This is to certify that the

thesis entitled

A COMPARATIVE ANALYSIS AND ERROR ESTIMATION OF PORTABLE DATA RECORDERS USED TO MEASURE PACKAGE DROP HEIGHTS

presented by

LINDA KAYE GRAESSER

has been accepted towards fulfillment
of the requirements for

MASTER degree in **PACKAGING**

S. Paul Singh
Major professor

Date **AUGUST 2, 1991**

A COMPARATIVE ANALYSIS AND ERROR ESTIMATION OF PORTABLE DATA RECORDERS USED TO MEASURE PACKAGE DROP HEIGHTS

By

Linda Kaye Graesser

A THESIS

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ABSTRACT

A COMPARATIVE ANALYSIS AND ERROR ESTIMATION OF PORTABLE DATA RECORDERS USED TO MEASURE PACKAGE DROP HEIGHTS

By

Linda Kaye Graesser

This study investigated the error associated in measuring package drop heights for two commercial recorders developed by Dallas Instruments (DHR) and Instrumented Sensor Technology (EDR). Four drop heights of 18, 24, 30, and 36 inches were studied. Drops were made on bottom, edge, and corner orientations. In addition, shock measuring capabilities of the two recorders were studied.

The results of the study are presented in the form of mean percent errors and corresponding variation in measuring drop height by the recorders for the various drop heights and orientations. The study concluded that the DHR predicts the drop height most accurately with the least variation, using the "zero-g" channel. Both recorders show much larger variation in predicted values (up to 30 percent) when using the acceleration-time data. The edge and corner orientation are generally underestimated by the two recorders due to the inability of the accelerometers to deduce between partial rotation on impact.

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This thesis is dedicated to Robert Frost, because it was he that said . . .

. . . Two roads diverged in a wood, and I-
I took the one less traveled by,
And that has made all the difference.

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1.0 INTRODUCTION

The damage to products resulting from the handling and transportation through logistical channels exceeds billions of dollars annually (Braddock et al., 1972). The shock and vibration environments encountered by packages during shipment, handling, and storage can cause severe and costly product damage. This economic waste may be decreased considerably by understanding the dynamic forces on the product that occur in distribution environments and packaging for optimum protection.

Packaging engineers need detailed information about the distribution environment to determine if products require packaging protection. If protection is needed, fragility information about the product is used for designing optimum packaging. Inadequate knowledge of a distribution channel may result in either overpackaging, raising serious environmental concerns, or underpackaging, resulting in product damage or hazard.

The information gathered to describe the severity of handling operations has historically been the height-of-drop. The height-of-drop or drop height refers to the vertical distance from the ground or impact surface that the package falls under the influence of gravity. Drop height data has been collected by several methods. Examples are visual observation, camera, and instrumented packages. Instrumenting packages is considered to be the most effective technique for gathering data related to the hazards of a typical distribution cycle (Godshall and Ostrem, 1979).

The main obstacle in the performance of field measurement programs has been the lack of self-contained instrumentation. The requirements for an instrument to be used for this purpose would include its ability to accurately measure drop height, nature of impact surface, drop orientation (side, top, bottom, edge, or corner), time reference to determine when impacts occurred, and an internal storage capability for unattended recording over several days.

The Drop Height Recorder (Dallas Instruments, 1988) and Environmental Data Recorder (Instrumented Sensor Technology, 1987) are two recording devices that can measure the distribution environment for extended periods of time. Both units are similar in size, weight, and appearance. They use internal tri-axial accelerometers to record the acceleration-time history and determine package drop height from this.

The purpose of this study was to compare these two portable data recorders and their ability to accurately measure package drop heights. Specifically, this study had the following objectives:

1) To measure equivalent drop heights using both the Drop Height Recorder and Environmental Data Recorder in a laboratory environment.

2) Analyze which recorder measures drop heights with the maximum accuracy and precision.

3) Establish relationships between recorder type, measured height, and drop orientation.

4) Determine the accuracy of recording acceleration-time histories for the two recorders types.

5) Examine if the recorders over or under estimate drop height, and if they record consistently within machine type.

6) Objectively analyze the recorders and accompanying software in ease of operation.

2.0 LITERATURE REVIEW

Devices which are capable of measuring and recording the package shock environment must be able to measure the impact conditions while the containers are in shipment, handling, and storage. Organizations which have been involved in the development of these devices include Wright Air Development Center, Air Force Packaging Research and Development Laboratories, Army Ballistic Missile Agency, Sandia Corporation, and the Packaging and Allied Trades Research Association (Surrey, England). Many prototype instruments were developed from these studies and used in various field measurement programs.

The literature review that follows will be presented in chronological order to highlight the studies which have produced the most successful shock data recorders.

The Wright Air Development Center conducted a study of the supply channels of the U.S. Air Force involving primarily Railway Express shipments (Bull and Kossack, 1960). They shipped 43 pound 19 inch cubical cleated plywood boxes instrumented with Impact-o-graph® accelerometers (Chatsworth Data Corporation) used in conjunction with a cubical spring suspension system. The purpose of the spring suspension system was to control the input to the recording instrument such that the instrument was independent of the type of surface impacted, i.e. compressibility of the surface. The Impact-o-graph® accelerometers record peak acceleration only. The study only included routes involved in shipments from one Air Material Area to another Air Material Area via Railway Express. Some of these shipments were also made via Air Freight. The results were based on 49 trips involving 13 packages. A total of 862 drops were recorded above 3 inches and the data showed that only 5% of the packages received drops in excess of 21 inches (Bull and Kossack, 1960).

Another extensive measurement program employing commercial impact recorders has been reported by Packaging Consultants Incorporated, Washington, D.C. (McAleese, 1962). In this study, thirty-three shipping containers with various shapes and weights (long 3:1:1, average 3:2:2, and tall 1:1:2; and light 60 and 90 lbs., medium 150 and 250 lbs., and heavy 500 and 1500 lbs.) were constructed and instrumented with Impact-o-graphs®. The packages were shipped by truck, ship, and air within a radius of 200 miles of Washington D.C. Laboratory tests were done to relate instrument peak acceleration to actual drop height. The wide variations in the instrument recordings made any comparisons with drop height difficult. Based upon these results, it was concluded that the rough handling tests for packaged electronic equipment were too severe.

The Packaging and Allied Trades Research Association (PATRA) of Surrey, England, conducted a study involving 22 pound, 17½" x 12" x 11½", corrugated fiberboard boxes (Gordon, 1963). The PATRA Drop Recorder was used in this study. This instrument consisted of an arrangement of weights pivoted about an axis perpendicular to a recording chart and arranged so that each was sensitive to shocks along one of the three sensitive axes. Three recording pens recorded drops on opposite paired faces of the container. Drops were recorded on a waxed paper chart which was driven at a constant speed. On impact, the paper was advanced by a shock operated driver. This separated individual shock traces and made it easier to read consecutive drops. The recorder was mounted inside a package with a 2 inch layer of polyurethane foam surrounding the recorder. The results were obtained from packages shipped via railroad in mixed goods consignments. Based on 196 trips, 1479 drops above 3 inches were recorded. Consistent with the study performed by the Wright Air Development Center, only 5% of the packages received drops in excess of 21 inches (Gordon, 1963).

The Packaging and Allied Trades Research Association developed another recorder called the PATRA Journey Shock

Recorder (Pierce, 1963). This instrument consisted of a spring-mass system attached to a counter unit and immersed in oil. Each unit had uni-directional sensitivity and counts the number of drops above a preset height on a given face of the package. By using a number of counters, one can cover the different faces and set them to record at different heights. The drops can be estimated between the heights set for the different counters. This instrument was also packed with a two inch layer of cushioning around the recorder. The cushioning made the shock recorded by the unit relatively independent of the hardness of the surface on which the package was dropped. Thus, the response of the recorder was a function of drop height and the angle of the package on impact. The instrumented packages, each containing a recorder, had a weight of 52 pounds and measured 17" x 12" x 13". Twenty-four packages were shipped over six different routes on passenger trains and mixed good railroad shipments. The results of this study showed that the distribution system does influence the drops received by packages. The most severe handling was felt by the packages shipped by passenger train, followed by truck and mixed goods rail shipments (Pierce, 1964).

Another investigation of the handling environment was conducted by the National Safe Transit Committee (The Railroad Environment, 1966). In this study, commercial impact recorders were mounted in wooden boxes and shipped as ordinary products. These instruments recorded the shocks encountered during shipment by the displacement of a spring-mass system. The system was linked to recording pens which recorded the deflections on a recording paper driven by a clock mechanism. The pen deflections were recorded in zones of shock from 1 to 5 with the 5th zone representing the most severe shock. The results of this study provided information on the relative severity of the transportation and handling environment. This study did not provide quantitative data on the drop heights during handling. No relationships were given in the report between the zones-of-shock and drop height. (The Railroad Environment, 1966).

One of the most sophisticated recorders of its time was the Natick Drop Recorder developed by the U.S. Army Natick Laboratories (Venetos, 1967). One of the primary goals of the recording device was to measure the important environmental conditions, such as, shock, temperature, humidity, and superimposed load experienced by containers during shipment, handling, and storage. The Natick Drop Recorder was a solid state electronic unit capable of recording unattended for a duration of six months. Impacts were sensed by a transducer consisting of a magnetic rod which rides within a rigid nylon tube. The magnet was connected at both ends to coil springs. Upon impact, the relative motion of the magnetic rod relative to coils of wire wrapped around the tube produces a voltage which is proportional to the impact velocity. The recording unit can record the voltage signals from three mutually perpendicular transducers. A fourth recording channel was used to record a timing mark. This instrument was extremely useful in measurement programs of the cargo handling environment. The Natick Drop Recorder was used in a study to show the percentage of drops over an indicated drop height. The data showed good correlation with regard to drop height probability and package weight (Ostrem and Rumerman, 1967).

In 1975 the U.S. Army Natick Development Center used the Natick recorder in a study involving shipments of 25 pound fiberboard boxes. The study was based on data from numerous shipments via truck, aircraft, Parcel Post, United Parcel Service, and overseas shipments aboard Navy ships. The latter shipments were made with the package positioned at the bottom center of a unitized load, using 15 packages on 80 trips. The data reported was not broad enough to characterize a particular distribution cycle (Barca, 1975). The Natick Drop Recorder was developed to provide the required instrumentation and has been used successfully in the field. However, today's knowledge of solid state electronics has advanced to the point where this instrument is now obsolete.

Another successful recorder was designed by the Air Force Packaging Evaluation Agency through a contract with

Bolt, Beranek & Newman, Inc. to develop a miniature electronic transportation environment recorder (Venetos, 1975). One of the advantages of this recorder was its smaller size (4⅞" x 5⅞" x 5⅞") and weight (six pounds). The reason for the significant reduction in size of this recorder was the use of metal oxide semi-conductor (MOS) technology circuitry combined with the use of miniature sensors. This technology yields compact circuitry with low power requirements.

This recorder was one of the first to use piezoelectric accelerometers. One accelerometer was used for each axis of the recorder. The triaxial accelerometer separated the shock data by polarity for each of the three recording channels. The recorder had a measuring range from 2.5 G to 90 G and also had the ability to measure temperature and humidity. Using internal batteries, it could operate for over two weeks. One of the main advantages of this recorder was its ability to readout pre-analyzed data.

The Air Force had tried to use the recorder in measurement of the shock environment experienced by a set of standardized cushion packs that were extensively used in the shipment of fragile items. In addition to the measurement of item response in terms of peak G, data was obtained on the shipping environment by placing the miniature shock recorder in a specially designed shipping container. This container provided approximately equivalent response regardless of the orientation of the container at impact. The information on drop height was used to verify the reliability of previously developed design criteria (Venetos, 1975).

In 1979, the U.S. Department of Agriculture, Forest Products Laboratory compared the data from a U.S. Air Force study and a U.S. Army Natick Development study (Godshall and Osterm, 1979). The U.S. Air Force study used was the 43 pound cleated plywood boxes used in their supply channels involving primarily Railway Express shipments. The data used from the U.S. Army Natick Development Center was the study of the 25 pound fiberboard boxes used in shipments via truck, aircraft, Parcel Post, United Parcel Service, and overseas shipments aboard Navy ships.

The data was plotted on log probability paper to indicate the percentage of drops over indicated drop heights. The data showed, for example, that only one package in hundred was dropped from a height greater than 58 inches for the 25 pound container, and 30 inches for the 43 pound container. Although completely different instrumentation was used to record data for each study, the data showed good correlation with regard to drop height probability and package weight. The data for drop heights was replotted to show the number of drops recorded at the different heights. Once again there was good correlation between the studies showing a large number of low level drops, and very few drops at the higher levels.

The Natick study also reported data on the angle of impact. The data showed that the container bottom surface received 70 percent of all the drops, and the edge and corner drops occurred from much greater heights than the flat drops. Distribution of drops were: 80 percent bottom and top surfaces combined, 12 percent front and back surfaces, and 8 percent side surfaces. Direct comparisons of the studies showed a similar trend regarding the effect of package weight and the distribution of drops, but the drop heights and probability levels are significantly different. The reason for the differences were not certain, but could be caused by a number of factors including a difference in data reduction procedures, or a difference in the sensitivity of the instrumentation, particularly for angle drops (Godshall and Osterm, 1979).

The United States Dairy Association's Agricultural Research Service and the Agricultural Engineering Department at Michigan State University developed an Instrumented Sphere (IS) data-acquisition system to dynamically measure and record impacts to agricultural products (Tennes et al., 1989). The IS was used to evaluate the impacts sustained by apples as they traveled from the applebox dumper at packing houses through distribution to the retail stores. The IS was a large apple sized battery powered data acquisition sphere 3.5 inches in diameter and weighing 0.77 pounds. The electronic components were cast in beeswax, which becomes the outer surface of the sphere. The unit used a triaxial accelerometer to record each impact pulse and determines peak acceleration, duration, total velocity change, and exact time of impact. Each IS was able to operate unattended for several hours, collecting and storing all accelerations above a user specified trigger level. The IS had an internal clock to record the time of impact in order to identify the source of the most severe impacts. It was used to determine the typical magnitude of apple bruise damage caused by commercial packing house operations, probable causes of major bruising, and to estimate the decay likely to result from packing line bruising. The IS had been used primarily in apple handling operations, but it had been used with other fruits. Researchers have estimated that within the next two years the IS and bruise damage relationships should be worked out for most fruits.

The IS system has been commercially available from Techmark, Inc. of Lansing, MI. Many packing line equipment manufacturers, dealers, and consultants have used the IS to analyze packing lines and to make modifications to reduce bruising and improve quality (Brown, 1991).

In 1991, Thomas Voss looked at the drop heights encountered in the United Parcel Service small parcel environment in the United States (Voss, 1991). In this study the Drop Height Recorder was used to analyze the movement of packaged goods through various United Parcel Service logistical channels. The study incorporated the effect of drops, tosses, and kicks encountered in the small parcel environment as a function of package weight and volume. Three size and weight configurations were used in this study. The container sizes were small (12" x 12" x 12"), medium (18" x 18" x 16"), and large (26" x 20" x 19") and the weight categories were light (20 pounds), medium (30 pounds), heavy (45 pounds). Seven size/weight combinations were used; the small/heavy and large/light combinations were eliminated due to the inability to meet weight restrictions needed for that size combination.

Thirty-five round-trip shipments were made from Lansing, MI to Monterey, CA, five shipments for each combination. The results of the study showed that the highest drop observed was 42.1 inches for the Small size package. The size of the package had no significant effect on the drop heights. Lighter weight packages for the smaller size experienced higher drop heights. Weight did not have a significant effect on the medium and large size package drop height. Ninety-five percent of all drops occurred at 30 inches for the small/light, 26 inches for the medium/heavy, 24 inches for the small/medium and medium/medium, and 18 inches for the medium/light, large/medium, and large/heavy packages.

3.0 BACKGROUND

Two portable data recorders were evaluated and compared in this study. The first type of units are called a Model DHR-1 Drop Height Recorder (DHR), (serial numbers 8806-5 and 8912-4), and is manufactured by Dallas Instruments of Dallas, TX. The second type of units are called a Model 200 EDR-1 Environmental Data Recorder (EDR), (serial numbers 0035 and 0038), and is manufactured by Instrumented Sensor Technology of Lansing, MI. This chapter discusses the features and capabilities of both recorders. It also describes the internal instrumentation used in these devices.

3.1 Drop Height Recorder

The Model DHR-1 Drop Height Recorder is intended for use in determining the free-fall drop heights experienced by product and packages over extended periods of time (up to 16 days). The DHR is a relatively small (6.6 inch cube) and lightweight (9.5 pounds) device whose exterior is made of shock resistant plastic, but not a complete shell. Two rechargeable nickel cadmium batteries are connected to the unit by the wiring carrying the voltage to the central unit, and a nylon cable surrounding the unit. This arrangement makes the unit somewhat unstable, due to the ease of disassembly of the batteries from the central unit.

The DHR has an internal programmable clock that provides the time and date of event occurrence. The clock has sixty-four user specified alarms which activate and de-activate the DHR's operation. This recorder has a piezoelectric triaxial accelerometer that can withstand acceleration up to 125 g's with a frequency response from 2 Hz. to 1000 Hz. The DHR is not equipped for external accelerometers. The recording capacity of the DHR is dependent upon the duration and sample rate selected by the user. For example, 200 events at 50 ms durations corresponds to a 10 kHz sampling rate. The DHR also allows the user to specify the type of memory: full/stop (when the memory is filled, it stops recording), wrap (will overwrite the oldest data in memory), and maximum (once the memory is filled, it compares new peak values to the lowest event in the summary data memory, and replaces it if the new value is greater). The recorder has an LCD display that permits the user to review the time, date, battery condition, number of events recorded, and other operating parameters to ensure that the proper data is being obtained while in the field (Dallas Instruments, Inc., 1988).

The DHR is designed as an event triggered, four channel data recorder. It stores digitized waveforms of selected shock events on three channels, including pre-trigger data. The fourth channel is used for storing the "zero G" summation signal. Auxiliary data, such as, temperature, battery voltage, time, and date, is recorded in random access memory (RAM) along with the signal data.

The DHR calculates a "true" drop height and an "equivalent" drop height. The DHR stores a composite signal consisting of the summation of the three acceleration signals of a triaxial accelerometer during free-fall (a "zero G" signal) as pre-trigger event data. It also stores the full time history of all three post-trigger acceleration signals in a solid state memory.

To calculate the "true" drop height, the triaxial accelerometer data is processed by a high gain amplifier that is used to sense a change to a zero-G state (a free-fall condition). The data is summed and the signal is processed as a separate fourth channel. It is digitized and stored in RAM for later analysis. Since the time from the onset of the zero-G state of the recorder to the time of impact is known, the free-fall distance is calculated using the free-fall equation:

$$h_z = \frac{g t^2}{2} \qquad (3\text{-}2)$$

where:

g = acceleration due to gravity (386.4 inches/second^2)

t = measured time of free-fall (seconds)

h_z = zero-g drop height (inches)

To calculate the "equivalent" drop height, the same triaxial output is also processed by a low gain circuit, digitized, and saved in RAM as the impact acceleration-time history. The three digitized waveforms represent the shocks in three perpendicular directions and may be vector summed to produce a resultant acceleration-time history and the orientation of the device at the moment of impact. The areas under the three acceleration-time curves are calculated to determine the velocity changes for the three directions. Once the velocity changes are known, the equivalent drop heights for each axis is calculated using the following equation:

$$h = \left(\frac{\Delta V}{1+e}\right)^2 \cdot \frac{1}{2g} \tag{3-3}$$

where:

ΔV = velocity change for each channel (inches/second)

e = coefficient of restitution

g = acceleration due to gravity

(386.4 inches/second^2)

h = equivalent drop height (inches)

Once equivalent drop heights are calculated for each of the three axes, the free-fall vertical drop height is calculated by adding the individual drop heights:

$$Height_{total} = h_x + h_y + h_z \tag{3-4}$$

The DHR does not use the coefficient of restitution directly, but uses a user specified correction factor when calculating equivalent drop height. These factors may be changed by the user to make the calculated equivalent drop heights as nearly equal to actual known drop heights (or the zero-G drop heights if a free-fall drop is made) as possible. The factors vary inversely with the value of the equivalent drop height calculated, that is, a larger factor will yield a smaller equivalent drop height. The DHR integrates the area under the waveform for each channel and multiplies it by the individual channel correction factors, which take into account the coefficient of restitution. In this study, reports were generated with the standard correction factor (the factor calibrated for use of the recorder with the foam cushioning shipped surrounding the unit), then regenerated with the correct correction factor calculated from the data recorded (Dallas Instruments, Inc., 1988).

3.2 Environmental Data Recorder

The Model EDR-1 Data Recorder is a portable, self-contained digital recorder and sensor. It contains three internal tri-axially mounted piezoresistive accelerometers which can withstand accelerations up to 200 g's. Instrumented Sensor Technology uses piezoresistive accelerometers because these accelerometers, in general, respond better to constant acceleration and offer more accurate response characteristics at lower frequencies. The unit does, however, have the internal electronics to support the use of either piezoresistive or piezoelectric type accelerometers. The housing of the EDR is made of highly durable polyurethane resin material.

The EDR does not have a LCD display to display the instrument's condition in the field. In a low battery condition, the EDR will not respond when trying to change modes; it puts itself into its "hibernation" mode. Also the EDR does not have the alarming capability to activate at preset times. It does allow the user to input one start time delay, and one stop time delay to start and stop when needed. The EDR has a recording battery capacity up to one month without recharging. The sampling rate for this recorder is similar to the DHR. The higher g-level, short duration events, would require a higher sample frequency than would be used for lower level, longer duration events. The EDR also allows the user to specify the type of memory: full/stop (when the memory is filled, it stops recording), and overwrite (uses a formula based on the slope of the acceleration-time history to compare new peak values to the lowest event in the summary data memory, and replaces it if the new value is greater).

The EDR has been designed as a self-contained shock recorder so that it can be mounted to a vehicle, container, or other structure. Its small size (5½ inch cube) and relatively low mass (8 pounds), enables the EDR to be shipped within a package or container, or even installed into larger pieces of equipment. The unit also has application as a shock recorder for external single-axis accelerometers. The unit accommodates four external channel inputs for using up to three remotely mounted piezoelectric accelerometers and a temperature sensor. The three accelerometer channels record simultaneously, and may be used to measure the distribution of shocks over different locations on a structure, or one shock in three different axes at a single location (Instrumented Sensor Technology, Inc., 1987).

The EDR senses accelerations resulting from drops and impacts. The triaxial acceleration waveforms are sensed and recorded in the unit. The recorded waveforms are processed using digital sampling techniques (Which is a process of converting analog waveforms into a series of discretely quantized time samples. It determines the effective resolution of the resulting digital samples and sample frequency) available in the EDR software program for deriving package drop height information on each recorded event.

The EDR records and stores acceleration waveform data only when certain pre-set acceleration waveform criteria are met. It records an acceleration event when any one or more of the three selected accelerometer input channels exceed a user specified preset G "trigger" level (positive or negative). Once a shock waveform is generated from a free falling object impacting a surface, the peak acceleration is determined. The peak acceleration (A_p) is the largest sampled g-value (positive or negative) on the shock waveform. The time at which the shock waveform reaches its peak acceleration is also recorded and denoted as 't_p'. The total velocity change is divided into two quantities, the area under the curve up to the point 't_p' is 'V_i', the impact velocity, and the area under the curve from 't_p' is 'V_r', the rebound velocity.

Velocity changes measured from shock waveforms can be used to compute drop height. The EDR calculates drop height from the change in velocity (ΔV) in each direction. The individual velocity changes are used to determine the resultant velocity change using the following equation:

$$\Delta V_{Resultant} = \sqrt{\Delta V_x^2 + \Delta V_y^2 + \Delta V_z^2} \qquad (3\text{-}6)$$

The resultant velocity is then used to calculate the equivalent drop height using the coefficient of restitution (e), determined by the ratio of 'V_r' to 'V_i'. The height is calculated by the following equation:

$$Height = \frac{\left(\frac{\Delta V_{Resultant}}{1+e}\right)}{2 \bullet g} \qquad (3\text{-}7)$$

The EDR has an acceptable range of 'e' between of 0.3 to 0.75. If the calculated value is out of this range, the EDR asterisks the value to notify the user that a default value of 0.5 has been used.

4.0 EXPERIMENTAL DESIGN

In order to achieve the objectives of this study, tests were designed to accurately and consistently obtain drop data. The analysis consists of comparing the DHR with the EDR in their ability to precisely and accurately measure equivalent drop heights. Two units of each model were used in this study.

A programmable shock machine system and free-fall drop tester were used to generate the shock pulses to the DHR and EDR. All testing was performed at standard laboratory conditions of 25° C and 50% relative humidity.

4.1 Shock Machine Test

The purpose of this test was to determine the capabilities of the two recorders to accurately measure shock pulses. A MTS 846 Shock Test System was used in this study. The velocity change was measured using the two recorders against a known shock input. The shock input was measured using a MTS 466 Waveform Analyzer. All drops were made on the gas programmers to produce a shock pulse with a square waveform. The gas pressure was set at 250 psi due to the DHR's inability to withstand high acceleration levels. The bare recorders were bolted down to the center of the platen of the shock table with a wooden fixture.

The shock table was dropped from 6", 12" 18", and 24" in replicates of six. All drops were made on the bottom surface of the recorder. All data was uploaded from the recorders and imported into Lotus's Symphony spreadsheets. All of the processed data is listed in Appendix A. The raw data is listed in Appendix C.

4.2 Drop Tester Test

The Lansmont model PDT 56E Precision Drop Tester was used for all free-fall drops. This machine is equipped with a drop leaf pneumatic actuation system. The high velocity pneumatic system accelerates the drop leaf vertically downward at a force greater than gravity. The packaged recorders are dropped on a 46" x 36", 0.5" thick steel plate which is mounted on a concrete base in accordance with ASTM D775.

The recorders were packaged in 200-pound C-flute corrugated regular slotted containers (RSCs) with an inch of Ethafoam 220® cushioning (Dow Chemical Company) surrounding the recorder on all six faces. Due to the different sizes of the recorders, containers were constructed to allow only the recorder and one inch of cushioning. Figure 1 shows a diagram of the units and cushioning material inside the RSC.

The recorders were dropped by orientation from four heights. They were dropped on the bottom, edge, and corner, from 18", 24", 30", and 36". The drops made on the bottom face, the recorders were dropped on the bottom of the container. The edge drops were at the front-bottom edge. The corner drops were at the right-back-bottom corner. This was done in replicates of six. A new container was used for each orientation and then dropped from the four heights. At least one minute between each cycle of drops was allowed for the cushions to recover. The data was uploaded from the recorders after each orientation of drops at all four heights. After the data was uploaded it was then imported into Lotus's Symphony spreadsheets. All of the processed data is listed in Appendix B. The raw data is listed in Appendix C.

Package Dimensions

DHR: 6.6" cube (recorder)
8.6" cube (inside RSC)

EDR: 5.5" cube (recorder)
7.5" cube (inside RSC)

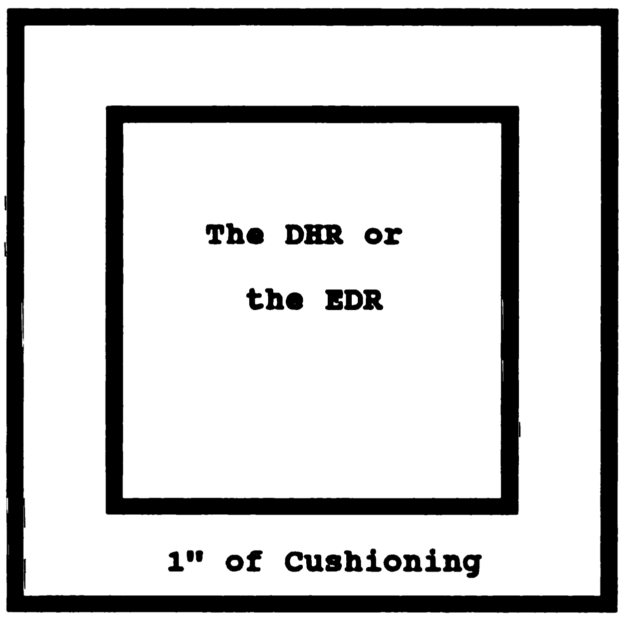

Figure 1: Cushion and Recorder Placement in the RSC (top view)

5.0 DATA AND RESULTS

All of the data was analyzed and the mean percent error determined. The results for the two tests performed are presented in the chapter. All of the DHR1 and DHR2 drop height values are computed using the acceleration-time data for the Dallas Instrument Recorder. The DHR1z and DHR2z drop height values are computed using the zero-g channel data for the Dallas Instruments Recorder. The EDR1 and EDR2 drop height values are computed using the acceleration-time data for the Instrumented Sensor Technology Recorder.

5.1 Shock Table Results

Table 1 shows the velocity changes measured by the recorders represented in mean percent error. The measuring system in all four recorders uniformly measures the velocity change from a known shock input. The EDR's record much more consistently than the DHR's not only by recorder, but also within machine type. The EDR's measure velocity change with an accuracy of about 1%. Overall, a mean percent error of about ten percent, for all recorders, is generally acceptable. An explanation for the much lower value measured by the DHR2 at 24 inches could be due to cushion

Table 1

Mean Percent Error of Measuring Velocity Change on Shock Table

Height	DHR1	DHR2	EDR1	EDR2
Mean Velocity Change				
6"	126.5 ±3.1	123.8 ±4.8	119.3 ±2.1	116.7 ±2.1
12"	188.5 ±10.7	181.5 ±8.8	170.3 ±1.7	169.0 ±1.2
18"	227.0 ±3.1	214.2 ±30.5	210.3 ±1.9	209.7 ±0.5
24"	267.8 ±9.4	191.0 ±27.0	245.7 ±1.5	246.2 ±1.1
Mean Percent Error				
6"	10.1 ±1.4	5.2 ±4.2	0.4 ±1.3	1.1 ±1.0
12"	10.3 ±5.4	5.8 ±4.3	0.1 ±1.3	1.4 ±0.6
18"	8.1 ±1.4	0.9 ±2.3	-0.9 ±0.6	1.7 ±0.9
24"	8.4 ±3.9	-22.7 ±10.9	-0.7 ±0.8	1.7 ±1.1

failure. Figure 2 describes the mean percent error and the corresponding variation for all the recorders evaluated.

5.2 Drop Tester Results

Tables 2, 3, and 4 represent the mean drop height and mean percent error values of the bottom, edge, and corner orientations, respectively, using the drop tester.

Figures 3, 4, and 5 describe the mean percent error for the two types of recorders and the corresponding variation for the four drop heights evaluated. The variations represented in these Figures were determined using pooled standard deviation values for the two recorders of each type that were compared. Individual standard deviation values for each recorder type are listed in Tables 2, 3, and 4. The most accurate device should have a mean percent error closest to zero with no variation. From these figures it is evident that the drop heights computed by the "zero-g" channel of the DHR (DHRz) is the most accurate method to measure package drop height. All the mean percent errors for the DHRz are the closest to zero with very small variation. The bottom orientation is most accurate, followed by edge and corner.

The mean percent errors for the drop height computed using the acceleration data by the DHR (DHR) and the EDR

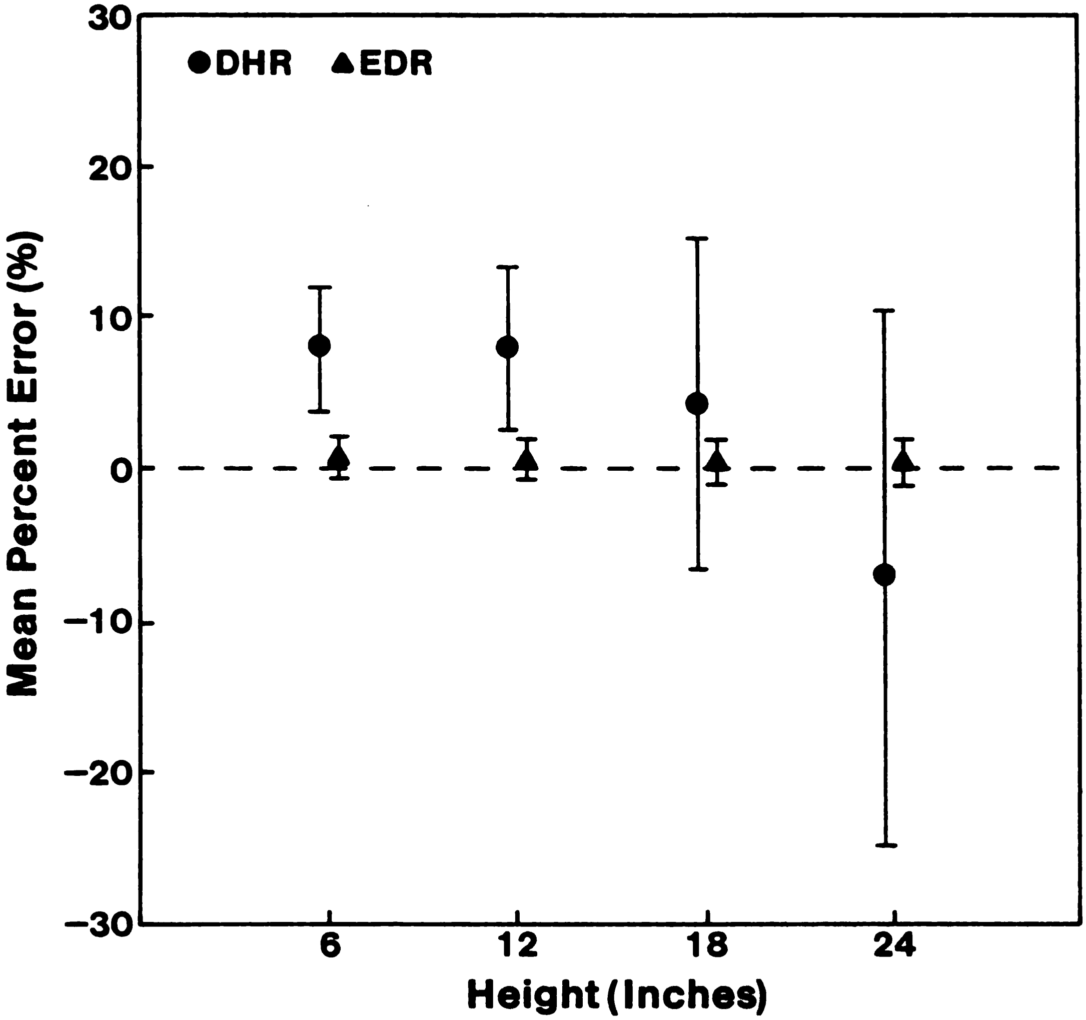

Figure 2: Mean Percent Error and Variation for Velocity Change Measurement

Table 2

Mean Drop Heights Measured, Percent Error, and Standard Deviation for Bottom Drops

Mean Drop Height

Height	DHR1	DHR2	DHR1s	DHR2s	EDR1	EDR2
18"	17.0 ±1.6	17.0 ±1.7	17.6 ±0.3	17.5 ±0.3	20.8 ±1.2	20.7 ±0.7
24"	21.9 ±2.2	25.1 ±1.4	23.2 ±0.3	23.4 ±0.1	28.7 ±1.4	27.8 ±2.1
30"	30.1 ±2.8	32.4 ±3.7	29.7 ±0.6	29.8 ±0.3	35.0 ±1.5	33.8 ±1.3
36"	37.9 ±1.6	40.9 ±2.5	35.6 ±0.5	35.4 ±0.2	42.2 ±1.5	40.5 ±4.3

Mean Percent Error

Height	DHR1	DHR2	DHR1s	DHR2s	EDR1	EDR2
18"	-5.6 ±9.0	-5.7 ±9.6	-2.1 ±1.6	-3.0 ±1.7	15.7 ±6.7	14.8 ±4.1
24"	-8.7 ±9.0	4.7 ±5.7	-3.5 ±1.1	-2.4 ±0.5	19.4 ±5.7	16.0 ±8.8
30"	0.2 ±9.4	8.1 ±12.3	-1.0 ±2.2	-0.8 ±0.9	16.7 ±5.1	12.8 ±4.5
36"	5.3 ±4.4	13.5 ±7.0	-1.2 ±1.5	-1.7 ±0.7	17.1 ±4.1	12.5 ±11.9

Table 3

Mean Drop Heights Measured, Percent Error, and Standard Deviation for Edge Drops

Mean Drop Height

Height	DHR1	DHR2	DHR1s	DHR2s	EDR1	EDR2
18"	14.7 ±1.3	12.4 ±2.3	17.6 ±0.1	16.3 ±0.3	16.7 ±1.4	15.3 ±0.7
24"	22.7 ±0.7	20.7 ±0.5	23.6 ±0.1	22.2 ±0.2	23.5 ±1.0	23.8 ±2.2
30"	26.4 ±2.7	25.6 ±1.3	28.6 ±0.2	28.4 ±0.4	29.8 ±3.2	30.8 ±2.0
36"	32.0 ±2.2	33.0 ±2.4	34.4 ±0.3	34.4 ±0.1	42.2 ±1.5	40.5 ±4.3

Mean Percent Error

Height	DHR1	DHR2	DHR1s	DHR2s	EDR1	EDR2
18"	-18.1 ±7.3	-31.3 ±12.8	-2.2 ±0.6	-9.3 ±1.9	-7.4 ±7.6	-14.8 ±4.1
24"	-5.5 ±3.1	-13.9 ±1.9	-1.9 ±0.5	-7.6 ±0.7	-2.1 ±4.0	-0.7 ±9.0
30"	-12.1 ±8.9	-14.6 ±4.2	-4.7 ±0.8	-5.4 ±1.4	-0.6 ±10.8	2.8 ±6.8
36"	-11.2 6.0	-8.4 ±6.8	-4.4 ±0.7	-4.5 ±0.4	12.0 ±2.6	11.1 ±3.9

Table 4

Mean Drop Heights Measured, Percent Error, and Standard Deviation for Corner Drops

Mean Drop Height

Height	DHR1	DHR2	DHR1s	DHR2s	EDR1	EDR2
18"	12.8 ±1.6	13.9 ±1.8	17.5 ±0.6	16.8 ±0.7	16.7 ±2.7	18.0 ±1.3
24"	19.7 ±1.1	20.4 ±1.7	23.1 ±0.2	23.5 ±0.4	21.8 ±1.8	23.2 ±1.7
30"	25.1 ±1.9	27.7 ±1.2	29.1 ±0.3	29.6 ±0.4	28.7 ±2.1	25.8 ±2.3
36"	28.0 ±1.4	33.6 ±0.9	34.9 ±0.6	35.5 ±0.4	36.5 ±3.7	32.2 ±3.8

Mean Percent Error

Height	DHR1	DHR2	DHR1s	DHR2s	EDR1	EDR2
18"	-28.8 ±9.2	-22.6 ±9.7	-2.6 ±3.5	-6.5 ±3.8	-7.4 ±14.9	0.0 ±7.2
24"	-18.1 ±4.6	-15.1 ±7.2	-3.6 ±0.9	-2.2 ±1.8	-9.0 ±7.4	-3.5 ±7.0
30"	-16.2 ±6.3	-7.8 ±3.9	-3.0 ±1.1	-1.4 ±1.2	-4.4 ±7.1	-4.4 ±7.1
36"	-22.2 ±3.8	-6.8 ±2.6	-3.7 ±1.7	-1.5 ±1.0	1.4 ±10.2	-10.6 ±10.6

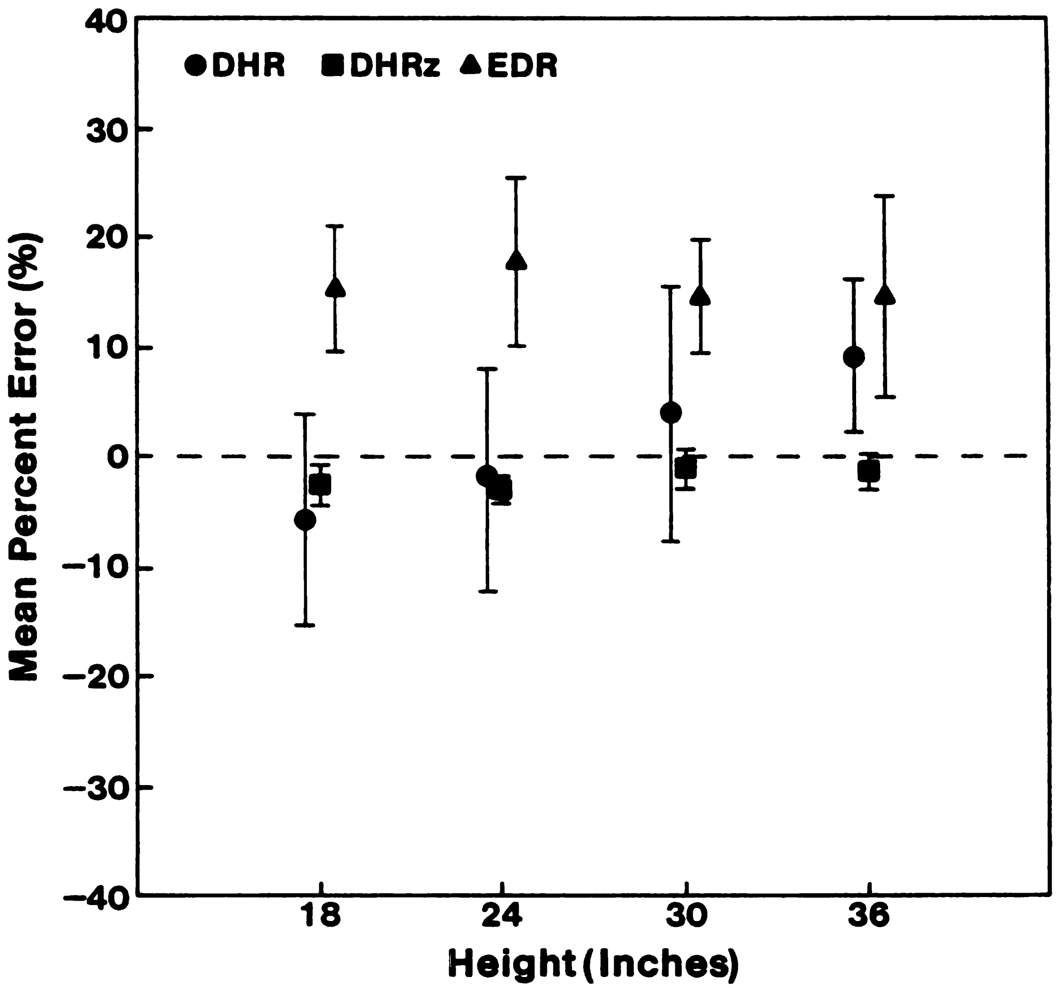

Figure 3: Mean Percent Error and Variation for Bottom Drops

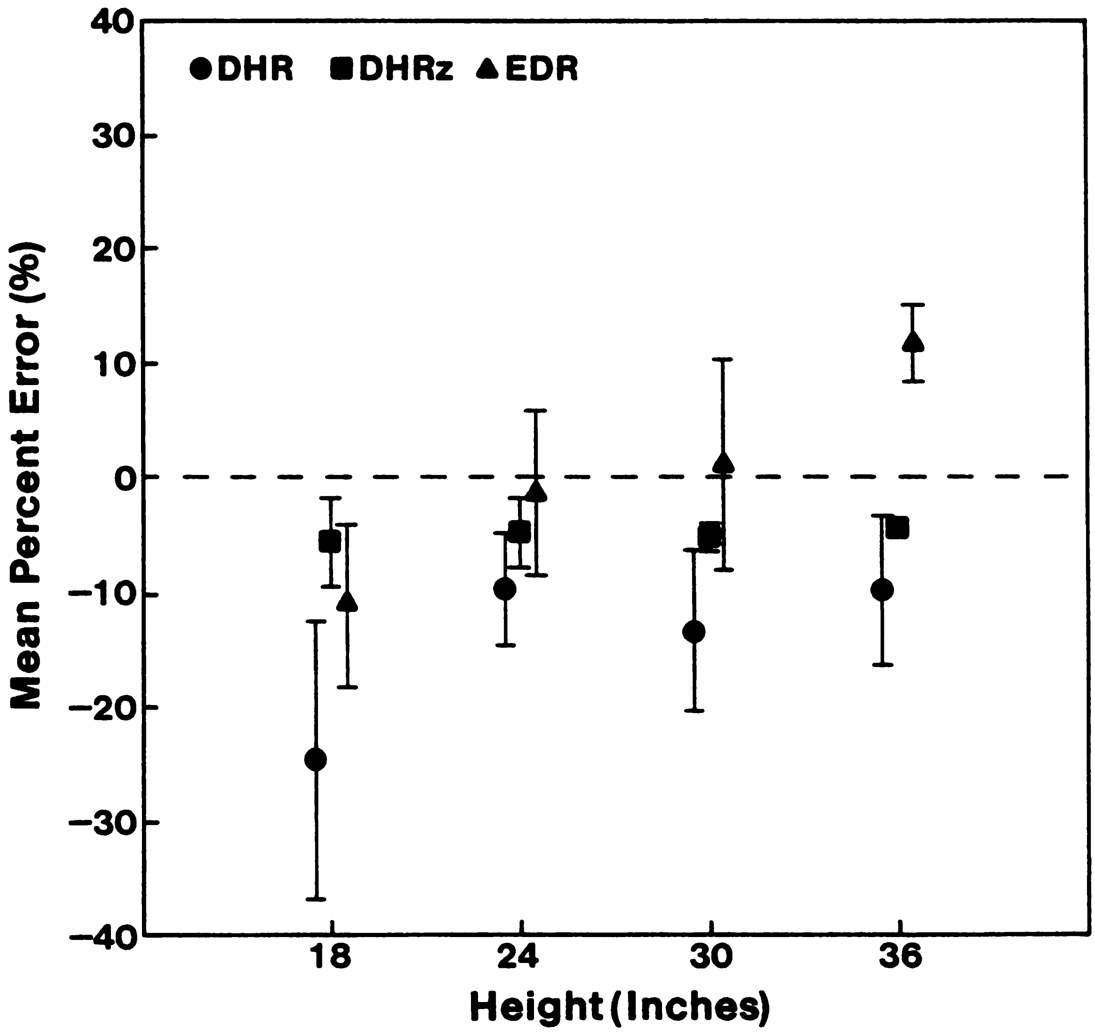

Figure 4: Mean Percent Error and Variation for Edge Drops

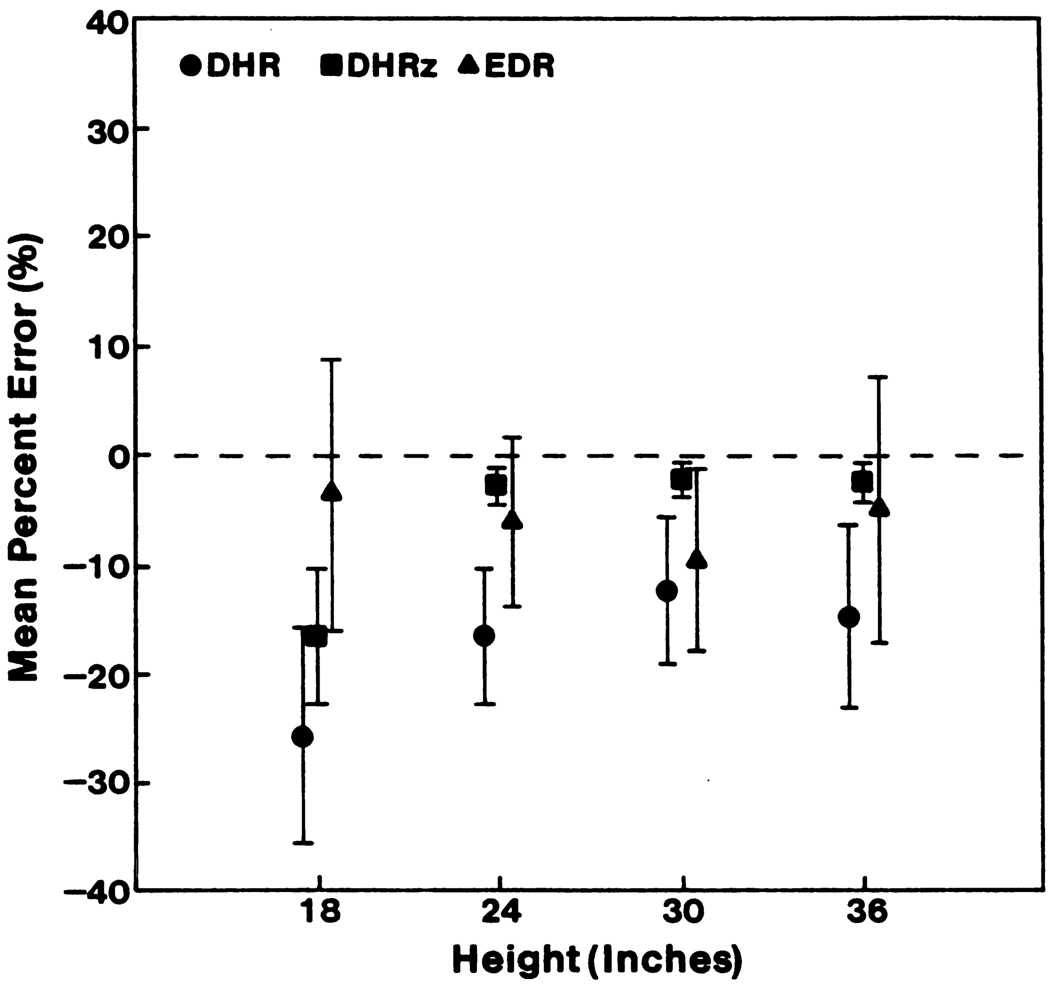

Figure 5: Mean Percent Error and Variation for Corner Drops

(EDR) are significantly larger and have a much larger variation associated to it. The DHR values are generally underestimated except for some bottom drops at 30 and 36 inches. The EDR values are overestimated for bottom drops. The edge and corner drops are generally underestimated by the EDR.

Both the DHR and EDR show very large variation, up to 30 percent, of the mean percent errors measured for various drop heights and orientations.

These figures provide a means to determine mean percent error and associated variation for drop height values measured by the two recorders for various orientations.

Tables 3 and 4 show the data for edge and corner drops. These values are all underestimated. On impact, the kinetic energy acquired during the free fall is converted partially into rebound and rotation. The triaxial accelerometers cannot sense rotation, so, in effect they cannot deduce how much of the free fall energy has been converted into rotation, and how much into translation. They automatically assume that the shock pulse corresponds to pure up and down movement (translation). They will therefore underestimate the drop height.

An inherent problem with the recorders is how they factor in the coefficient of restitution. The DHR allows the user to use correction factors to manipulate the data towards the actual values. The unit is now calibrated and ready to be shipped into the distribution environment. The EDR uses a much simpler method, but not always correct. The EDR allows an acceptable range for the coefficient to lie, and if it falls outside that range, the unit uses a default coefficient factor of 0.5. It asterisks the event on the impact summary report to notify the user of the coefficient used.

Another problem with the EDR is its inability to distinguish between a drop and an impact to the package from a material handling equipment or another package. It converts the measured shock pulse into a drop height value even though the package did not fall freely. The DHR can distinguish between a drop and an impact due to the zero-g channel.

Table 5 shows a comparative analysis of the recorders of selected features and capabilities.

Table 5: Comparative Analysis of Recorder Features

	Drop Height Recorder	Environmental Data Recorder
Size	6.6 inch cube	5.5 inch cube
Weight	9.5 pounds	8.0 pounds
Alarms	64 user specified	1 stop/start
Memory Modes	Wrap, Full/stop, and Maximum	Full/stop and Overwrite
In-field Conditions	LCD display conditions	Self-hibernation mode
Battery life	16 days	30 days
Drop height Calculations	Equivalent drop heights Zero-g channel	Equivalent drop heights
Use of Software	Named file driven	Menu driven
Accelerometer Types	1 triaxial accelerometer	3 tri-axially mounted

CONCLUSIONS

The following conclusions were made in this study:

1. The DHR measures the drop height most accurately and with the least variation using the "zero-g" channel.

2. Both the DHR and EDR show large mean percent errors and associated variation (up to 30 percent) for drop heights measured using the acceleration-time data.

3. The drop heights for bottom orientation are most accurately measured followed by edge and corner which are generally underestimated.

4. The EDR can measure shock pulses more accurately than the DHR.

5. The advantages and disadvantages of each recorder are described in this study.

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APPENDICES

APPENDIX A

Shock Table Data - Velocity Change (in/sec)

Type	6"	6" True	% Error	12"	12" True	% Error
DHR1						
	121.0	110.2	9.8	165.0	168.0	-1.8
	125.0	114.0	9.6	191.0	169.6	12.6
	126.0	115.5	9.1	192.0	171.3	12.1
	128.0	113.2	13.1	194.0	171.8	12.9
	128.0	117.9	8.6	192.0	169.8	13.1
	131.0	118.7	10.4	197.0	174.1	13.2
Average	126.5	114.9	10.1	188.5	170.8	10.3
DHR2						
	123.0	113.3	8.6	162.0	168.3	-3.7
	128.0	116.2	9.9	186.0	170.6	9.0
	118.0	117.5	0.4	184.0	170.8	7.7
	120.0	118.6	1.2	186.0	171.9	8.2
	122.0	120.3	1.4	185.0	173.6	6.6
	132.0	120.6	9.5	186.0	174.2	6.8
Average	123.8	117.8	5.2	181.5	171.6	5.8
EDR1						
	116.0	116.5	-0.4	167.0	166.8	0.1
	118.0	116.6	1.2	170.0	168.0	1.2
	120.0	117.3	2.3	172.0	170.0	1.2
	119.0	117.5	1.3	172.0	169.8	1.3
	120.0	122.1	-1.7	170.0	171.4	-0.8
	123.0	123.0	0.0	171.0	175.2	-2.4
Average	119.3	118.8	0.4	170.3	170.2	0.1
EDR2						
	113.0	113.9	-0.8	167.0	165.6	0.8
	116.0	113.3	2.4	169.0	166.5	1.4
	116.0	114.9	1.0	171.0	166.5	2.7
	117.0	115.8	1.0	169.0	166.9	1.3
	119.0	116.9	1.8	169.0	167.3	1.0
	119.0	117.5	1.3	169.0	167.2	1.1
Average	116.7	115.4	1.1	169.0	166.7	1.4

APPENDIX A (cont'd)

Type	18"	18" True	% Error	24"	24" True	% Error
DHR1						
	225.0	208.8	7.8	272.0	246.0	10.6
	223.0	210.6	5.9	272.0	245.9	10.6
	232.0	210.5	10.2	247.0	247.6	-0.2
	225.0	209.6	7.3	273.0	247.6	10.3
	230.0	209.9	9.6	273.0	248.1	10.0
	227.0	210.5	7.8	270.0	246.7	9.4
Average	227.0	210.0	8.1	267.8	247.0	9.4
DHR2						
	146.0	211.6	-31.0	172.0	246.9	-30.3
	230.0	213.4	7.8	182.0	247.5	-26.5
	225.0	213.2	5.5	251.0	247.5	1.4
	228.0	209.5	8.8	179.0	247.5	-27.7
	228.0	212.8	7.1	180.0	247.2	-27.2
	228.0	213.4	6.8	182.0	246.4	-26.1
Average	214.2	212.3	0.9	191.0	247.2	-22.7
EDR1						
	207.0	210.4	-1.6	244.0	245.5	-0.6
	210.0	210.4	-0.2	246.0	247.8	-0.7
	210.0	210.4	-0.2	248.0	246.8	0.5
	210.0	211.6	-0.8	247.0	247.4	-0.2
	212.0	214.6	-1.2	245.0	250.7	-2.3
	213.0	216.3	-1.5	244.0	246.7	-1.1
Average	210.3	212.3	-0.9	245.7	247.5	-0.7
EDR2						
	209.0	209.0	0.0	247.0	239.2	3.3
	210.0	205.3	2.3	245.0	245.1	-0.0
	210.0	210.4	2.5	245.0	241.1	1.6
	210.0	205.2	2.3	248.0	241.6	2.6
	209.0	207.2	0.9	246.0	242.6	1.4
	210.0	205.6	2.1	246.0	243.2	1.2
Average	209.7	206.2	1.7	246.2	242.1	1.7

APPENDIX B

Drop Tester Data - Drop Height

Orientation	Type	18"	% Error	24"	% Error
Bottom	DHR1	14.5	-19.4	21.3	-11.2
		17.3	-3.9	21.9	-8.8
		16.6	-7.8	24.7	2.9
		15.7	-12.8	24.7	2.9
		19.2	6.7	19.8	-17.5
		18.7	3.9	19.1	-20.4
	Average	17.0	-5.6	21.9	-8.7
	DHR1s	17.7	-1.7	23.0	-4.2
		17.4	-3.3	22.8	-5.0
		17.3	-3.9	23.5	-2.1
		17.4	-3.3	23.5	-2.1
		18.1	0.6	23.1	-3.7
		17.8	-1.1	23.0	-4.2
	Average	17.6	-2.1	23.2	-3.5
	DHR2	16.6	-7.8	26.5	10.4
		16.2	-10.0	27.2	13.3
		18.3	1.7	24.2	0.8
		14.6	-18.6	23.1	-3.7
		16.1	-10.6	24.8	3.3
		20.0	11.1	24.9	3.7
	Average	17.0	-5.7	25.1	4.7
	DHR2s	17.7	-1.7	23.5	-2.1
		17.5	-2.8	23.6	-1.7
		17.7	-1.7	23.4	-2.5
		17.0	-5.6	23.4	-2.5
		17.1	-5.0	23.5	-2.1
		17.8	-1.1	23.2	-3.3
	Average	17.5	-3.0	23.4	-2.4

APPENDIX B (cont'd)

Orientation	Type	18"	% Error	24"	% Error
Bottom	**EDR1**	20.0	11.1	31.0	29.2
		20.0	11.1	28.0	16.7
		22.0	22.2	28.0	16.7
		20.0	11.1	30.0	25.0
		23.0	27.8	28.0	16.7
		20.0	11.1	27.0	12.5
	Average	20.8	15.7	28.7	19.4
	EDR2	21.0	16.7	24.0	0.0
		22.0	22.2	29.0	20.8
		20.0	11.1	30.0	25.0
		20.0	11.1	29.0	20.8
		20.0	11.1	29.0	20.8
		21.0	16.7	26.0	8.3
	Average	20.7	14.8	27.8	16.0

Orientation	Type	30"	% Error	36"	% Error
Bottom	**DHR1**	32.4	8.0	39.8	10.6
		31.6	5.3	38.8	7.8
		30.7	2.3	37.4	3.9
		29.3	-2.3	36.7	1.9
		24.2	-19.3	39.4	9.4
		32.2	7.3	35.3	-1.9
	Average	30.1	0.2	37.9	5.3
	DHR1z	31.0	3.3	36.7	1.9
		29.8	-0.7	35.4	-1.7
		29.4	-2.0	35.2	-2.2
		29.4	-2.0	35.2	-2.2
		28.9	-3.7	35.2	-2.2
		29.7	-1.0	35.7	-0.8
	Average	29.7	-1.0	35.6	-1.2

APPENDIX B (cont'd)

Orientation	Type	30"	% Error	36"	% Error
Bottom	DHR2	29.9	-0.3	42.4	17.8
		35.2	17.3	44.0	22.2
		36.6	22.0	43.0	19.4
		35.7	19.0	40.0	11.1
		26.3	-12.3	39.1	8.6
		30.9	3.0	36.7	1.9
	Average	32.4	8.1	40.9	13.5
	DHR2s	29.2	-0.3	35.4	-1.7
		29.8	-0.7	35.4	-1.7
		29.8	-0.7	35.5	-1.4
		29.8	-0.7	35.7	-0.8
		29.8	-0.7	35.5	-1.4
		30.1	0.3	34.9	-3.1
	Average	29.8	-0.8	35.4	-1.7
	EDR1	34.0	13.3	42.0	16.7
		37.0	23.3	41.0	13.9
		33.0	10.0	45.0	25.0
		35.0	16.7	41.0	13.9
		37.0	23.3	41.0	13.9
		34.0	13.3	43.0	19.4
	Average	35.0	16.7	42.2	17.1
	EDR2	32.0	6.7	46.0	27.8
		32.0	6.7	41.0	13.9
		35.0	16.7	37.0	2.8
		35.0	16.7	35.0	-2.8
		35.0	16.7	46.0	27.8
		34.0	13.3	38.0	5.6
	Average	33.8	12.8	40.5	12.5

APPENDIX B (cont'd)

Orientation	Type	18"	% Error	24"	% Error
Edge	**DHR1**	12.2	-32.2	22.1	-7.9
		14.0	-22.2	22.1	-7.9
		14.8	-17.8	22.4	-6.7
		15.7	-12.8	22.2	-7.5
		16.0	-11.1	23.2	-3.3
		15.7	-12.8	24.1	0.4
	Average	14.7	-18.1	22.7	-5.5
	DHR1s	17.4	-3.3	23.4	-2.5
		17.5	-2.8	23.6	-1.7
		17.7	-1.7	23.5	-2.1
		17.6	-2.2	23.5	-2.1
		17.7	-1.7	23.8	-0.8
		17.7	-1.7	23.5	-2.1
	Average	17.6	-2.2	23.6	-1.9
	DHR2	12.9	-28.3	20.1	-16.2
		14.2	-21.1	20.3	-15.4
		14.2	-21.1	20.3	-15.4
		14.5	-19.4	21.4	-10.8
		9.0	-50.0	21.0	-12.5
		9.4	-47.8	20.9	-12.9
	Average	12.4	-31.3	20.7	-13.9
	DHR2s	16.2	-10.0	22.0	-8.3
		16.1	-10.6	22.4	-6.7
		16.0	-11.1	22.3	-7.1
		16.5	-8.3	22.2	-7.5
		17.0	-5.6	21.9	-8.8
		16.2	-10.0	22.2	-7.5
	Average	16.3	-9.3	22.2	-7.6

APPENDIX B (cont'd)

Orientation	Type	18"	% Error	24"	% Error
Edge	**DHR1**	12.2	-32.2	22.1	-7.9
		14.0	-22.2	22.1	-7.9
		14.8	-17.8	22.4	-6.7
		15.7	-12.8	22.2	-7.5
		16.0	-11.1	23.2	-3.3
		15.7	-12.8	24.1	0.4
	Average	14.7	-18.1	22.7	-5.5
	DHR1z	17.4	-3.3	23.4	-2.5
		17.5	-2.8	23.6	-1.7
		17.7	-1.7	23.5	-2.1
		17.6	-2.2	23.5	-2.1
		17.7	-1.7	23.8	-0.8
		17.7	-1.7	23.5	-2.1
	Average	17.6	-2.2	23.6	-1.9
	DHR2	12.9	-28.3	20.1	-16.2
		14.2	-21.1	20.3	-15.4
		14.2	-21.1	20.3	-15.4
		14.5	-19.4	21.4	-10.8
		9.0	-50.0	21.0	-12.5
		9.4	-47.8	20.9	-12.9
	Average	12.4	-31.3	20.7	-13.9
	DHR2z	16.2	-10.0	22.0	-8.3
		16.1	-10.6	22.4	-6.7
		16.0	-11.1	22.3	-7.1
		16.5	-8.3	22.2	-7.5
		17.0	-5.6	21.9	-8.8
		16.2	-10.0	22.2	-7.5
	Average	16.3	-9.3	22.2	-7.6

APPENDIX B (cont'd)

Orientation	Type	18"	% Error	24"	% Error
Edge	**EDR1**	15.0	-16.7	24.0	0.0
		18.0	0.0	23.0	-4.2
		18.0	0.0	25.0	4.2
		18.0	0.0	22.0	-8.3
		15.0	-16.7	23.0	-4.2
		16.0	-11.1	24.0	0.0
	Average	16.7	-7.4	23.5	-2.1
	EDR2	15.0	-16.7	20.0	-16.7
		16.0	-11.1	24.0	0.0
		14.0	-22.2	22.0	-8.3
		16.0	-11.1	25.0	4.2
		16.0	-11.1	26.0	8.3
		15.0	-16.7	26.0	8.3
	Average	15.3	-14.8	23.8	-0.7

Orientation	Type	30"	% Error	36"	% Error
Edge	**DHR1**	21.3	-29.0	35.0	-2.8
		28.1	-6.3	30.4	-15.6
		29.6	-1.3	34.3	-4.7
		25.6	-14.7	32.7	-9.2
		25.8	-14.0	30.4	-15.6
		27.9	-7.0	29.1	-19.2
	Average	26.4	-12.1	32.0	-11.2
	DHR1s	28.6	-4.6	34.4	-4.4
		28.5	-5.0	34.7	-3.6
		28.9	-3.7	34.7	-3.6
		28.9	-3.7	34.2	-5.0
		28.2	-6.0	34.5	-4.2
		28.5	-5.0	34.0	-5.6
	Average	28.6	-4.7	34.4	-4.4

APPENDIX B (cont'd)

Orientation	Type	30"	% Error	36"	% Error
Edge	**DHR2**	27.5	-8.3	33.8	-6.1
		25.6	-14.7	30.5	-15.3
		23.5	-21.7	36.2	0.6
		26.6	-11.3	33.6	-6.7
		25.7	-14.3	34.7	-3.6
		24.8	-17.3	29.1	-19.2
	Average	25.6	-14.6	33.0	-8.4
	DHR2s	28.0	-6.7	34.5	-4.2
		27.9	-7.0	34.5	-4.2
		28.8	-4.0	34.5	-4.2
		28.6	-4.7	34.2	-5.0
		28.9	-3.7	34.4	-4.4
		28.0	-6.7	34.2	-5.0
	Average	28.4	-5.4	34.4	-4.5
	EDR1	32.0	6.7	40.0	11.1
		27.0	-10.0	40.0	11.1
		33.0	10.0	42.0	16.7
		27.0	-10.0	39.0	8.3
		34.0	13.3	41.0	13.9
		26.0	-13.3	40.0	11.1
	Average	29.8	-0.6	40.3	12.0
	EDR2	28.0	-6.7	38.0	5.6
		30.0	0.0	41.0	13.9
		32.0	6.7	41.0	13.9
		32.0	6.7	38.0	5.6
		29.0	-3.3	41.0	13.9
		34.0	13.3	41.0	13.9
	Average	30.8	2.8	40.0	11.1

APPENDIX B (cont'd)

Orientation	Type	30"	% Error	36"	% Error
Edge	**DHR2**	27.5	-8.3	33.8	-6.1
		25.6	-14.7	30.5	-15.3
		23.5	-21.7	36.2	0.6
		26.6	-11.3	33.6	-6.7
		25.7	-14.3	34.7	-3.6
		24.8	-17.3	29.1	-19.2
	Average	25.6	-14.6	33.0	-8.4
	DHR2s	28.0	-6.7	34.5	-4.2
		27.9	-7.0	34.5	-4.2
		28.8	-4.0	34.5	-4.2
		28.6	-4.7	34.2	-5.0
		28.9	-3.7	34.4	-4.4
		28.0	-6.7	34.2	-5.0
	Average	28.4	-5.4	34.4	-4.5
	EDR1	32.0	6.7	40.0	11.1
		27.0	-10.0	40.0	11.1
		33.0	10.0	42.0	16.7
		27.0	-10.0	39.0	8.3
		34.0	13.3	41.0	13.9
		26.0	-13.3	40.0	11.1
	Average	29.8	-0.6	40.3	12.0
	EDR2	28.0	-6.7	38.0	5.6
		30.0	0.0	41.0	13.9
		32.0	6.7	41.0	13.9
		32.0	6.7	38.0	5.6
		29.0	-3.3	41.0	13.9
		34.0	13.3	41.0	13.9
	Average	30.8	2.8	40.0	11.1

APPENDIX B (cont'd)

Orientation	Type	30"	% Error	36"	% Error
Edge	**DHR2**	27.5	-8.3	33.8	-6.1
		25.6	-14.7	30.5	-15.3
		23.5	-21.7	36.2	0.6
		26.6	-11.3	33.6	-6.7
		25.7	-14.3	34.7	-3.6
		24.8	-17.3	29.1	-19.2
	Average	25.6	-14.6	33.0	-8.4
	DHR2s	28.0	-6.7	34.5	-4.2
		27.9	-7.0	34.5	-4.2
		28.8	-4.0	34.5	-4.2
		28.6	-4.7	34.2	-5.0
		28.9	-3.7	34.4	-4.4
		28.0	-6.7	34.2	-5.0
	Average	28.4	-5.4	34.4	-4.5
	EDR1	32.0	6.7	40.0	11.1
		27.0	-10.0	40.0	11.1
		33.0	10.0	42.0	16.7
		27.0	-10.0	39.0	8.3
		34.0	13.3	41.0	13.9
		26.0	-13.3	40.0	11.1
	Average	29.8	-0.6	40.3	12.0
	EDR2	28.0	-6.7	38.0	5.6
		30.0	0.0	41.0	13.9
		32.0	6.7	41.0	13.9
		32.0	6.7	38.0	5.6
		29.0	-3.3	41.0	13.9
		34.0	13.3	41.0	13.9
	Average	30.8	2.8	40.0	11.1

APPENDIX B (cont'd)

Orientation	Type	18"	% Error	24"	% Error
Corner	DHR1	11.9	-33.9	20.2	-15.8
		10.3	-42.8	19.4	-19.2
		11.7	-35.0	19.5	-18.8
		14.4	-20.0	17.9	-25.4
		13.6	-24.4	21.6	-10.0
		15.0	-16.7	19.4	-19.2
	Average	12.8	-28.8	19.7	-18.1
	DHR1z	18.8	4.4	23.2	-3.3
		17.3	-3.9	23.1	-3.7
		17.8	-1.1	22.8	-5.0
		17.4	-3.3	23.5	-2.1
		16.9	-6.1	23.5	-2.1
		17.0	-5.6	23.1	-3.7
	Average	17.5	-2.6	23.1	-3.6
	DHR2	11.9	-33.9	21.0	-12.5
		11.6	-35.6	20.6	-14.2
		13.4	-25.6	22.3	-7.1
		15.3	-15.0	16.8	-30.0
		16.2	-10.0	20.3	-15.4
		15.2	-15.6	21.3	-15.1
	Average	13.9	-22.6	20.4	-15.1
	DHR2z	17.8	-1.1	24.0	0.0
		17.1	-5.0	23.8	-0.8
		16.9	-5.0	23.5	-2.1
		15.9	-11.7	22.7	-5.4
		16.0	-11.1	23.6	-1.7
		17.3	-3.9	23.2	-3.3
	Average	16.8	-6.5	23.5	-2.2

APPENDIX B (cont'd)

Orientation	Type	18"	% Error	24"	% Error
Corner	EDR1	13.0	-27.8	24.0	0.0
		15.0	-16.7	20.0	-16.7
		15.0	-16.7	19.0	-20.8
		19.0	5.6	22.0	-8.3
		21.0	16.7	23.0	-4.2
		17.0	-5.6	23.0	-4.2
	Average	16.7	-7.4	21.8	-9.0
	EDR2	16.0	-11.1	25.0	4.2
		19.0	5.6	25.0	4.2
		20.0	11.1	23.0	-4.2
		17.0	-5.6	23.0	-4.2
		18.0	0.0	20.0	-16.7
		18.0	0.0	23.0	-4.2
	Average	18.0	0.0	23.2	-3.5

Orientation	Type	30"	% Error	36"	% Error
Corner	DHR1	24.5	-18.3	29.0	-19.4
		26.7	-11.0	30.2	-16.1
		28.1	-6.3	27.4	-23.9
		23.4	-22.0	26.8	-25.6
		25.5	-15.0	28.4	-21.1
		22.6	-24.7	26.2	-27.2
	Average	25.1	-16.2	28.0	-22.2
	DHR1z	28.8	-4.0	34.4	-4.4
		28.9	-3.7	35.5	-1.4
		29.1	-3.0	34.2	-5.0
		29.8	-0.7	34.5	-4.2
		28.9	-3.7	35.9	-0.3
		29.1	-3.0	34.9	-3.1
	Average	29.1	-3.0	34.9	-3.1

APPENDIX B (cont'd)

Orientation	Type	30"	% Error	36"	% Error
Corner	DHR2	28.5	-5.0	32.8	-8.9
		27.9	-7.0	32.5	-9.7
		29.4	-2.0	34.7	-3.6
		26.0	-13.3	35.0	-2.8
		26.4	-12.0	33.2	-7.8
		27.7	-7.7	33.2	-7.8
	Average	27.7	-7.8	33.6	-6.8
	DHR2s	29.4	-2.0	36.2	0.6
		29.5	-1.7	35.2	-2.2
		29.5	-1.7	35.4	-1.7
		29.7	-1.0	35.5	-1.4
		30.3	1.0	35.0	-2.8
		29.1	-3.0	35.4	-1.7
	Average	29.6	-1.4	35.5	-1.5
	EDR1	32.0	6.7	32.0	-11.1
		26.0	-13.3	32.0	-11.1
		28.0	-6.7	39.0	8.3
		27.0	-10.0	40.0	11.1
		31.0	3.3	35.0	-2.8
		28.0	-6.7	41.0	13.9
	Average	28.7	-4.4	36.5	1.4
	EDR2	24.0	-20.0	27.0	-25.0
		27.0	-10.0	36.0	0.0
		28.0	-6.7	36.0	0.0
		24.0	-20.0	27.0	-25.0
		29.0	-3.3	33.0	-8.3
		23.0	-23.3	34.0	-5.6
	Average	25.8	-13.9	32.2	-10.6

APPENDIX C

Shock Table Data - DHR1

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
1.109	2.419	60.990	61.048	0	0	121	121	8.3	12.1
2.218	2.419	59.881	59.940	1	0	125	125	8.1	13.0
2.218	2.419	59.881	59.940	1	0	126	126	8.2	13.2
2.218	3.629	58.772	58.895	1	1	128	128	8.1	13.6
2.218	3.629	58.772	58.785	1	1	128	128	8.4	13.6
2.218	3.629	59.881	59.893	2	1	131	131	8.7	14.2
4.436	2.419	60.990	61.002	2	0	165	165	15.9	22.5
2.218	3.629	60.990	60.990	1	1	191	191	15.0	30.3
3.327	3.629	59.881	59.930	1	1	192	192	15.1	30.7
3.327	3.629	59.881	59.893	1	1	194	194	15.2	31.2
-2.218	3.629	60.990	61.002	0	1	192	192	15.2	30.7
3.327	3.629	59.881	59.930	0	1	197	197	15.2	32.0
2.218	3.629	59.881	60.001	0	3	225	225	22.2	41.9
6.653	3.629	60.990	61.038	4	3	223	223	21.1	41.2
5.545	2.419	63.208	63.229	8	0	232	232	21.4	44.6
2.218	3.629	60.990	61.038	3	1	225	225	21.3	42.0
2.218	-2.419	60.990	61.002	2	0	230	230	21.3	43.8
2.218	3.629	60.990	61.002	1	1	227	227	21.1	42.5
2.218	3.629	64.317	64.326	1	1	272	272	29.1	61.3
-3.327	3.629	63.208	63.218	0	0	272	272	27.7	61.3
-3.327	4.839	60.990	61.002	1	2	247	247	27.0	50.5
3.327	3.629	63.208	63.247	1	0	273	273	27.1	61.5
3.327	3.629	63.208	63.218	1	0	273	273	27.9	61.7
-3.327	3.629	63.208	63.218	0	0	270	270	27.9	60.5

APPENDIX C (cont'd)

Shock Table Data - DHR2

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
-3.232	-2.965	61.781	61.852	-1	-1	123	123	8.5	12.6
-2.155	-2.965	62.865	62.896	-2	-1	128	128	8.0	13.5
-2.155	3.953	58.529	58.604	-3	-1	118	118	8.1	11.6
-2.155	3.953	65.032	65.062	-2	0	120	120	8.1	11.9
-2.155	4.941	59.613	59.660	-2	-2	122	122	8.3	12.2
-2.155	-3.953	62.865	62.934	-2	-3	132	132	8.4	14.3
-2.155	-3.953	62.865	62.934	-2	-4	161	162	15.9	21.6
-3.232	-3.953	69.368	69.431	-2	-4	186	186	14.8	28.5
-3.232	-3.953	59.613	59.652	-4	-4	184	184	14.9	27.9
-3.232	-3.953	68.284	68.348	-2	-3	186	186	14.8	28.7
-2.155	-3.953	67.200	67.216	-2	-3	185	185	14.7	28.4
-2.155	-3.953	63.948	64.070	-3	-4	186	186	14.7	28.5
-4.310	-3.953	61.781	61.907	-24	-3	144	146	22.2	17.7
-3.232	-4.941	70.452	70.488	-4	-2	230	230	21.3	43.7
-2.155	-4.941	62.865	63.058	-3	-3	225	225	20.8	42.0
-3.232	-4.941	70.452	70.479	-2	-2	228	228	21.8	43.1
-3.232	4.941	60.697	60.743	-4	-5	228	228	21.3	43.1
-3.232	-4.941	71.535	71.597	-1	-5	228	228	20.5	42.9
-4.310	-4.941	66.116	66.301	-26	-2	170	172	28.5	24.4
-4.310	-4.941	72.619	72.680	-26	-5	180	182	26.9	27.6
-4.310	-4.941	69.368	69.489	-5	-6	251	251	26.7	52.0
-4.310	-4.941	72.619	72.688	-27	-5	177	179	26.9	26.5
-4.310	-5.929	66.116	66.125	-26	-5	178	180	26.7	26.8
-4.310	-4.941	70.452	70.488	-28	-2	179	182	26.6	27.3

APPENDIX C (cont'd)

Shock Table Data - EDR1

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
0	0	112	122	41	8	0.55
0	0	115	124	41	10	0.39
0	0	116	125	41	11	0.33
1	0	118	125	41	11	0.35
1	0	120	126	41	11	0.38
1	1	119	128	41	11	0.44
1	1	120	129	41	11	0.41
1	0	123	131	41	10	0.50
0	1	167	181	45	21	0.43
0	1	170	182	45	21	0.44
0	1	172	182	45	18	0.55
1	-1	172	182	45	21	0.44
0	-1	170	185	45	25	0.34
0	-1	171	185	45	22	0.42
1	0	174	184	46	23	0.39
-1	1	207	223	47	33	0.40
1	0	210	224	49	25	0.62
1	0	210	226	49	32	0.44
1	0	210	225	48	23	0.68
-1	0	212	227	48	26	0.60
0	0	213	228	48	28	0.55
-1	0	244	263	50	39	0.53
0	-1	246	263	49	31	0.70
0	1	248	261	49	31	0.68
0	0	247	260	48	36	0.55
-1	-1	245	259	50	34	0.61
0	1	244	263	49	36	0.58

APPENDIX C (cont'd)

Shock Table Data - EDR2

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
0	0	113	118	38	8	0.52
0	0	116	121	37	11	0.32
0	0	116	122	37	11	0.35
0	0	117	123	37	9	0.45
1	0	119	124	38	10	0.40
0	0	119	124	38	9	0.45
0	0	167	179	42	23	0.35
1	0	169	183	42	25	0.32
0	0	171	185	43	23	0.38
1	0	169	184	40	23	0.37
0	0	169	183	42	20	0.47
1	0	169	183	42	20	0.48
0	0	209	227	48	35	0.39
0	0	210	229	47	29	0.52
0	-1	210	230	46	29	0.53
0	0	210	229	49	28	0.55
0	0	209	228	48	28	0.55
0	-1	210	229	48	39	0.32
0	0	247	264	49	36	0.58
1	-1	245	263	52	49	0.36
0	0	245	263	49	30	0.73
0	0	245	263	48	49	0.35
0	0	248	264	47	35	0.61
0	0	246	264	51	38	0.55
0	0	246	264	46	53	0.30

APPENDIX C (cont'd)

Drop Tester Data - DHR1 - Bottom Drops

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
-24.396	-2.419	54.337	59.574	-39	0	169	173	17.7	14.5
-7.762	26.614	90.931	92.820	-7	41	185	189	17.4	17.3
-16.634	22.985	80.950	82.986	-20	43	179	185	17.3	16.6
-22.178	13.307	63.208	65.751	-38	23	175	181	17.4	15.7
-18.851	-21.775	85.386	90.113	-27	-30	195	200	18.1	19.2
16.634	-22.985	94.257	95.508	18	-25	195	197	17.8	18.7
25.505	-7.258	80.950	85.089	48	-14	204	210	23.0	21.3
22.178	-19.356	85.386	89.799	38	-35	207	213	22.8	21.9
21.069	27.258	113.109	113.466	16	11	225	226	23.5	24.7
9.980	10.887	116.436	116.884	7	15	226	226	23.5	24.7
7.762	30.243	76.515	79.893	1	61	193	203	23.1	19.8
11.089	27.824	67.644	69.219	10	60	189	199	23.0	19.1
-18.851	-7.258	116.436	116.651	-20	-0	258	259	31.0	32.4
-7.762	-37.501	112.000	115.750	-10	-60	249	256	29.8	31.6
-33.267	-6.049	103.129	105.493	-53	-7	247	252	29.4	30.7
-16.634	27.824	107.564	111.000	-17	48	241	246	29.4	29.3
-25.505	14.517	58.772	63.633	-63	22	214	224	28.9	24.2
-29.941	-16.936	104.238	109.767	-45	-25	253	259	29.7	32.2
15.525	-19.356	138.614	138.973	15	-11	287	287	36.7	39.8
18.851	7.258	139.723	140.350	16	11	283	284	35.4	38.8
29.941	-6.049	138.614	138.821	23	0	278	279	35.2	37.4
29.941	16.936	134.178	136.009	32	26	273	276	35.2	36.7
18.851	10.887	139.723	140.256	15	16	285	286	35.2	39.4
23.287	33.872	113.109	115.657	31	62	256	266	35.0	34.0
-32.158	25.404	105.347	110.840	-55	38	262	270	35.7	35.3

APPENDIX C (cont'd)

Drop Tester Data - DHR2 - Bottom Drops

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
26.936	6.918	84.542	86.780	30	3	181	184	17.7	16.6
7.542	29.647	74.787	76.509	14	47	175	182	17.5	16.2
7.542	22.729	99.716	102.552	11	22	191	193	17.7	18.3
-9.394	5.929	42.271	46.035	-60	4	162	173	17.0	14.6
19.394	10.871	53.110	54.515	-44	19	175	181	17.1	16.1
-10.774	-33.600	85.626	89.502	-13	-48	196	202	17.8	20.0
-4.310	-37.553	96.465	103.539	-7	-65	223	232	23.5	26.5
-10.774	-31.624	100.800	105.913	-17	-47	230	235	23.6	27.2
24.781	-19.765	76.955	80.869	52	-37	213	222	23.4	24.2
31.246	-5.929	84.542	90.180	65	-6	207	217	23.4	23.1
11.852	34.588	97.548	99.530	17	46	219	225	23.5	24.8
-29.091	11.859	68.284	71.396	-62	14	205	215	23.2	22.7
-10.774	-35.576	92.129	99.346	-22	-61	231	240	23.6	28.3
21.549	19.765	107.303	110.171	33	20	222	225	23.5	24.9
35.556	14.824	99.716	106.201	61	11	239	247	29.2	29.9
-10.774	-23.718	119.226	119.747	-13	-24	266	268	29.8	35.2
-8.620	-21.741	125.729	126.117	-12	-20	272	273	29.8	36.6
-10.774	-33.600	121.394	124.805	-23	-51	264	270	29.8	35.7
25.859	-16.800	70.452	75.978	72	-20	219	231	29.8	26.3
-31.246	15.812	104.052	106.315	-47	22	245	251	30.0	30.9
-17.239	-14.824	135.484	135.814	-17	-13	293	294	35.4	42.4
4.310	-34.588	135.484	139.358	4	-50	295	299	35.4	44.0
14.007	-36.565	128.981	134.010	16	-54	291	296	35.5	43.2
24.781	-29.647	117.058	122.014	48	-49	277	285	35.7	40.0
-31.246	19.765	132.232	134.135	-36	24	279	282	35.5	39.1
-33.401	18.776	109.471	111.949	-50	33	267	273	34.9	36.7

APPENDIX C (cont'd)

Drop Tester Data - DHR1 - Edge Drops

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
-7.762	-26.614	29.941	37.899	-19	-106	117	159	17.4	12.2
-8.871	-27.824	34.376	44.058	-25	-103	134	170	17.5	14.0
-12.198	-26.614	32.158	42.675	-36	-103	137	175	17.7	14.8
-14.416	-30.243	37.703	49.590	-35	-108	141	181	17.6	15.7
-7.762	-36.292	46.574	59.552	-20	-110	144	182	17.7	16.0
-12.198	-25.404	38.812	47.964	-40	-88	152	180	17.7	15.7
3.327	-32.662	41.030	49.586	0	-109	147	183	18.0	16.2
-15.525	-32.662	54.337	65.271	-36	-98	179	208	23.4	20.8
-11.089	-44.760	52.119	68.306	-26	-134	165	214	23.6	22.1
-12.198	-48.389	54.337	72.624	-32	-135	164	214	23.8	22.1
6.653	-37.501	46.574	57.155	13	-126	175	216	23.5	22.4
-16.634	-32.662	51.010	61.916	-42	-112	178	215	23.5	22.2
-5.545	-45.969	58.772	70.376	-7	-134	173	219	23.8	23.2
-4.436	-47.179	58.772	74.615	-4	-138	176	224	23.5	24.1
17.743	-37.501	27.723	47.707	71	-148	112	199	28.6	19.0
18.851	-52.018	34.376	62.302	69	-166	109	210	28.5	21.3
2.218	-54.437	58.772	77.690	-2	-171	170	241	28.9	28.1
-3.327	-55.647	72.079	88.187	-3	-151	197	248	29.5	29.6
18.851	-32.662	63.208	71.770	53	-100	201	231	28.9	25.6
19.960	-45.969	53.228	72.813	66	-142	170	231	28.2	25.8
14.416	-56.857	64.317	84.721	42	-158	177	241	28.5	27.9
17.743	-71.374	82.059	105.638	40	-177	199	269	34.4	35.0
-21.069	-61.696	54.337	83.878	-49	-186	161	251	33.9	30.4
6.653	-75.003	77.624	107.945	13	-188	189	267	34.7	34.3
33.267	-39.921	65.426	79.788	82	-118	198	245	34.7	28.9
31.050	-56.857	83.168	101.691	60	-149	205	261	34.2	32.7
-15.525	-71.374	41.030	81.130	-34	-221	114	251	34.5	30.4
31.050	-66.535	55.446	87.989	71	-179	152	245	34.0	29.1

APPENDIX C (cont'd)

Drop Tester Data - DHR2 - Edge Drops

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
-15.084	18.776	20.594	31.113	-58	101	113	162	16.2	12.9
-15.084	21.741	24.929	34.788	-56	105	121	170	16.1	14.2
-12.929	23.718	31.432	40.309	-49	99	129	170	16.0	14.2
-12.929	28.659	30.348	43.391	-50	118	115	172	15.7	14.5
-7.542	21.741	39.019	41.414	-2	57	107	121	16.5	7.2
-6.465	21.741	41.187	44.916	-17	58	121	136	17.0	9.0
-4.310	22.729	39.019	44.681	-11	68	120	138	16.2	9.4
-24.781	30.635	32.516	51.087	-84	126	134	202	22.0	20.1
-22.626	25.694	42.271	54.396	-70	109	156	203	22.4	20.3
-30.168	29.647	36.852	55.080	-104	112	134	203	22.3	20.3
-4.310	-33.600	43.355	52.071	-12	-118	155	195	22.2	18.6
-25.859	32.612	36.852	55.590	-96	134	127	208	21.9	21.4
-30.168	28.659	46.606	60.526	-97	112	144	206	22.2	21.0
-11.852	34.588	44.439	56.498	-50	121	159	206	22.8	20.9
-34.478	46.447	33.600	66.347	-125	165	114	237	28.0	27.5
-7.542	42.494	52.026	65.942	-28	144	175	228	27.9	25.6
18.316	36.565	44.439	59.799	36	139	166	219	28.8	23.5
-15.084	43.482	52.026	67.198	-48	145	175	233	28.8	26.6
-33.401	42.494	56.361	77.635	-94	137	158	229	28.6	25.7
-30.168	32.612	49.858	64.511	-95	115	169	225	28.9	24.8
-21.549	-27.671	42.271	53.494	-83	-102	162	209	28.0	21.4
-30.168	64.235	72.619	98.873	-66	178	181	262	34.5	33.8
-24.781	26.682	71.535	79.047	-63	85	226	249	34.5	30.5
-11.852	66.212	61.781	91.197	-42	215	160	272	34.5	36.2
-46.330	71.153	79.123	109.258	-92	178	169	262	34.5	33.6
-34.478	69.176	83.458	105.697	-69	177	186	266	34.2	34.7
-31.246	27.671	66.116	75.546	-84	97	207	244	34.4	29.7
-53.872	55.341	79.123	103.272	-120	139	150	237	34.2	27.7

APPENDIX C (cont'd)

Drop Tester Data - DHR2 - Edge Drops

Peak G's X	Y	Z	VS	dVel(in/sec) X	Y	Z	VS	D.H. Inch	Drop Equv
-15.084	18.776	20.594	31.113	-58	101	113	162	16.2	12.9
-15.084	21.741	24.929	34.788	-56	105	121	170	16.1	14.2
-12.929	23.718	31.432	40.309	-49	99	129	170	16.0	14.2
-12.929	28.659	30.348	43.391	-50	118	115	172	15.7	14.5
-7.542	21.741	39.019	41.414	-2	57	107	121	16.5	7.2
-6.465	21.741	41.187	44.916	-17	58	121	136	17.0	9.0
-4.310	22.729	39.019	44.681	-11	68	120	138	16.2	9.4
-24.781	30.635	32.516	51.087	-84	126	134	202	22.0	20.1
-22.626	25.694	42.271	54.396	-70	109	156	203	22.4	20.3
-30.168	29.647	36.852	55.080	-104	112	134	203	22.3	20.3
-4.310	-33.600	43.355	52.071	-12	-118	155	195	22.2	18.6
-25.859	32.612	36.852	55.590	-96	134	127	208	21.9	21.4
-30.168	28.659	46.606	60.526	-97	112	144	206	22.2	21.0
-11.852	34.588	44.439	56.498	-50	121	159	206	22.8	20.9
-34.478	46.447	33.600	66.347	-125	165	114	237	28.0	27.5
-7.542	42.494	52.026	65.942	-28	144	175	228	27.9	25.6
18.316	36.565	44.439	59.799	36	139	166	219	28.8	23.5
-15.084	43.482	52.026	67.198	-48	145	175	233	28.8	26.6
-33.401	42.494	56.361	77.635	-94	137	158	229	28.6	25.7
-30.168	32.612	49.858	64.511	-95	115	169	225	28.9	24.8
-21.549	-27.671	42.271	53.494	-83	-102	162	209	28.0	21.4
-30.168	64.235	72.619	98.873	-66	178	181	262	34.5	33.8
-24.781	26.682	71.535	79.047	-63	85	226	249	34.5	30.5
-11.852	66.212	61.781	91.197	-42	215	160	272	34.5	36.2
-46.330	71.153	79.123	109.258	-92	178	169	262	34.5	33.6
-34.478	69.176	83.458	105.697	-69	177	186	266	34.2	34.7
-31.246	27.671	66.116	75.546	-84	97	207	244	34.4	29.7
-53.872	55.341	79.123	103.272	-120	139	150	237	34.2	27.7

APPENDIX C (cont'd)

Drop Tester Data - DHR1 - Corner Drops

Peak G's X	Y	Z	VS	dVel(in/sec) X	Y	Z	VS	D.H. Inch	Drop Equv
29.941	-33.872	-7.762	44.976	97	-122	-20	157	18.8	11.9
19.960	-15.726	21.069	33.010	95	-72	85	146	17.3	10.3
27.723	-13.307	25.505	39.952	116	-46	93	156	17.8	11.7
32.158	-3.629	33.267	46.285	123	0	121	173	17.4	14.4
23.287	-18.146	24.396	37.033	95	-87	108	168	16.9	13.6
33.267	-18.146	29.941	47.854	124	-64	109	177	17.0	15.0
41.030	-30.243	37.703	63.400	136	-100	116	205	21.9	20.2
37.703	-37.501	33.267	60.491	126	-119	100	200	23.2	19.4
45.465	-31.453	12.198	55.951	166	-108	34	201	23.1	19.5
36.594	-38.711	23.287	58.137	119	-136	67	192	22.8	17.9
45.465	-21.775	41.030	63.217	143	-75	137	212	23.1	21.6
15.525	-32.662	36.594	51.449	60	-123	147	201	23.5	19.4
36.594	-45.969	31.050	65.261	107	-131	76	186	23.1	16.6
58.772	-14.517	47.683	76.643	175	-45	134	225	28.8	24.5
43.248	-43.550	60.990	83.400	130	-126	150	235	28.9	26.7
63.208	-33.872	73.188	94.836	155	-90	162	241	27.9	28.1
63.208	-44.760	36.594	81.382	165	-117	89	220	29.1	23.4
42.139	-58.067	34.376	75.731	106	-146	80	198	29.8	18.9
37.703	-36.292	63.208	78.381	105	-115	169	230	28.9	25.5
80.950	-50.808	51.010	95.817	150	-119	100	216	29.1	22.6
77.624	-48.389	87.604	113.354	158	-108	153	245	34.4	29.0
47.683	-32.662	76.515	94.352	122	-84	201	250	35.5	30.2
56.554	-56.857	63.208	92.858	133	-144	135	238	34.2	27.4
80.950	-54.437	67.644	109.941	156	-134	115	236	33.9	26.8
82.059	-50.808	72.079	115.312	160	-125	133	243	34.5	28.4
45.465	-61.696	63.208	90.330	97	-165	133	233	35.9	26.1
45.465	-61.696	63.208	92.833	101	-168	126	233	34.9	26.2

APPENDIX C (cont'd)

Drop Tester Data - DHR2 - Corner Drops

Peak G's				dVel(in/sec)				D.H.	Drop
X	Y	Z	VS	X	Y	Z	VS	Inch	Equv
-29.091	11.859	16.258	29.339	-144	23	54	156	17.8	11.9
-18.316	18.776	24.929	36.187	-86	73	104	154	17.1	11.6
-18.316	18.776	18.426	31.452	-98	98	89	165	16.9	13.4
-23.704	24.706	29.265	43.416	-104	94	106	176	15.9	15.3
-24.781	22.729	28.181	42.178	-103	89	120	182	16.0	16.2
-30.168	13.835	31.432	45.711	-120	49	119	176	17.3	15.2
-36.633	25.694	42.271	61.555	-129	88	135	206	24.0	21.0
-39.865	34.588	36.852	64.371	-129	112	112	205	23.8	20.6
-31.246	37.553	36.852	60.591	-109	137	121	213	23.5	22.3
-21.549	-28.659	24.929	43.671	-101	-121	97	185	22.7	16.8
-39.865	41.506	33.600	64.563	-132	129	86	203	23.6	20.3
-17.239	28.659	37.935	48.251	-79	116	154	208	23.2	21.3
-52.795	39.529	53.110	82.061	-144	105	132	222	31.2	24.3
-52.795	57.318	68.284	102.530	-143	139	136	241	29.4	28.5
-61.414	49.412	65.032	98.439	-141	117	128	224	29.5	24.6
-49.562	61.271	66.116	100.862	-134	148	129	238	29.5	27.9
-53.872	56.329	72.619	105.272	-137	134	152	245	29.7	29.4
-59.259	27.671	55.277	84.249	-154	76	153	230	30.3	26.0
-51.717	34.588	59.613	85.020	-134	94	164	232	28.3	26.4
-15.084	40.518	53.110	67.664	-51	145	181	238	29.1	27.7
-51.717	56.329	65.032	99.291	-121	154	169	258	36.2	32.8
-67.879	62.259	76.955	118.304	-160	144	141	257	35.2	32.8
-64.646	72.141	78.039	118.666	-150	164	146	266	36.9	34.7
-21.549	53.365	69.368	89.416	-71	163	199	267	35.4	35.0
-65.724	10.871	44.439	79.559	-191	30	134	235	35.5	27.1
-70.034	62.259	75.871	117.236	-150	135	164	260	35.0	33.2
-71.111	72.141	32.516	106.388	-168	193	46	260	35.4	33.2
-46.330	54.353	69.368	93.029	-108	141	170	246	34.7	29.7

APPENDIX C (cont'd)

Drop Tester Data - EDR1 - Bottom Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
9	25	185	195	75	20	0.59
10	43	186	200	76	20	0.62
53	25	177	197	62	22	0.50
61	22	169	193	56	20	0.54
13	-60	177	197	65	23	0.49
-60	-13	179	201	63	20	0.61
2	-67	209	231	82	31	0.50
-63	13	213	235	81	28	0.59
36	-29	221	238	89	28	0.62
-68	1	213	236	82	30	0.54
52	32	206	233	83	28	0.60
-29	51	216	236	83	27	0.63
65	26	235	259	94	34	0.59
-56	64	227	257	77	37	0.53
89	3	216	245	80	33	0.53
43	-56	240	264	93	35	0.59
74	29	232	259	90	37	0.53
-12	95	220	251	84	34	0.55
-72	45	233	262	85	42	0.45
-93	48	236	274	80	41	0.54
-89	-13	261	291	104	45	0.56
-81	-25	266	294	110	41	0.65
-79	-59	242	289	100	41	0.62
-74	83	231	270	80	43	0.48
-61	87	246	284	97	41	0.60

APPENDIX C (cont'd)

Drop Tester Data - EDR2 - Bottom Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
44	14	169	186	74	21	0.47
30	-44	172	190	62	22	0.45
23	-39	179	195	73	20	0.58
-23	-22	187	198	81	20	0.58
-29	-38	183	199	76	20	0.59
-28	-14	189	200	81	21	0.58
5	-28	211	228	96	24	0.67
-61	-20	205	226	81	29	0.50
-47	-50	203	228	70	30	0.50
-29	16	213	231	92	29	0.55
-66	-30	201	226	73	29	0.52
-58	5	15	61	31	2	0.74
-30	29	218	230	89	26	0.61
-43	-28	244	260	104	32	0.64
56	45	224	248	86	32	0.58
-50	-61	224	253	81	35	0.54
80	28	214	243	80	35	0.49
15	-79	227	254	86	35	0.55
26	-74	228	255	85	34	0.58
23	-92	245	280	89	46	0.48
-12	70	250	276	103	41	0.55
-14	32	273	286	118	37	0.70
91	33	236	269	87	35	0.64
71	-40	260	287	105	46	0.53
85	-10	30	108	36	6	0.55
-102	-24	235	274	91	38	0.60

APPENDIX C (cont'd)

Drop Tester Data - EDR1 - Edge Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
-113	-3	115	161	39	15	0.49
-119	-11	121	171	39	18	0.47
-122	-3	134	181	50	18	0.54
-126	-4	135	185	54	18	0.55
-116	-22	142	186	53	15	0.72
-120	-16	144	189	57	16	0.72
-158	7	140	212	60	24	0.54
-136	24	166	217	68	23	0.63
-154	8	151	217	70	25	0.55
-138	-19	171	221	68	22	0.70
-132	-10	175	220	70	23	0.66
-135	2	175	222	73	24	0.63
-161	10	184	245	86	32	0.55
-174	8	168	242	81	27	0.69
-161	3	189	249	92	33	0.55
-163	11	191	252	95	27	0.74
-172	8	180	250	96	34	0.55
-151	58	180	245	79	26	0.72
-136	-9	230	270	99	35	0.65
-173	29	209	274	117	40	0.55
-96	-15	32	106	33	5	0.70
-174	31	206	273	121	40	0.55
-175	6	215	278	122	42	0.55
-183	30	193	269	142	39	0.55
-173	11	215	277	124	41	0.55
-176	48	197	271	153	40	0.55
-20	15	-144	149	36	11	0.58

APPENDIX C (cont'd)

Drop Tester Data - EDR2 - Edge Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
-109	-1	120	163	50	15	0.53
7	-7	76	79	31	3	0.56
-114	-20	128	174	53	16	0.59
-100	-54	128	174	48	14	0.67
-117	-22	137	182	58	16	0.63
-119	-29	133	183	53	16	0.64
-141	-35	148	209	59	20	0.68
-132	-56	155	213	61	24	0.55
-132	-26	165	214	66	22	0.63
-146	-37	155	217	69	25	0.55
113	6	-10	120	42	6	0.71
-134	-31	169	219	71	26	0.55
-134	-44	167	219	67	26	0.55
-164	37	156	232	64	28	0.59
-134	-96	164	234	69	30	0.55
-149	-33	188	243	88	32	0.55
-160	-73	169	246	101	32	0.55
-143	11	198	246	82	29	0.64
-166	-7	188	252	94	34	0.55
-149	-14	220	266	102	38	0.55
-162	-31	218	275	106	41	0.55
-191	-29	193	277	140	41	0.55
-172	15	199	264	109	38	0.55
-173	19	212	276	118	41	0.55
-184	21	205	277	138	41	0.55

APPENDIX C (cont'd)

Drop Tester Data - EDR1 - Corner Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
62	-116	115	175	47	13	0.72
131	-112	37	178	49	15	0.68
98	-92	127	185	51	15	0.70
97	-110	116	188	64	19	0.55
109	-142	83	197	75	21	0.55
105	-109	141	209	87	24	0.55
104	-127	94	191	102	20	0.55
100	-129	88	190	113	19	0.55
11	-119	164	204	52	22	0.56
124	-90	129	205	101	23	0.55
104	-116	126	207	148	23	0.55
115	-142	140	244	209	32	0.55
97	-117	158	221	128	26	0.55
78	-147	148	230	150	28	0.55
111	-101	138	215	190	25	0.55
140	-115	125	224	173	27	0.55
115	-145	127	238	202	31	0.55
82	-149	136	230	189	28	0.55
117	-201	57	244	107	32	0.55
86	-119	176	245	167	32	0.55
102	-99	158	243	217	32	0.55
136	-155	145	270	262	39	0.55
149	-143	150	273	272	40	0.55
140	-117	146	254	256	35	0.55
149	-154	144	276	275	41	0.55

APPENDIX C (cont'd)

Drop Tester Data - EDR1 - Corner Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
62	-116	115	175	47	13	0.72
131	-112	37	178	49	15	0.68
98	-92	127	185	51	15	0.70
97	-110	116	188	64	19	0.55
109	-142	83	197	75	21	0.55
105	-109	141	209	87	24	0.55
104	-127	94	191	102	20	0.55
100	-129	88	190	113	19	0.55
11	-119	164	204	52	22	0.56
124	-90	129	205	101	23	0.55
104	-116	126	207	148	23	0.55
115	-142	140	244	209	32	0.55
97	-117	158	221	128	26	0.55
78	-147	148	230	150	28	0.55
111	-101	138	215	190	25	0.55
140	-115	125	224	173	27	0.55
115	-145	127	238	202	31	0.55
82	-149	136	230	189	28	0.55
117	-201	57	244	107	32	0.55
86	-119	176	245	167	32	0.55
102	-99	158	243	217	32	0.55
136	-155	145	270	262	39	0.55
149	-143	150	273	272	40	0.55
140	-117	146	254	256	35	0.55
149	-154	144	276	275	41	0.55

APPENDIX C (cont'd)

Drop Tester Data - EDR2 - Corner Drops

Velocity Changes X	Y	Z	R	Peak Accel	Drop Ht.	e
105	-73	125	179	41	16	0.59
93	-109	122	188	54	19	0.55
91	-114	122	191	54	20	0.55
101	-122	106	192	52	17	0.67
43	-141	146	208	49	25	0.49
111	-142	114	215	76	25	0.55
93	-151	102	206	69	23	0.55
27	-143	163	219	61	23	0.64
146	-131	56	205	59	20	0.63
91	-142	118	208	101	23	0.55
182	-59	87	213	67	24	0.55
132	-147	100	224	126	27	0.55
107	-149	131	228	158	28	0.55
38	-190	113	225	75	24	0.66
113	-127	157	233	144	29	0.55
146	-108	95	206	98	23	0.55
147	-124	104	225	170	27	0.55
147	-156	135	259	238	36	0.55
154	-145	133	260	241	36	0.55
125	-163	85	225	153	27	0.55
89	-153	166	246	187	33	0.55
151	-119	145	251	216	34	0.55