion characteristics.

(4) A guideline was established, that all data should be measured and recorded with an end-to-end frequency response greater than the generally accepted level of significance. DC to 1000 HZ was recommended for all acceleration and load data. Filtering is assumed to be in accordance with SAE J211.

(5) Recommended method of telemetry is via the umbilical cable approach. This is identified as the most common and most reliable method.

(6) Signal conditioning electronics should be solid state devices and should be located on-board the crash vehicle. Multiplexers are also required for large data acquisition capacity. The signal conditioner output should be analog-frequency modulated for multiplexing prior to transmission by umbilical cable.

(7) FM magnetic tape recorders should be the primary means of data recording. Multiplexing data is suggested as a means of reducing cost by reducing the number of recorders required. Recorder location is off-board.

(8) High speed photography of displacement-time data should be utilized on-board for coverage of relative motion between dummy and the vehicle, and off-board, for coverage of the crush dynamics. Nominal frame rate of 1000 frames/sec is recommended.

(9) A detailed description of transducer location and mounting, or a criterion for such, is lacking, although some precautions are outlined (e.g. locating accelerometers at "hinge points" which will undergo gross deformation or will re-orient the transducer should be avoided for data accuracy as well as reliability considerations).

(10) It is recommended that a "dummy" transducer having appropriate impedance characteristics be used to determine the (electrical) noise levels associated with various telemetry paths, and especially to the most noise prone channels, such as those requiring the highest voltage gain.

(11) The need for impact time and time synchronization signals for all data acquisition is stated. For camera coverage, the use of a timing flash triggered by bumper contact, visible to all cameras and timing marks superimposed on the film edge, is recommended.

(12) It is recommended that transducer mounting blocks be used to permit proper orientation of the transducer and to provide electrical insulation.

(13) Major inputs to an abort decision are defined as:

- Determining that crash vehicle (or moving barrier) is on course and has attained proper speed. Automatic monitoring is recommended for quickly reacting to out-of-tolerance speeds. Speed tolerance recommended for ESV testing is $\pm$ 1%.

- Monitoring output from several key data acquisition parameters, which are excited with a dummy input prior to crash, or by monitoring outputs on a visual display (oscilloscope).

(14) A digitizing rate of 1000 samples/second (per channel) is recommended, for analog to digital conversion. Also, to assure accurate frequency reproduction, a digitizing rate of 8 times the maximum data frequency is recommended. This may require reduced tape playback speeds. Automatic reading and digitizing of photographic data and suppliers of this service are recommended and identified.

(15) Data processing and reduction should utilize digital computers and peripheral plotting equipment. The need for generating plots in a standardized format including standardized scales is emphasized. Specific computations to be made are identified as:

- Analysis of peak accelerations, pressures, or force levels
- Analysis of time above a particular acceleration, pressure or force threshold
- Shock spectral analysis
- Gadd Severity Index

(16) The need for rigid specification of filtering properties is cited.

(17) A consensus regarding a primary injury index was sought but none was identified. The same was true for a means of comparing structural response.

AI.4.3 Practices of the G.M. Safety Research and Development Laboratory

General Motors has supplied information on test methodology utilized by the Safety Research and Development Laboratory (SRDL) in the form of Table A-VI. These measurements and instrumentations are primarily used in compliance testing. Methods of telemetry, filtering, recording, on-board vs. off-board location of signal support equipment, and data reduction processes, are very similar to the other methodologies reviewed. An important departure in methodology is the use of signal averaging, rather than filtering, for passenger compartment acceleration data acquisition. Typically, accelerations monitored in four corner locations of the occupant compartment are averaged to reduce effects of localized structural resonances, and in GM's opinion, this has more importance for evaluation purposes, than filtering the data.[11] The location chosen for mounting the passenger compartment accelerometers is the rocker panel segment located virtually under the door sill. This has been found, through experience, according to G.M. to be the most rigid resonance-free location. Longitudinal positioning is such that the accelerometers are spread as far apart as possible without putting them in a location which is expected to undergo deformation. This practice may provide a convenient means of specifying accelerometer location, offered by the distinctive natural geometry of the longitudinally positioned rocker panel. The accelerometer package used by SRDL consists of a small tri-axial package, enclosed in a protective metal housing. Size is approximately 2x2x3 inches which is very desirable since it maintains a low mass, low profile, character. Attachment to the rocker panel is made using four self-tapping sheet metal screws. Data which supposedly substantiates the benefits of multiple location acceleration averaging techniques was once generated but has not been made available. Other facets of the methodology have evidently evolved through trial and error, and very little documentation is available for the methodology.

Another distinction in the methodology involves an instrumented barrier used for frontal crashes, which has force measurement capability. The flat barrier surface consists of five sections of steel plate; each plate having dimensions approximately 20 x 30 x 2 in. thick. Each plate is mounted to five load cells (GM designed) which are mounted to a concrete barrier. The five load cell outputs are summed for each plate, and the five resultant barrier segment force vectors could probably be used to determine load transmission properties of the structure. Exactly how this data is used by GM was not disclosed.

GM has supplied descriptive information relative to its ESV test program (Reference 12), however the contents are labeled to restrict disclosure. What is described of the test methodology used in the GM ESV testing is very similar to that used in the government developed ESV program. An exception is the averaging of passenger compartment accelerations as previously described in the SRDL procedures. Where multiple transducers are not used, data is filtered in accordance with SAE J211. The methodology also requires that accelerometer mounting locations be found such that the natural frequencies of localized vibrations be above those of interest in the vehicle acceleration history. Details of how (or if) this requirement was implemented, and what is meant by "above those (frequencies) of interest" unfortunately, are not known.

AI.4.4 Characterization of AMF Instrumentation Requirement

Questionnaire comments submitted by AMF Inc. Advanced System Laboratory (ASL) indicates that the ASL is a user of crash test services and is more concerned with test results than with specific equipment used. The following comments on data acquisition, reduction, and instrumentation, were made. (Because these comments are a direct response to the questionnaire and are useful in the exact form transmitted, they are reproduced as received and enclosed in quotations.)

(a) FILM - Timing

"Exact" film speed calibration is usually provided in the form of 100 Hz timing marks on the film (for frame rates from 800 to 2500 per second). This has been a convenient means of calibration in our operations. A 100 Hz timing signal provides adequate resolution for determining camera speed variations and is less confusing to work with than a 1000 Hz timing signal.

Timing marks are frequently missing from one or more of the cameras used to record an event. Some backup means for calibration is needed. The exact time of initial vehicle contact is also of interest.

A flashbulb triggered by initial vehicle contact is useful for establishing the start time of a crash. The flashbulb should be visible to all cameras that are filming the event, especially those filming from underneath. The flashbulb should be masked so that it doesn't wash out the pictures for the first few milliseconds of the crash. Flashbulbs that are triggered later, say 50 milliseconds after initial contact, are very helpful in double checking film speeds and in correlating films taken from different angles.

An independent measurement of vehicle approach velocity is useful for double checking film speed or for determining film speed in the event timing marks are absent."

(b) FILM - Dimensional Scale Factor

"Distance measurements on a motion picture film are facilitated if reference targets are mounted on the vehicle at regular intervals along the direction of travel. Velocities can then be accurately determined by observing the time required for successive targets to pass a fixed point in the field of view. These measurements are reasonably insensitive to lens distortion and parallax. If target spacing is uneven or unknown, less satisfactory methods must be used to determine velocities.

Displacements measurements are facilitated if evenly spaced targets or standard scales are located in the plane of objects that are of interest. For instance, if an overhead camera is to record engine displacements, a scale should be placed on the engine. If a scale on the roof is all that is available, corrections for sight angle and sight distance have to be made before engine displacements can be determined. Reference targets and scales are often omitted from the underside of the vehicle."

(c) FILM - General Considerations

"Special problems seem to recur with underside shots. Exposure is often set for the sky above the pit. When a vehicle appears over the pit and is lighted from below by floodlights, underexposure results. Gratings or other obstructions on the pit or on the vehicle itself often obscure items of interest. Use of cameras shooting from several directions is helpful in overcoming this problem."

(d) ACCELEROMETERS

"The placement and means for installing accelerometers are as important as their mechanical and electrical characteristics. Correlation of results among various tests will require that accelerometer locations be standardized and defined in detail for each particular type of test. Selection of these locations is bound to be illustrated by the case of a frontal barrier test. Acceleration measured on the driveshaft tunnel will contain high frequency components that are not present elsewhere in the passenger compartment and that will not be seen by a passenger. These must be removed by electronic filtering or by data manipulation of some kind. Acceleration measured on the floor pan more closely approaches that which is seen by the passenger. But it may be obscured by excitation of resonances in the relatively flexible floor pan structures. Deformation of the floor pan in a severe impact may interfere with accelerometer data obtained at the floor pan or driveshaft tunnel. Summing the acceleration from several locations can provide a measure of passenger compartment acceleration. But this requires that clean data be available from each location. This introduces a factor of judgement in eliminating "bad" data that may have been obtained from a location that was unduly disturbed.

Longitudinal acceleration measured at the trunk floor may provide the best means for an overall comparison of crash pulses recorded in various frontal barrier tests. The trunk floor is relatively rigid and well integrated with the rest of the passenger compartment. It is not subject to deformation except in the most severe frontal impacts. While mechanical filtering may remove the highest frequency components of the crash pulse, trunk floor acceleration usually closely duplicates the results that are recorded elsewhere.

Of course the fine structure of a crash event will still be determined by means of accelerometers at several locations. But a single location should be designated for each type test for determination of 'the' crash pulse for comparison with other tests."

Acceleration and load measurement data acquisition parameters specified by AMF in a recently completed program on "Frontal and Side Impact Crashworthiness of Compact Cars" is listed in Table A-VII. This data was acquired for both baseline and modified vehicles in the development and crash evaluation phases and serves to illustrate some typical practices. The transducer locations and some mounting details, corresponding to each parameter, are shown in Figures A-6 through A-10. Performance evaluation based on filmed data and the parameters listed in Table A-VII included the following criteria:

(1) Structural damage evaluation using existing collision damage severity index specifications

(2) Characteristics of the deceleration pulse shape of the passenger compartment including determination of rise time, rise rate, maximum values, durations of various maxima, average value and total duration

(3) Passenger compartment intrusion measurements

(4) Barrier load data was for aggressiveness evaluation of design concepts,

(5) Deceleration vs. displacement curves generated from available data to study utilization of available crush space, and

(6) Photographic data to provide event sequencing and time occurrence information for superimposing on acceleration time history data.

AI.4.5 Characterization of Methodology Utilized by Transportation Research Center of Ohio (TRC)

Current test capability at the Transportation Research Center of Ohio (TRC) consists primarily of sled testing, and the corresponding data acquisition practices are described with reference to Table II as follows:

I-a	1. 2. 4.	used as described.
I-b.	1. 2. 3. 4. 5.	used as described.
I-c	1.	Rotational measurements not in current inventory.
	2.	Rotational transducers not in current inventory.
	3. 4.	used as described.
	5.	Tibia load transducers not current inventory.

6. No in-house procedure developed.

7. used as described.

TRC has the function of preparing test set ups, conducting the specified tests, and collecting data; data acquisition and test details as well as interpretation of the data is done by others, contracting the services of TRC. Principal measurements which are collected by TSC regardless of the ultimate usage or the individual objective include acceleration, force, photographic and pressure data. (Refer to Table A-VIII.)

Accelerometer data is taken on test structures, the test sled, and test components such as passenger seats, child seats, and dummies. Data is processed to yield maximum acceleration, velocity, and displacement values and also, Gadd Severity Index and Head Injury Criteria values.

Force measurements include axial load measurements in dummy limbs, using strain gage transducers. Seat belt loads are measured by typical strain gage transducers.

Photographic coverage is characterized by on-board and off-board coverage using 16 mm color film, film speeds of 1000 to 3000 frames /sec. and use of a superimposed timing signal for synchronizing data and establishing true film speed. Visual cues such as electronic flashes are used for event correlation.

Pressure transducers are used to monitor sled gas pressures and air bag pressure time history.

The above data is collected in analog form and recorded on magnetic tape. Accelerometer and force data is processed in analog or digital form. Filtering is in accordance with SAE Recommendation J211, however, a variety of cutoff frequencies are used, from 1 Hz to 20 KHz.

AI.4.6 Comments on Instrumentation Methodology: Agbabian Associates

Agbabian Associates has supplied a review of and comments on the contents of Tables I through III, suggesting additions and modifications to these contents along with some basic methodology data.

AA crash testing methodology is characterized by on-board location of signal conditioning equipment, transmission of data through umbilical cables to an instrument van and recording signals on 1 inch, 14 channel FM tape recorders. Data is recorded directly unless the 42 channel capacity is exceeded, in which case the data would be multiplexed. Table A-IX is partial list of instrumentation, containing principal transducers and their specification, as utilized by AA in crash testing. Filtering characteristics listed correspond to SAE Recommended Practice J211, using the maximum roll-off rate specified.

The following comments and suggestions were made regarding the contents of Table II:

(a) Referring to item I-a, add No. 7: Dynamic displacement measurements of main structural members and pillars and other occupant compartment perimeter elements which may be critical to occupant survival space. The usefulness is to provide relative motion and displacement due to elastic motion data that cannot be estimated by post-test measurements. AA claims that linear sensor measurements are relatively simple to install and interpret, when compared to photographic coverage.

(b) The following additional restraint system measurements have been suggested (i.e. for addition to Item I-b):

6. IORS Electrical Functions

"Measure IORS sensor and ignition system voltage supply condition, sensor closing point, and sensor signal characteristics in those systems which utilize some form of proportional signaling. These electrical functions are critical to proper deployment of the IORS, and should be considered in conjunction with measurements of bag pressure(s) and possibly some form of mechanical measurement of deployment time and/or rate."

7. Occupant Dummy Displacement:

   "Dummy displacement may be measured directly, at least in one plane. This measurement may be more precise, and more efficient, than attempting to utilize photogrammetric procedures for tracing dummy travel within the passenger compartment. Also, fluctuations in dummy velocity within the compartment may be quite difficult to measure photographically, and may be more easily measured directly through use of some form of electrical or electromechanical transducer system."

8. IORS Reaction Loads

   "It may be desirable to measure IORS mounting system reaction loads, both for purposes of structural development of the IORS mounting system and also as means for cross-checking dummy head, chest and pelvic acceleration measurements. Direct IORS reaction load measurement may be accomplished with strain gages and/or load cells, and could be very helpful in relating dummy loads with respect to crash event time. Combined with measurement of vehicle structure accelerations, IORS reaction loads could be used to determine whether dummy load is due primarily to dummy velocity within the passenger compartment or whether there is a significant contribution from loads transmitted through the vehicle structure into the forward surfaces of the IORS."

(c) The following comments on Head Acceleration measurement were made (Item I-c, no. 1): "Reference is made to use of six linear accelerometers for measurement of head accelerations in translation and rotation. It should be noted that these measurements likely will be referenced to the motion of the center of gravity of the dummy head.

Thus, location of accelerometers within the dummy head cavity is critical. Further, many of the accelerometers which have proven satisfactory for the measurements of this type are fairly large and heavy. Thus, placement of the accelerometers at locations distant from the natural center of gravity of the head may alter the kinematics of motion of the dummy head during the crash test.

Accelerometer placement within the head cavity also must consider the continuous change of axis orientation during head motion. Further, accelerometer ranging is very important, since inadvertent contact with the windshield or pillar areas of the vehicle interior may produce acceleration peaks of very large magnitude compared to levels normally encountered with a properly functioning air bag. For good accuracy and resolution of the latter condition, it is almost imperative that at least some of the accelerometers be ranged to accurately produce large data channel deflections at low accelerations. These accelerometers then would be subject to off-scale deflections in the event of a bag malfunction, or "bottoming" through a bag unit during a severe collision. Also consideration should be given to use of Log-Amplifiers to circumvent this problem."

(d) Regarding Item I-c no 7, it was suggested that the parameters listed be defined as computed values (based on direct measurements), to eliminate the implication that these parameters were direct measurements.

AA has suggested an expanded number of crash test modes in addition to the original Table III (refer to Table A-X), to include additional impact locations (such as center, and fore and aft of center) and consideration of various types of barriers such as resilient and rigid, non planar faces. The field of test barrier design and application is cited as a relatively untouched research area, and the development of such barriers is expected to yield a more reasonable simulation of real world car to car collisions while maintaining the repeatability of standard barrier testing. Table XIII (which could probably be significantly reduced following an optimization study) is suggested as a comprehensive test battery for use in establishing the crash performance of a particular vehicle.

AI.4.7 Principal Characteristics of Dynamic Science's Methodology

The methodology utilized by Dynamic Science is characterized by on-board signal conditioning using "Remote Signal Conditioning Modules", hard mounted to the structures. The modules (RSCM) also contain electronics for calibrating multiplexing, and radio telemetry of each data channel (typically 14 channels/RSCM). Telemetry is accomplished by either radio frequency transmission or by umbilical cable, and permanent recordings are made using 14 channel IRIG format, one inch magnetic tape recorders. Data reduction and filtering are accomplished digitally; filtering characteristics are per SAE Recommended Practice, J211a. The instrumentation methodology used is primarily that developed for ESV testing simplified in terms of the number of measurements taken and the redundancy of measurement, for production vehicle testing, based on the recommendations of Reference 10. This is summarized in Tables A-XI and A-XII for flat barrier and pole impact tests as described in Reference 13.

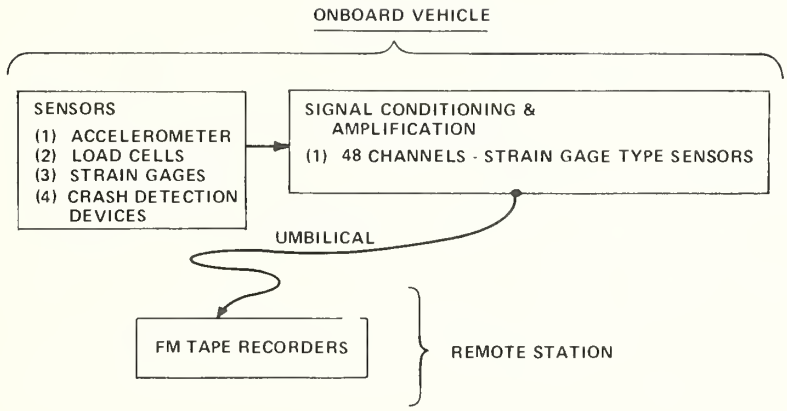


Figure A-1. Block Diagram Of Basic Data Recording System

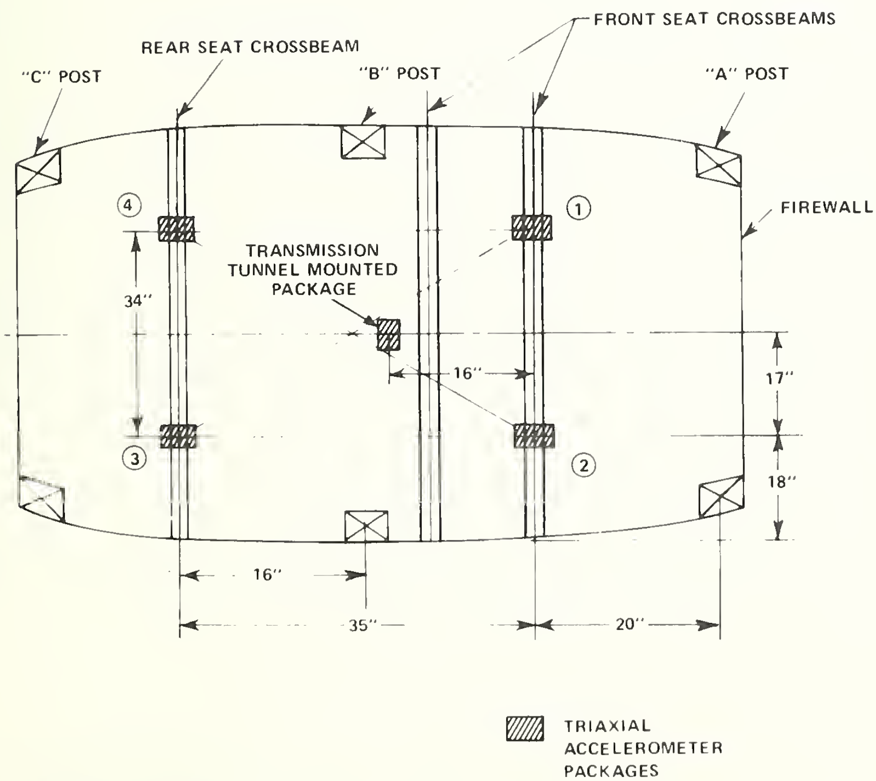


Figure A-2. Schematic Of Passenger Compartment Showing Accelerometer Locations

NO. 1 VEHICLE TESTED ______________________________ DATE __________

NO. 2 VEHICLE TESTED ______________________________

NOMINAL TEST CONDITIONS

VEHICLE WEIGHT 1 ________ LBS. CAL TEST NO. ____________________

VEHICLE WEIGHT 2 ________ LBS. P. ENG. ____________________

DESCRIPTION OF TEST OBJECTIVES

MEASURED VEHICLE IMPACT VELOCITY (MPH):

ROAD TRIP SWITCHES ____________*

FILM DATA __________, REBOUND ____________

COMPARTMENT ACCELEROMETERS ______________**

MEASURED VEHICLE IMPACT ANGLE __________ DEGREE

IMPACT POINT ON VEHICLE ______________________________

TOW ROAD CONDITIONS ______________________________

AMBIENT TEMPERATURE ______ °F

CHANNELS RECORDED ON FM TAPE ______________________________

CHANNELS RECORDED ON OSCILLOGRAPH ______________________________

POST TEST VISUAL INSPECTION CAR NO. 1 CAR NO. 2

FINAL REBOUND DISTANCE __________ INCHES __________ INCHES

FINAL CRUSH DISTANCE __________ INCHES __________ INCHES

Figure A-3. Vehicle Impact Test - Data Summary

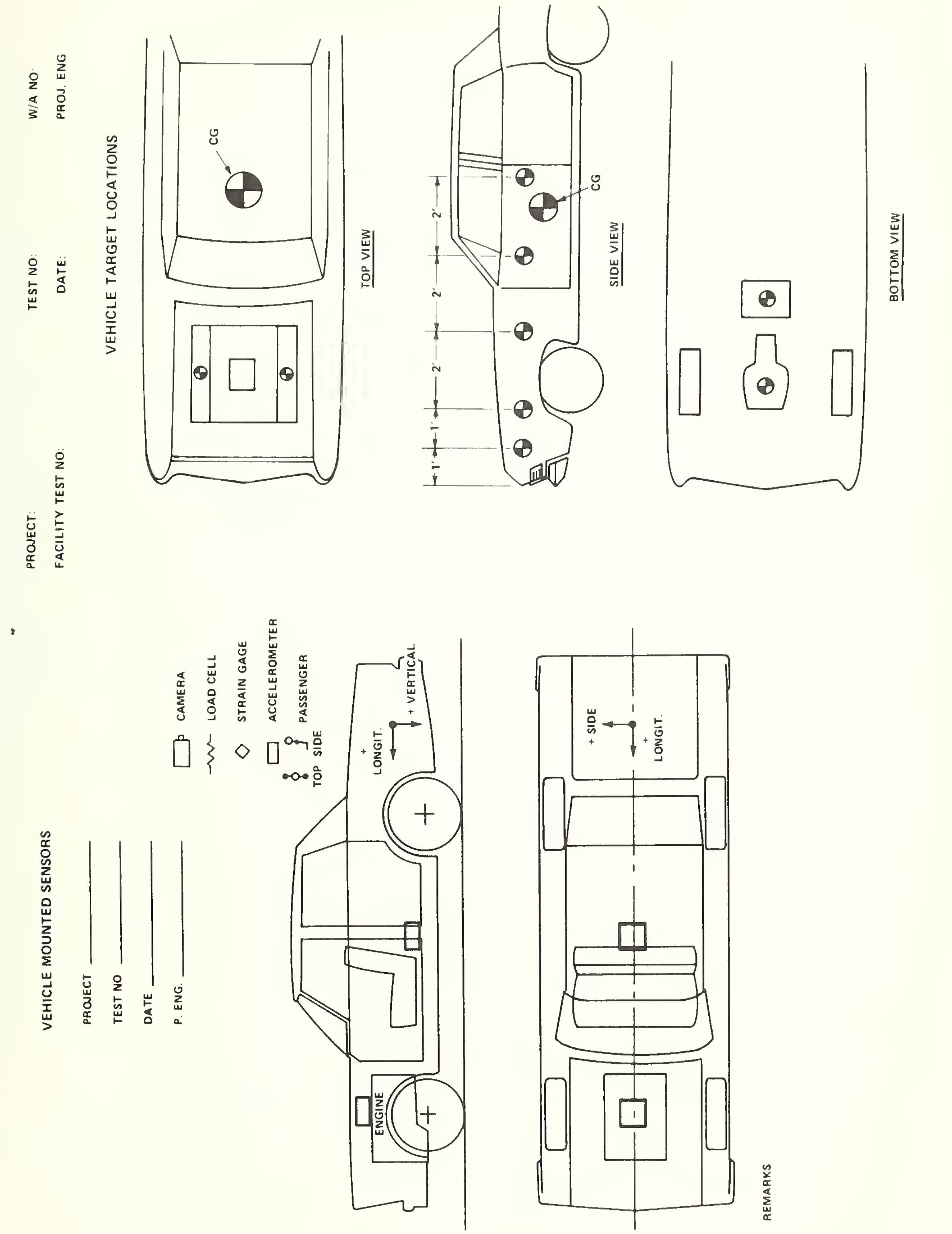
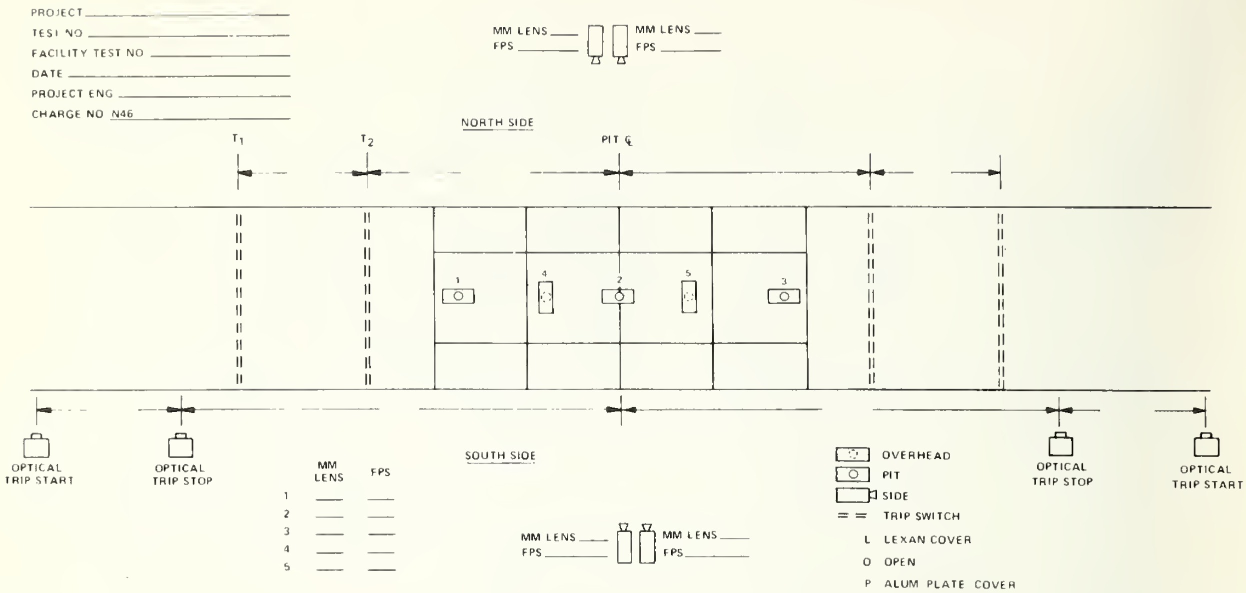


Figure A-4. Vehicle Sensor and Target Location Description



PROJECT: TEST NO: W/A NO.

FACILITY TEST NO: DATE: PROJ ENG

TEST SITE LOCATION OF SENSORS AND CAMERAS

TEST VEHICLE ______________

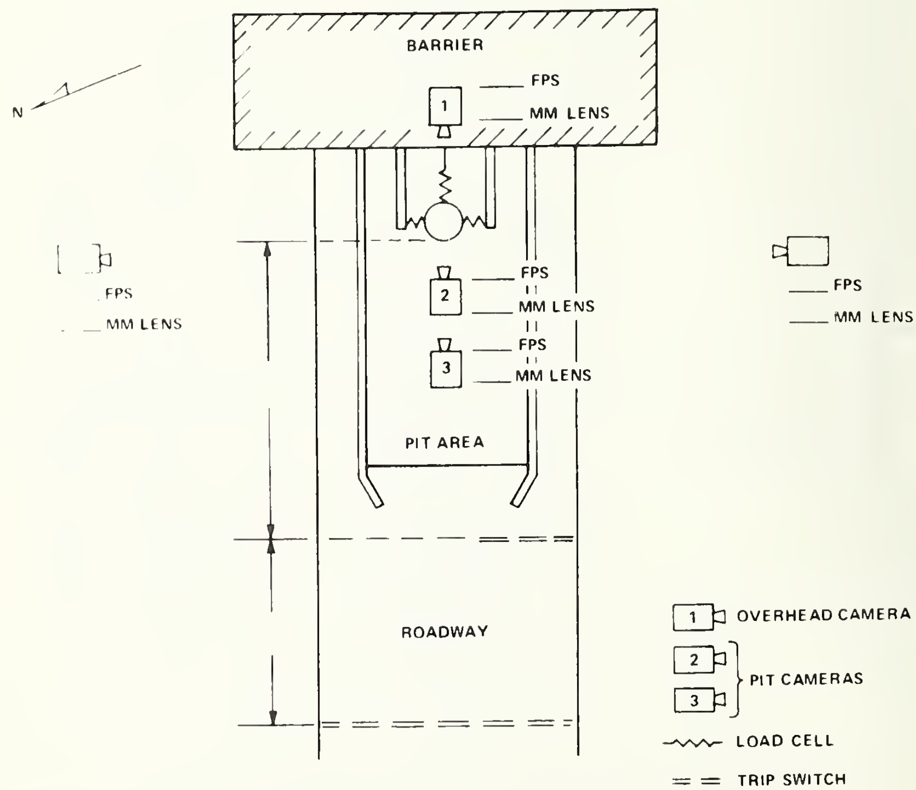


Figure A-5. Test Site Location Of Sensors And Cameras

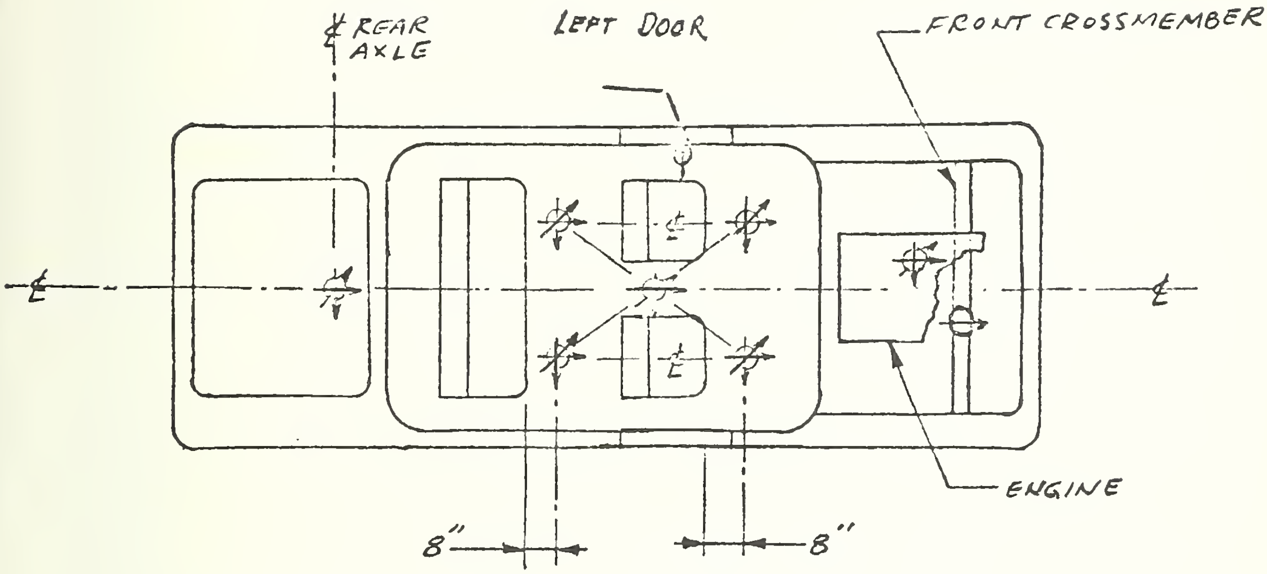


Figure A-6. Compact Car Floor Plan, Typical Accelerometer Locations

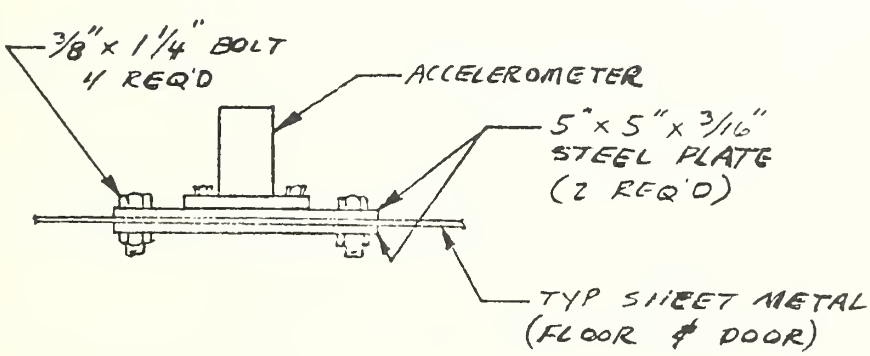


Figure A-7. Typical Accelerometer Mounting on Sheet Metal Surfaces

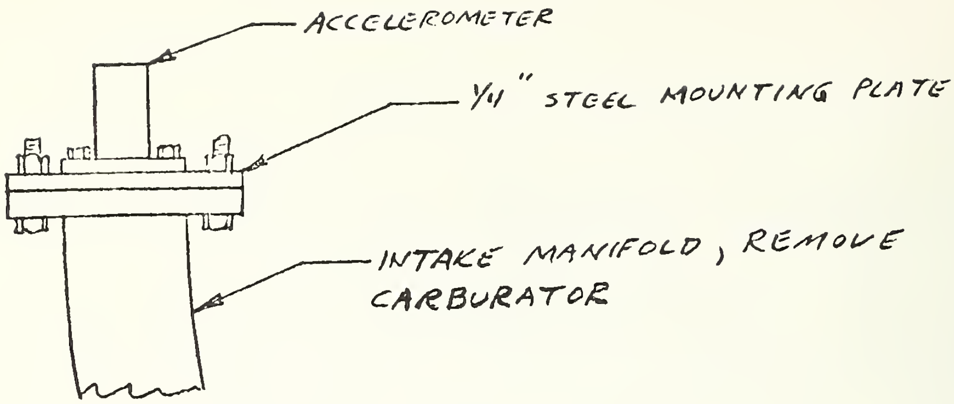


Figure A-8. Engine Accelerometer Location

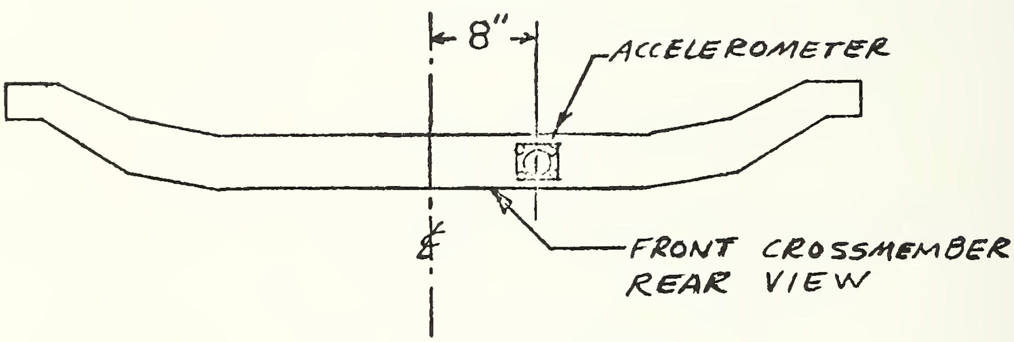


Figure A-9. Front Crossmember Accelerometer Location

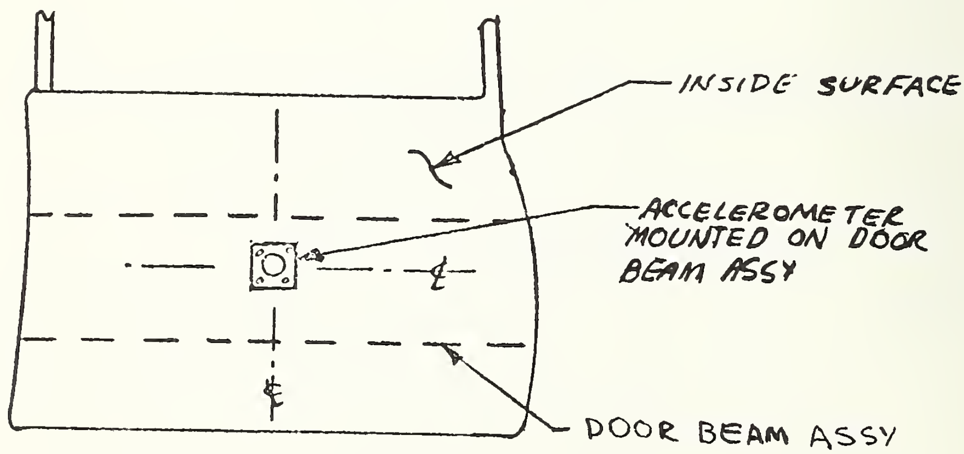


Figure A-10. Door Accelerometer Location

TABLE A-I. DATA ACQUISITION LIST AND CORRESPONDING INSTRUMENTATION REQUIREMENTS AND SELECTION

Detailed Data Acquisition Parameter	Principal Instrumentation Req'ments and Sources					Selected Transducer Data					Associated Equipment and Techniques			
	Transducer Type	Range	B.W.	Accuracy	Ref. Report	Mfg.	Model No.	Range	B.W.	Accuracy	Telemetry	Recording	Filtering	Calibration

TABLE A-II. PRINCIPAL DATA AQUISITION PARAMETERS AND CORRESPONDING PRINCIPAL CHARACTERISTICS OF INSTRUMENTATION (Calspan Corporation)

VEHICLE PARAMETERS	Component	Resultant		Mounting	Location	Mfr	Model No.	Range	Accuracy	Bandwidth
Tunnel Acceleration	x, y and/or z	√		Note 5	Figure 2	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
Pass. Compartment										
Accelerations, Corners 1,2,3,4	x, y and/or z	√		Note 5	Figure 2	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
Rear Deck Accelerations	x, y and/or z	√		Note 5	Note 1	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
Engine Acceleration	X, y and/or z	√		Note 2	Note 2	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
Strain Measurements	uniaxial			Note 9	Note 9	BLH	SR4-A13, A7	±1000μIN/IN	1%	Note 3
DUMMY PARAMETERS										
Head Acceleration	x, y and/or z	√		Note 4	Note 4	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
(4) Passenger Locations										
Chest Acceleration	x, y and/or z	√		Note 4	Note 4	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
(4) Passenger Locations										
Pelvis Acceleration	x, y and/or z	√		Note 4	Note 4	CEC	4-202 and 4-203	±250g	±.5%FS	DC-1400HZ
(4) Passenger Locations										
Femur Loads - Right	Uniaxial			Note 6	Note 6	GSE	2430	3000LB	Note 10	Note 3
Femur Loads - Left	Uniaxial			Note 6	Note 6	GSE	2430	3000LB	Note 10	Note 3
(4) Passenger Locations										

TABLE A-II. PRINCIPAL DATA AQUISITION PARAMETERS AND CORRESPONDING PRINCIPAL CHARACTERISTICS OF INSTRUMENTATION (Calspan Corporation) (Continued)

RESTRAINT SYSTEM PARAMETERS	Component	Resultant		Mounting	Location	Mfr.	Model No.	Range	Accuracy	Bandwidth
Lap Strap - Right	uniaxial			Note 7	Note 7	Lebow	3371	3500 LB	Note 8	Note 3
Lap Strap - Left	uniaxial			Note 7	Note 7	Lebow	3371	3500 LB	Note 8	Note 3
(4) Passenger Locations										
Shoulder Strap - Upper	uniaxial			Note 7	Note 7	Lebow	3371	3500 LB	Note 8	Note 3
Shoulder Strap - Lower	uniaxial			Note 7	Note 7	Lebow	3371	3500 LB	Note 8	Note 3
IORS Deployment Time	scalar						N/A	N/A	N/A	N/A
IORS Pressure History	scalar			Note 12	Note 12	Viatran	PTB209	±20 PSI	EST 1%	DC-7300 HZ
Compartment Noise Level	scalar			Note 13	Note 13	Kistler	206M112	±50 PSI	.0005 PSI*	2-20 KHZ
BARRIER PARAMETERS										
Pole Support Structure										
Top, Center	parallel to impact					BLH	C2P1	200,000 LB	1%	1 KHZ (MIN)
Top, left and right side	parallel to impact					BLH	C2P1	50,000 LB	1%	1 KHZ (MIN)
Bottom, Center	parallel to impact					BLH	C2P1	200,000 LB	1%	1 KHZ (MIN)
Bottom, left and right side	parallel to impact					BLH	C2P1	50,000 LB	1%	1 KHZ (MIN)

*resolution

NOTES CORRESPONDING TO TABLE A-II

1. Location appears to be on vehicle centerline on deck above rear axle.

2. Accelerometer package is mounted to a flat steel plate, the carburetor is removed, the accelerometer package is recessed into the intake manifold for protection, and the flat plate secured to the engine using the carburetor tie down hole pattern. If the carburetor cavity is not large enough to accomodate the accelerometer package, a large hole is burned-out and a new hole pattern provided, as necessary.

3. Information for suitable description, not available.

4. Installation of instrumentation in dummies is a function of mounting and available space configuration within dummy head, chest and pelvic cavities, and the geometry of the selected instrumentation. These details are not available in the literature.

5. Mounting is accomplished by welding a flat, steel plate (5 x 5 1/4 in thick) with tapped holes, to the structure. The accelerometer package is attached to a second plate (of equal size) which is in turn, bolted to the welded plate. The mating surfaces between the accelerometer package and the intermediate plate, and intermediate plate to the (top surface of) welded plate, are surface finished for good mechanical fit. The unit is enclosed in a "protective" sheet metal cover.

6. Location is in upper leg; exact location is unknown. Position may vary with dummy used. Mounting for this transducer is pin-mounted at each end, 3/8 in dia pins on 4 in centers.

7. Location and mounting is on belt, on either side of dummy. Mounting is accomplished by removing two removable rods, positioning transducer on the belt and replacing the rods.

8. Accuracy is affected by changes in belt thickness as load is applied. Stated accuracy is for a "best fit" curve. Errors up to 12% are possible, as quoted by manufacturer.

9. Mounted by cementing to a flat surface on a (shaft or structure) where the strain is to be measured. Locations are quite variable.

10. Accuracy can be affected by off-center loading or torque loading on the transducer. This is usually a specification which is not stated by manufacturer (e.g. a 150 ft lb static torque generated an error of approximately 7% of fuel rated load).

11. Crash sensor squib (ignitor) voltage is monitored directly - a matter of electrically tapping this voltage.

NOTES CORRESPONDING TO TABLE A-II (CONTINUED)

12. A piece of copper tubing is mounted, fed into deflated bag, transducer mounted to other end of tubing, in general area of airbags (location is flexible).

13. Location per Air Cushion Deployment Sound Intensity Measurements, by E.H. Klove, Fisher Body Div, GM Corp. (There is a location recommendation per SAE J247). Mounted using ceiling bracket. DC shifts in measurements were common.

TABLE A-III. DESIRED DATA

(1) Basic Vehicle Parameters

Approach velocity and acceleration
Impact velocity (also, rebound velocity, distance, and resistance)
Angle of impact
Force/time response (and/or acceleration/time response) - various locations on frame, seat anchorages, engine, etc.
Force/distance response (and/or acceleration/distance response) - various locations on frame, seat anchorages, engine, etc.
Net crush and crush/time data of key structural members, including the frame; front bumper subsystem; rear bumper subsystem; and occupant compartment
Steering column load/time and displacement/time characteristics
Fuel loss
Vehicle electrical-system performance
Vehicle curb weight and test weight (total and at each wheel)
Vehicle roll, pitch, and yaw - displacement, velocity, and acceleration
Contact indicators (various points between engine and firewall, wheels and wheel housings, etc.)

(2) Vehicle/Restraint System Dynamic-Interaction Parameters

Lap and shoulder belt loads (if applicable)
Thrust loads of inflatable restraints (if applicable)
Motion characteristics of restraint system mountings (including those which would affect the angle of IORS bag deployment, if applicable) and/or anchorages
IORS triggering time and supply voltage (if applicable)
IORS bag internal pressure (if applicable)
IORS detonator voltage (if applicable)
Noise level in occupant compartment
Air pressure level in occupant compartment

(3) Barrier Parameters

Acceleration/time and/or force time

(4) Dummy Dynamics

Head displacement, velocity, acceleration, and rate of onset - triaxial
Chest displacement, velocity, acceleration, and rate of onset - triaxial
Pelvis displacement, velocity, acceleration, and rate of onset - triaxial
Head angular displacement, acceleration, and rate of onset
Chest deflection
Chest load
Femur load
Tibia load
Head laceration (measured according to the Wayne State University Laceration Severity Index procedure)

(5) General Test Information

Calibration and checkout data - including (a) dummy muscle tone and dynamic response and (b) channel and test identification information
High-speed photographs of overall vehicle and dummy response, including coverage of the side, top, and bottom of the vehicle
Documentary film and/or video tape coverage of critical precrash (including vehicle in-run) and postcrash activities
Precision still photographs (before and after shots in all major projections taken from given camera locations)
Time of impact (t_0) and master time base data
Signal noise level (various sensor/transmission paths)
Natural frequency of "transducers" as installed

TABLE A-IV. CANDIDATE ELECTRONIC EQUIPMENT

Location: Major	Location: Detailed	Parameter	System Rank	Approximate Maximum Range of Interest: Amplitude	Approximate Maximum Range of Interest: Frequency, Hz	Approximate Maximum Channel Amplitude	Candidate Transducer(s)[a]: Type	Candidate Transducer(s)[a]: Make	Candidate Transducer(s)[a]: Model	Power Supply[b]	Signal Conditioning[b]	Telemetering Technique[b]	Recording Technique[b]	Calibration Technique[b]
Vehicle	Approach	Velocity	Primary	75 mph	--	100 mph	DC tachometer on 5th wheel	Labeco	Part No. TT621	None required	S-3	T-1	R-1 R-3	C-2
			1st backup	75 mph	--	100 mph	Magnetic-pulse generator on 5th wheel	Labeco	Part No. TT593 1 pulse/ft	None required	S-5	T-2	R-1 R-2 R-3	C-2
Vehicle	Impact	Velocity	Primary	75 mph	--	100 mph	Doppler/radar meter with voltage output	West Bend	1200	Self-contained	S-4	T-1	R-1 R-3	C-3
			1st backup	75 mph	--	100 mph	2 Photosensors 2 Light sources Interval timer	Texas Instruments Hewlett Packard		P-3	Self-contained	T-1	R-1 after manual coding	C-3
Vehicle	Rebound	Acceleration, uniaxial	Primary	±10 G	dc-180	±20 G	Accelerometer	Setra	100-25 G	P-1	S-3	T-1-U	R-1 R-3	C-1
			1st backup	±10 G	dc-180	±20 G	String potentiometer – differentiate signal twice – electronic or manual calculation	Transducer Controls Corp.	TCC-PT-101	P-3	S-4	T-1	R-1 R-3	C-2
			2nd backup	±10 G	dc-180	±20 G	Doppler/radar meter with voltage output analogous to velocity	West Bend	1200	Self-contained	S-4	T-1	R-1 R-3	C-3
Vehicle	Rebound	Resistance	Primary	6000 lb	dc-50	10,000 lb	Strain gage, load cell	Lebow	3124-10K	P-3	S-4	T-1	R-1 R-3	C-2
Vehicle	Seat anchors, engine, several places on frame/ occupant compartment	Acceleration, triaxial (also vehicle roll, pitch, and yaw – calculated from linear values at a fixed distance)	Primary	±200 G	dc-180	±500 G	Accelerometer	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-2-U	R-1 R-3	C-1
			1st backup	±200 G	dc-180	±500 G	Accelerometer	Statham or Setra	A69T6-500 G 111-500 G	P-1	S-1 or S-3	T-2	R-2	C-1
			2nd backup	±200 G	0.1-180	±500 G	Accelerometer	Kistler	891	P-2	S-2	T-3	R-1 R-3	C-1
Vehicle	Frame and structural members	Relative crush/time	Primary	36 in.	dc-120	50 in.	String potentiometer	Transducer Controls Corp.	TCC-PT-101	P-1	S-3	T-1-U	R-1 R-3	C-2
			1st backup	36 in.	dc-120	50 in.	Accelerometer (output double integrated)	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-2	R-2	C-1
			2nd backup	36 in.	dc-120	50 in.	Doppler/radar meter with voltage output analogous to velocity	West Bend	1200	Self-contained	S-4	T-1	R-1 R-3	C-3

TABLE A-IV. CANDIDATE ELECTRONIC EQUIPMENT (CONT'D)

Location		Parameter	System	Approximate Maximum Range of Interest		Approximate Maximum Channel	Candidate Transducer(s)(a)			Power	Signal Condit-	Telemetering	Recording	Calibration
Major	Detailed		Rank	Amplitude	Frequency, Hz	Amplitude	Type	Make	Model	Supply(b)	ioning(b)	Technique(b)	Technique(b)	Technique(b)
Vehicle	Electrical system	Voltage	Primary	12 vdc	dc-1000	20 vdc	None required, direct measurement	--	--	--	S-3	T-2-U	R-1 R-3	C-2
			1st backup	12 vdc	dc-1000	20 vdc	Ditto	--	--	--	S-3	T-3	R-1 R-3	C-2
Vehicle	Steering wheel	Force, axial, and moments 2 axes at 90 deg	Primary	1800 lb	dc-1000	3000 lb	Strain-gage force sensor	Custom made	--	P-1	S-1	T-1-U	R-1 R-3	Force C-1, Moment C-2
Vehicle	Steering wheel	Angular rotation	Primary	±1080 deg	dc-100	±1200 deg	RVDT	--	--	P-1	S-3, plus perhaps self-contained carrier sys.	T-1-U	R-1 R-3	C-1
Vehicle/ restraint system	Seat belt	Force	Primary	2500 lb	dc-1000	3500 lb	Load cell, strain gage	Lebow	3371 3500 lb	P-1	S-1	T-1-U	R-1 R-3	C-2
Vehicle/ restraint system	Inflatable restraint mounting	Force	Primary	Unknown	dc-1000	Unknown	Load cell, strain gage			P-1	S-1	T-1-U	R-1 R-3	C-2
Vehicle/ restraint system	Restraint system mounting	Motion	Primary	10 in.	dc-120	20 in.	String potentiometer	Transducer Controls Corp.	TCC-PT-101	P-1	S-3	T-1-U	R-1 R-3	C-2
Vehicle/ restraint system	Inflatable restraint system	Triggering time and supply voltage	Primary	12 vdc	dc-120	20 vdc	None required, direct meas. of 12 vdc step	--	--	--	S-3	T-1-U	R-1 R-3	C-2
Vehicle/ restraint system	Inflatable restraint system	IORS detonator voltage	Primary	12 vdc	dc-120	20 vdc	None required, direct meas. of 12 vdc step	--	--	--	S-3	T-1-U	R-1 R-3	C-2
Vehicle/ restraint system	Inflatable pressure system	IORS bag internal pressure	Primary	9 psig	dc-1000	20 psig	Pressure transducer	Setra	200-100 psig	P-1	S-1	T-1-U	R-1 R-3	C-2
Barrier	Face	Force	Primary	600,000 lb	dc-180	1,000,000 lb	Load cell, strain gage	Lebow	3117-150K-dual bridge 2S required	P-3	S-4	T-1	R-1 R-3	C-2
			1st backup	600,000 lb	dc-180	1,000,000 lb	Load cell, strain gage	Lebow	Common with above	P-3	S-4	T-1	R-1 R-3	C-2
Simulated occupant (dummy)	Head	Acceleration linear and angular*, triaxial (*angular values to be calculated from linear values at a fixed distance)	Primary	±100 G and ±1800 rad sec^2	dc-1000	±200 G	Accelerometer	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-2-U	R-1 R-3	C-1
			1st backup for linear accel. and primary for angular accel.	±100 G and ±1800 rad sec^2	dc-1000	±200 G	Accelerometer	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-2-U T-2	R-1 R-2 R-3	C-1

TABLE A-IV. CANDIDATE ELECTRONIC EQUIPMENT (CONT'D)

Location Major	Location Detailed	Parameter	System Rank	Approximate Maximum Range of Interest: Amplitude	Approximate Maximum Range of Interest: Frequency, Hz	Approximate Maximum Channel Amplitude	Candidate Transducer(s)[a] Type	Candidate Transducer(s)[a] Make	Candidate Transducer(s)[a] Model	Power Supply[b]	Signal Conditioning[b]	Telemetering Technique[b]	Recording Technique[b]	Calibration Technique[b]
General items (Cont'd)							Contact strips on barrier and bumper	Custom-made	--	P-1 P-3	S-5	T-2 T-2-U	R-1 R-2 R-3	C-2
			Primary	1000 sec	100 Hz and 1000 Hz	Continuous	IRIG 1000 Hz and 100 Hz Contact strips on barrier and bumper	EE Co. of California	911	Self-contained or P-2	Self-contained	T-2 T-2-U	R-1 R-2 R-3	C-3
			1st backup	1000 sec	--	Continuous	Visible clock with analog output signal at 1000 and 100 Hz	Not avail., make in-house or contract out	--	P-3	S-4	T-2	R-1 R-3	C-3
General items	Vehicle	Weight per wheel	Primary	1500 lb	dc	2000 lb	Strain gage, load cell, or precision scale			P-3	S-1	T-1	Data sheet	C-2

(a) The instruments and other equipment identified are not necessarily the best or only means of accomplishing the desired measurement. They are listed because either (1) researchers in the automotive-crash field have found these to be satisfactory or (2) members of the project staff have identified these as having good potential for accurate measurements under the specified test conditions.

(b) Legend

Power Supply
- P-1 Battery/Ni-Cd/on board/6-10 vdc
- P-2 Battery/Ni-Cd/on board/28 vdc
- P-3 Battery/off board

Signal Conditioning: Should have limiting on inputs of VCOS to limit signal to maximum channel amplitude, and filtering to 1000 Hz; should use ruggedized solid-state circuits and calibration connectors
- S-1 Bridge-balancing resistors, VCO or MVCO, mixer, driver amplifier/on board
- S-2 Similar to S-1 except charge amplifier replaces bridge balance
- S-3 VCO, mixer, driver amplifier/on board
- S-4 VCO, mixer/off board
- S-5 Voltage divider and/or amplifier to adjust voltage to desired channel height

Telemetry:
- T-1 2-conductor w/ IRIG shield cable
- T-2 Cable, coax w/ shield

  "U" identifier, as in T-1-U, denotes umbilical cable
- T-3 Radio-telemetering equipment VHF/FM/216-220 MHz

Recording:
- R-1 Mag tape/AM/14 channel/off board
- R-2 Mag tape/AM/14 channel/on board
- R-3 Recording oscilliograph/multichannel/off board

  Note: For calibration and "quick-look" use — not necessarily on-line during the crashes
- R-4 Interval timer

Calibration:
- C-1 ±1/4, ±1/2, and ± full scale, using shunt resistors for strain-gage transducers, battery voltage to simulate the output of some transducers, or physically operating the transducers where possible
- C-2 1/4, 1/2, and full scale, using shunt resistors for strain-gage transducers, battery voltage to simulate the output of some transducers, or physically operating the transducers where possible
- C-3 Lab comparison

TABLE A-IV. CANDIDATE ELECTRONIC EQUIPMENT (CONT'D)

Location: Major	Location: Detailed	Parameter	System Rank	Approximate Maximum Range of Interest: Amplitude	Approximate Maximum Range of Interest: Frequency, Hz	Approximate Maximum Channel Amplitude	Candidate Transducer(s)[a]: Type	Candidate Transducer(s)[a]: Make	Candidate Transducer(s)[a]: Model	Power Supply[b]	Signal Conditioning[b]	Telemetering Technique[b]	Recording Technique[b]	Calibration Technique[b]
Simulated occupant (dummy) (Cont'd)			2nd backup	±100 G and ±1800 rad/sec[2]	0.1-1000	±200 G	Accelerometer	Kistler	891	P-2	S-2	T-3	R-1 R-3	C-1
Simulated occupant	Chest	Acceleration, triaxial	Primary	±100 G	dc-1000	±200 G	Accelerometer	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-2-U	R-1 R-3	C-1
			1st backup	±100 G	dc-1000	±200 G	Accelerometer	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-2	R-2	C-1
			2nd backup	±100 G	dc-1000	±200 G	Accelerometer	Kistler	891	P-2	S-2	T-3	R-1 R-3	C-1
Simulated occupant	Pelvis	Acceleration, triaxial	Primary	±100 G	dc-1000	±200 G	Accelerometer	Setra or Endevco	111-500 G 2260 C	P-1	S-3 or S-1	T-1-U	R-1 R-3	C-1
Simulated occupant	Chest	Deflection	Primary	2.0 in.	dc-180	2.5 in.	Potentiometer, linear	CIC	Rectilinear 2-3/4 in. stroke	P-1	S-3	T-1-U	R-1 R-3	C-2
Simulated occupant	Chest	Force	Primary	1800 lb	dc-180	2500 lb	Infer from load/defl. characteristic and dynamic defl.							
Simulated occupant	Femur	Force	Primary	1400 lb compression	dc-1000	2000 lb	Strain gage, bridge	Baldwin	FAET-06C-1256	P-1	S-1	T-1-U	R-1 R-3	C-2
Simulated occupant	Tibia	Force	Primary	1400 lb compression	dc-1000	2000 lb	Strain gage, bridge	Baldwin	FAET-06C-1256	P-1	S-1	T-1-U	R-1 R-3	C-2
General items	Occupant compartment	Noise level	Primary	180 db	20-20,000	184 db	Condenser microphone	Bruel & Kjaer	4138	P-1	Special covered in text	T-2-U	R-1 R-3	C-1
			1st backup	180 db	20-20,000	184 db	Condenser microphone	Bruel & Kjaer	4138	P-1	Ditto	T-2	R-2	C-1
General items	Occupant compartment	Pressure level	Primary	2 psig	dc-1000	4 psig	Pressure sensor	Setra	230-5 psig	P-1	S-3	T-2-U	R-1 R-3	C-1
			1st backup	2 psig	dc-1000	4 psig	Pressure sensor	Setra	230-5 psig	P-1	S-3	T-2	R-2	C-1
General items	Instrument signals	Noise level	Primary	--	dc-1000	--	Direct meas., umbilical cable	--	--	--	S-3	T-2-U	R-1 R-3	--
			1st backup	--	dc-1000	--	Direct meas., on-board tape	--	--	--	S-3	T-2	R-2	--
General items (Cont'd)			2nd backup	--	dc-1000	--	Direct meas., radio-telemetry system	--	--	--	S-3	T-3	R-1 R-3	--
General items	Time	t_o and master time data	Primary	1000 sec	--	59.999 sec and repeat	Digital gen.	Adtrol	N-S	Self-contained	Self-contained	--	Film only	C-3
							Flash tubes	G.E.	FP-2	Self-contained	--	--	Film only	--

TABLE A-V. KEY INSTURMENT SPECIFICATIONS

Location		Parameter	Approximate Range of Primary Interest		Required End-to-End Accuracy (a)
Major	Detailed		Amplitude	Minimum Flat Frequency Response, Hz	
Vehicle	Approach	Velocity	0-75 mph	--	±4% for data ±0.1% for control
"	Impact	Velocity	0-75 mph	--	±0.1%
"	Rebound	Acceleration	±10 G	DC-180	No greater than ±4%
"	Rebound	Resistance	6000 lb	--	Ditto
"	Seat anchors, engine, numerous place on frame, etc.	Acceleration	±200 G	DC-180	"
"	Frame and structural members	Relative crush/time	0-50 inch	DC-120	"
"	--	Attitude (roll, pitch, and yaw)	Indefinite	DC-120	"
"	Steering column	Load/time	1800 lb	DC-1000	"
"	Steering wheel	Angle	±1080°	DC-100	"
" "	Occupant compartment	Noise level	180 db	20-20,000	±1 db
"	Occupant com partment	Pressure level	2 psig	DC-1000	≤±4%
"	Electrical system	Voltage	12 volts	DC-1000	≤±4%
"	--	Weight	1500 lb/wheel	DC	±10 lb
Vehicle/restraint system	Seat belt	Load	2500 lb	DC-1000	No greater than ±4%
Ditto	IORS	Mounting reaction force	Unknown	DC-1000	Ditto
"	IORS & seat belt mounting	Motion	10 inches	DC-120	"
"	IORS	Triggering time and voltage	12 v dc	DC-120	"
"	IORS	Bag internal pressure	9 psig	DC-1000	"
Barrier	--	Force	600,000 lb	DC-180	"
Dummy	Head	Acceleration, linear	±100 G	DC-1000	"
		Acceleration, angular	1800 rad/sec^2	DC-1000	"
"	Chest	Acceleration	±100 G	DC-1000	"
"	Pelvis	Acceleration	±100 G	DC-1000	"
"	Chest	Deflection	2.0 inches	DC-180	"
"	Chest	Force	1800 lb	DC-180	"
"	Femur	Force	1400 lb compression	DC-1000	"
"	Tibia	Force	1400 lb compression	DC-1000	"
t_0 and master time data	--	Time	--	--	1 ms
General	Signal	Noise level	Millivolts	DC-1000	≤±4%

(a) This accuracy specification applies across the complete minimum flat frequency response listed in the adjacent column (see Appendix B for a discussion of data accuracy). Maximum rolloff above the cutoff frequency should be in accordance with the SAE Proposed Recommended Practice for Barrier Collision Tests - SAEJ211. This is approximately 12 db/octave starting at 1.67 times the frequency at the top end of the specified flat frequency range.

TABLE A-VI. SAFETY R&D LAB COMMON DATA CHANNELS

LOCATION	TYPE	AXIS	MFG.	MODEL	MAX. RANGE	SAE CLASS	
DUMMIES							
HEAD	Acc	Triax	Endevco	7231C-S	750g	1000	
CHEST	Acc	Triax	Endevco	7231C-S	750g	180	
FEMUR	Load	Axial	GSE	T-2430	3000#	600	
HEAD	Contact						
VEHICLE							
ROCKER PANEL	Acc	Axial	Endevco	7231C-S	750g	60	Average 4 corners
IMPACT	Velocity	Axial	SRDL				4' Light Trap
COLUMN	Displacement	Axial	SRDL				String Pots
RESTRAINT							
BELTS	Load	Axial	SRDL	5100	4000#	60	
BARRIER							
FACE	Load	Axial	SRDL		750#/unit	60	

PRE TEST

WEIGHT - Gas Tank Filled W/Stoddard Solvent

POST TEST

VEHICLE CRUSH

GAS TANK LEAKAGE

WINDSHIELD RETENTION

FILM ANALYSIS

DUMMY HEAD KINEMATICS & GLOVE BOX DOOR

HEAD - CONTACT - BACKUP

UNDERBODY - FRONT & REAR

WINDSHIELD RETENTION - FRONT

TABLE A-VII. ACCELERATION AND LOAD MEASUREMENTS

Meas. No.	Description	Location	Test Numbers	Drawing or Figure	Range
1	Acceleration, longitudinal, Car A	Left Front Passenger	1 - 14	1 & 2	0-200'G
2	" lateral, "	" " "	"	"	"
3	" vertical, "	" " "	"	"	"
4	" longitudinal, "	Right " "	"	"	"
5	" lateral, "	" " "	"	"	"
6	" vertical, "	" " "	"	"	"
7	" longitudinal, "	Left Rear "	"	"	"
8	" lateral, "	" " "	"	"	"
9	" vertical, "	" " "	"	"	"
10	" longitudinal, "	Center of other four passenger accelerometers			
11	" lateral, "	" " "	"	"	"
12	" vertical, "	" " "	"	"	"
13	" longitudinal, "	Right Rear "	"	"	"
14	" lateral, "	" " "	"	"	"
15	" vertical, "	" " "	"	"	"
16	" longitudinal, "	Rear Trunk	"	"	"
17	" lateral, "	" "	"	"	"
18	" vertical, "	" "	"	"	"
19	" longitudinal, "	Engine	"	1 & 3	"
20	" lateral, "	"	"	"	"
21	" vertical, "	"	"	"	"
22	" longitudinal, "	Front Crossmember	1,2,3	1 & 4	"
23	Acceleration, lateral Car A	℄ right door (inside)	4	1 & 5	0-200"G"
24	" longitudinal Car B	Left front passenger	5-14	1 & 2	
25	" lateral "	Left Front passenger	5-14	"	
26	" vertical "	Left front passenger	5-14	"	
27	" longitudinal "	Right front passenger	5-14	"	
28	" lateral "	Right front passenger	5-14	"	
29	" vertical "	Right front passenger	5-14	"	
30	" longitudinal "	Left rear passenger	5-14	"	
31	" lateral "	Left rear passenger	5-14	"	
32	" vertical "	Left rear passenger	5-14	"	
33	" longitudinal "	Center of other four passenger accelerometers	5-14	"	
34	" lateral "	" " "	5-14	"	
35	" vertical "	" " "	5-14	"	
36	" longitudinal "	Right rear passenger	5-14	"	
37	" lateral "	Right rear passenger	5-14	"	
38	" vertical "	Right rear passenger	5-14	"	
39	" longitudinal "	Rear trunk	5-14	"	
40	" lateral "	Rear trunk	5-14	"	
41	" vertical "	Rear trunk	5-14	1 & 2	
42	Acceleration longitudinal Car B	Engine	5-14	1 & 2	0-200"G"
43	" lateral "	"	5-14	1 & 2	
44	" vertical "	"	5-14	1 & 2	
45	" lateral "	℄ Left door (inside)	12,13,14	1 & 5	
46	" lateral "	℄ Right door (inside)	10,11	1 & 5	
47	Load Cell Barrier	Upper left	1,3		
48	"	Lower left	1,3		
49	"	Upper right	1,3		
50	"	Lower right	1,3		
51	Load Cell Pole	Upper	2 & 4		
52	"	Lower	2 & 4		

Test No. 1 & 3
Acc. Total 22
Load 4
Total 26

Test No. 2 & 4
Acc. Total 22
Load 2
Total 24

Test No. 5-9
Acc. Total 42

Test No. 10-14
Acc. Total 43

TABLE A-VIII. DESCRIPTION OF TRANSDUCERS UTILIZED BY TRANSPORTATION RESEARCH CENTER OF OHIO (TRC)

TRANSDUCER	TYPE	RANGE	B.W.	ACCURACY	REF. REPORT	MFR	MODEL	LOCATION	MOUNTING
Accelerometers a)	Strain-gage	±25g				B&H	4-202-0001		
b)	Strain-gage	±50g				B&H	4-202-0001		
c)	Strain-gage	±100g				B&H	4-202-0001		
d)	Piezorestive	±25g				Endevco	2260C		
e)	Piezorestive	±75g				Endevco	7232C-750		
f)	Piezorestive	±							
	triaxial	±75g							
Femur load transducer a)	Straingage	3000#				Sensotec	00A0206		
Pressure transducers a)	Straingage	0-50 psia				Statham	PA 288TC-50-350		
b)	Straingage	0-2500 psig				B & H	4-326-0012		
c)	Straingage	0-5000 psig				B & H	4-326-0001		

TABLE A-IX. DATA ACQUISITION LIST & CORRESPONDING INSTRUMENTATION REQUIREMENTS & SELECTION

DETAILED DATA ACQUISITION PARAMETER	PRINCIPAL INSTRUMENTATION REGIMENTS & SOURCE				
	Transducer Type	Range	B.W.	Accuracy	Ref. Report
Accelerations	Acceleration	0-200	0-200	±5%	--
Femur Loads	Force	0-2000	0-600	±2%	--
Seat Belt Loads	Force	0-3000	0-50	±3%	--
Dummy Nodding Torque	Force	0-200	0-5	±3%	--
Dummy Chest Compression	Displacement	0-1	0-5	±2%	--

SELECTED TRANSDUCERS DATA					ASSOCIATED EQUIP. & TECH.			
Manufacturer	Model	Range	B.W.	Accuracy	Telemetry	Recording	Filtering	Calib.
Serta	113	0-250	1800	2%	T-1	R-1	F-1	C-1
Endevco		0-3000	2000	2%	T-1	R-1	F-2	C-2
LeBow	3371	0-3500	>50	3%	T-1	R-1	F-3	C-2
LeBow	3101	0-300	>50	3%	T-1	R-1	F-3	C-2
CIC	Various	0-2 1/2	>50	+2%	T-1	R-1	F-3	C-3

T-1 Telemetry over twisted-pair multiconducter cables (umbilical)

R-1 FM recording on 1" magnetic tape, off-board vehicle.

F-1 Analog filter 0-1650 Hz, 3dB, Butterworth 4-pole, 24 dB/octave rolloff

F-2 Analog filer 0-1000 Hz, 3dB, Butterworth 4-pole, 24 dB/octave rolloff

F-3 Analog filter 0-300 Hz, 3dB, Butterworth 4-pole, 24 dB/octave rolloff

C-1 Schock pulse (drop) 200 G, 40 M sec at 10% level

C-2 Press loading with seriesed standard cell

C-3 Linear displacement measured with Micrometer

TABLE A-X. COMPREHENSIVE LIST OF CRASH TEST MODES

T1 FRONTAL BARRIER

(a) Perpendicular impacts - rigid flat barrier

(b) Perpendicular impacts - deformable/deflecting flat barrier

(c) Perpendicular impacts - irregular shape rigid barrier

(d) Angled impacts - rigid flat barrier

(e) Angled impacts - deformable/deflecting flat barrier

(f) Angled impacts - irregular shape rigid barrier

T2 FRONTAL CAR TO CAR

(a) Aligned longitudinal centerlines

(b) Offset, parallel longitudinal centerlines

(c) Angled (up to 45 degrees), centered fronts

(d) Angled, offset fronts

T3 FRONTAL RIGID POLE

(a) Centered

(b) Offset from vehicle centerline

T4 SIDE IMPACT, CAR TO CAR

(a) Perpendicular at longitudinal center of struck car

(b) Perpendicular, aft of center of struck car

(c) Perpendicular, forward of center of struck car

(d) Angled, at center of struck car

(e) Angled, aft of center of struck car

(f) Angled, forward of center of struck car

TABLE A-X. COMPREHENSIVE LIST OF CRASH TEST MODES (CONTINUED)

(c) Offset, vehicle longitudinal centerlines parallel

(d) Offset, angled vehicle centerlines

T10 ROLLOVER

(a) FMVSS 208 dolly rollover

(b) Rollover from flat surface

T11 STATIC CRUSH

(a) Component/subsystem crush

(b) Total vehicle crush, longitudinal

(c) Total vehicle crush, lateral

(d) Total vehicle crush, vertical

T12 SLED ACCELERATION

(a) Occupant subsystem impact

(b) Total vehicle system impact

TABLE A-X. COMPREHENSIVE LIST OF CRASH TEST MODES (CONTINUED)

T5 SIDE IMPACT, RIGID POLE

(a) Centered in side of car

(b) Aft of car center

(c) Forward of car center

T6 MOVING BARRIER, RIGIT/FLAT BARRIER FACE

(a) Side impact, centered

(b) Rear impact, parallel to vehicle longitudinal centerline

(c) Rear impact, angled to vehicle longitudinal centerline

T7 MOVING BARRIER, RIGID POLE FRONT

(a) Side impact, centered

(b) Side impact, aft of vehicle center

(c) Side impact, forward of vehicle center

(d) Rear impact, center of vehicle

(e) Rear impact, offset from vehicle longitudinal centerline

T8 MOVING BARRIER, DEFORMABLE/DEFLECTING BARRIER FACE

(a) Side impact, centered

(b) Side impact, aft of vehicle center

(c) Side impact, forward of vehicle center

(d) Rear impact, perpendicular at vehicle longitudinal centerline

(e) Rear impact, angled at vehicle longitudinal centerline

T9 REAR IMPACT, CAR TO CAR

(a) Centered, vehicle longitudinal centerlines parallel

(b) Centered, angled vehicle centerlines

TABLE A-XI. TRANSDUCER REQUIREMENTS AND PERFORMANCE CHARACTERISTICS FOR FLAT BARRIER IMPACT

TRANSDUCER REQUIREMENTS AND PERFORMANCE CHARACTERISTICS FOR FLAT BARRIER IMPACT

Measurand	Measurement Priority	Type of Transducer	Manufacturer and Model	Full-Scale Capacity	Full-Scale Output	Transducer Accuracy (% F.S.)	Frequency Response (minimum)	Qty.	Remarks
I. Test Vehicle									
Approach and Impact Velocity	1	Fifth Wheel	Labeco TT481	>100 mph	0.077 v/mph	0.5	N/A	1	Primary Measurement
Approach Velocity	1	Velocity Digital Counter	Dynamic Science	>100 mph	10^4 counts		N/A	1	Backup Measurement, Displayed, Not Recorded
Impact Velocity	1	Speed Trap Digital Counter	Dynamic Science	-	10^4 counts		-	2	Backup Measurement, Displayed, Not Recorded
Engine Acceleration (Biaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	2	Priorities: Longitudinal = 1, Vertical = 2, Lateral = 3. See Tables 2-3 and 2-4 for location.
Occupant Compartment Acceleration (Triaxial) - 5 locations	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	15	Priorities: Longitudinal = 1, Vertical = 2, Lateral = 3. See Tables 2-3 and 2-4 for location.
Frame Acceleration, 5 locations (Triaxial) 1 location (Biaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	17	Priorities: Longitudinal = 1, Vertical = 2, Lateral = 3. See Tables 2-3 and 2-4 for location.
Vehicle Impact	1	Switch	Dynamic Science	On-Off	2.5V	-	Rise Time 350μs	2	One Switch on Vehicle, One Switch on Barrier.
II. Restraint System									
IORS Initiation Time	1	Voltage Divider	Dynamic Science	On-Off	1V	-	Rise Time 350 μs	1	See Table 2-5 for connections.
IORS Supply Voltage (Battery Voltage)		Voltage Divider	Dynamic Science	15V	2.5V	1.0	Rise Time 350 μs	1	See Table 2-5 for connections.
Vehicle Electrical System (Battery Inertial Switch)	1	Voltage Divider	Dynamic Science	On-Off	2.5V	-	Rise Time 350 μs	1	
Squib Fire	1	Toroid	Dynamic Science	N/A	N/A	1.0	-	1	
IORS Trigger Signal	1	Voltage Divider	Dynamic Science	Off-On	2.5V	1.0	Rise Time 350 μs	1	
Occupant Compartment Noise Level	1	N.S.G. Microphone	B & K 4138+ UA0160+2618	194 db		1.0	5-140 KHz	2	One in front, right-hand side, facing center. One in rear right-hand side, facing center.
Occupant Compartment Pressure Level	1	N.S.G. Pressure Transducer	Kulite CQL-125-5	0-10 psig	1.5MV/V/psi	0.5	0-50 KHz	3	Two in front, one on each side, facing center. One in rear, right-hand side, facing center.
III. Occupant									
No. 1 Head Acceleration (Triaxial)	1	N.S.G Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	9	
No. 2 Head Acceleration (Triaxial)	1	N.S.G. Linear Accelerometer	Statham A514TC-200-350	±200G	4MV/V	0.75	>1000 Hz	9	
Chest Acceleration (Triaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69-TC-200-350	±200G	4MV/V	0.75	840 Hz	9	Priorities: Longitudinal = 1, Vertical = 2, Lateral = 3.
Pelvic Acceleration (Triaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69-TC-200-350	±200G	4MV/V	0.75	840 Hz	9	Priorities: Longitudinal = 1, Vertical = 2, Lateral = 3.
Femur Loads	1	N.S.G. Strain Gage	Interface Model 1210	±5000 lb	4MV/V	0.5	>1000 Hz	4	
	1	N.S.G. Strain Gage	GSE	±3000 lb	0.9MV/V/FS	0.5	>1000 Hz	2	
IV. Barrier									
Cable Velocity	1	Digital Proximity	Probe Airpax	>100 mph				1	Backup Measurement.
Flat-Faced Barrier Loads (Fixed)	1	N.S.G. Load Cell	Interface Model 1330	1000KLB	4MV/V	0.5	1000 Hz	4	

TABLE A-XII. TRANSDUCER REQUIREMENTS AND PERFORMANCE CHARCATERISTICS FOR POLE BARRIER COLLISION

TRANSDUCER REQUIREMENTS AND PERFORMANCE CHARACTERISTICS FOR POLE BARRIER COLLISION

Measurand	Measurement Priority	Type of Transducer	Manufacturer and Model	Full-Scale Capacity	Full-Scale Output	Transducer Accuracy (% F.S.)	Frequency Response (minimum)	Qty.	Remarks
I. Test Vehicle									
Approach and Impact Velocity	1	Fifth Wheel	Labeco TT481	>100 mph	0.077 V/mph	0.5	N/A	1	Secondary Measurement
Approach Velocity	1	Velocity Digital Counter	Dynamic Science	>100 mph	10^4 counts	-	N/A	1	Backup Measurement, Displayed, Not Recorded
Impact Velocity	1	Speed Trap Digital Counter	Dynamic Science	-	10^4 counts	-	-	2	Primary Measurement, Displayed, Not Recorded
Engine Acceleration (Triaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	3	Priorities: Longitudinal = 3, Vertical = 2, Lateral = 1
Occupant Compartment Acceleration (Triaxial) - 5 locations	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	15	Priorities: Longitudinal = 3, Vertical = 2, Lateral = 1
Frame Acceleration, 6 locations (Triaxial)	Remarks	N.S.G. Linear Accelerometers	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	18	Priorities: Longitudinal = 3, Vertical = 2, Lateral = 1
Vehicle Impact	1	Switch	Dynamic Science	On-Off	2.5V	-	Rise Time 350 μs	2	One Switch on Vehicle, One on Barrier
II. Occupant									
No. 1 Head Acceleration (Triaxial)	1	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	9	
No. 2 Head Acceleration (Triaxial)	1	N.S.G. Linear Accelerometer	Statham A514TC-200-350	±200G	4MV/V	0.75	>1000 Hz	9	
Chest Acceleration (Triaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	9	Priorities: Longitudinal = 3, Vertical = 2, Lateral = 1
Pelvic Acceleration (Triaxial)	Remarks	N.S.G. Linear Accelerometer	Statham A69TC-200-350	±200G	4MV/V	0.75	840 Hz	9	Priorities: Longitudinal = 3, Vertical = 2, Lateral = 1.
Femur Loads	1	N.S.G. Strain Gage	Interface Model 1210	±5000 lb	4MV/V	0.5	>1000 Hz	4	
	1	N.S.G. Strain Gage	GSE	±3000 lb	0.9MV/V/FS	0.5	>1000 Hz	2	
III. Barrier									
Cable Velocity	1	Digital Proximity	Probe Airpax	>100 mph	-	-		1	Backup Measurement
Pole Barrier Loads (Fixed)	1	N.S.G. Load Cell	Interface Model 1330	100KLB	4MV/V	0.5	>1000 Hz	6	