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Reliability and Error Estimation For
Mechanical Shock Recorders and Impact Indicators

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S. Paul Singh
Major professor

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RELIABILITY AND ERROR ESTIMATION
FOR MECHANICAL SHOCK RECORDERS AND IMPACT INDICATORS

By

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ABSTRACT

RELIABILITY AND ERROR ESTIMATION
FOR MECHANICAL SHOCK RECORDERS AND IMPACT INDICATORS

By

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There were significant developments in battery powered sensing and digital data recording systems by the electronic industry over the past decade. This led to the development of a variety of electronic based dynamics measuring devices that can be placed in packages to both record and save shock and vibration data that occur during shipment. However, most of the earlier devices are mechanical in nature and they use a paper output or a visual indicator to quantify the shock levels. There are many of these types of mechanical devices that are still being used today because of their low cost. This study determined the reliability and error estimation of various mechanical shock recorders and impact indicators.

The study concluded that the Impact-O-Graph recorder measured shock values more accurately than the Impact Register recorder.

The order of preference among mechanical indicators is as follows: Omni-G, Mag 2000, Shockranger, and Shockwatch.

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1.0 INTRODUCTION

The damage to products resulting from 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. The use of package dynamics measuring instruments helps us understand the dynamic forces that products encounter in distribution environments, and also identify shipments that may arrive in damaged condition. Mechanical shock recorders and impact indicators are commonly used to detect if packages have been exposed to damage causing shocks during transportation and handling. These devices have been used for many years without formal studies to compare the different types and determine their accuracy.

The need for accurately and conveniently measuring the distribution environment to develop optimum packaging for products during shipment is becoming increasingly important. There have been significant developments in battery powered sensing and digital data recording systems by the electronic industry over the past decade, which has led to the development of a variety of electronic based dynamics measuring devices that can be placed in packages to both record and save shock and vibration data that occur during shipment. However, most of the earlier devices were purely mechanical in nature and they used a paper output or a visual indicator to quantify the shock levels. There are many of these types of mechanical devices that are still being used today because of their low cost. This study was performed to determine the reliability and to estimate the error of the various types of mechanical shock recorders and impact indicators.

The industry seems to find numerous use and application areas for shock recorders and impact indicators. Many companies see the advantages of using shock recorders and impact indicators when evaluating their distribution environments, and to use these as a basis for quality control of their transportation and handling methods. Trost (1993) provided a broad description of various shock recorders and impact indicators that are currently available. The report is based on a detailed survey of the world market. In all, some 25 instruments are described. Trost presented a qualitative comparison between the various devices in terms of the cost, accuracy, ease of use, and data capabilities. The results of his study showed that most PC based electronic measuring recorders provide larger amounts of information, but are relatively more expensive when compared to the mechanical devices. The single-use impact indicators are easier to use, but provide very little information on the impact history as compared to the multiple use (re-settable) type of devices. Like the mechanical recorders, the impact indicators are relatively inexpensive. The use of these devices in transport surveys can provide an increased awareness of the distribution environment (Trost, 1993).

Trost's study also contains a description of tipping and tilting indicators. These instruments show if the product/package has tipped or tilted beyond a pre-set limit. This is indicated by powder or pearls that adhere to a sticky surface when the package is tipped or tilted. In other cases, a plastic washer releases a red background which indicates that tipping or tilting has taken place.

There are also a small variety of electronic devices that are currently available to determine the dynamics of product package shipments. A recent study (Graesser et-al., 1992) determined the reliability of and error in certain electronic dynamic data recorders. These types of recorders generally have a tri-axial accelerometer that senses the dynamic events and stores them in memory for later processing using a PC. This study investigated the error in measuring package drop heights and shock values using the DHR recorders developed by Dallas Instruments (Dallas, TX) and the EDR recorders from Instrumented Sensor Technology (Okemos, MI). Drops were made onto the bottom, edge and corner orientations from heights of 18, 24, 30, and 36 inches. It was found that the DHR was more accurate in predicting drop heights using the zero-G channel (drop height is computed by determining the elapsed during which time the package experiences free fall). Both the recorders were inaccurate by as much as 35% in predicting drop heights using accelerometer data . The study found that both recorders employ questionable methods to determine the coefficient of restitution, which is a critical factor in determining drop height from accelerometer data. The recorders were also tested for measuring shock levels using programmed impacts on the shock machine. The EDR was found to be both more accurate (mean percent error closer to zero) and more precise (lower spread in mean percent error) than the DHR. The EDR measures shock values with an accuracy of approximately 1% overall while the error for the DHR varies between +10% (overestimated) and -25% (underestimated) for similar shock values. A mean error of approximately 5% for a recorder is considered acceptable. However, these types of instruments are also known to be significantly more expensive as compared to all types of mechanical recorders.

In another study (Association of American Railroads, 1990) Low G Shockwatch Devices made by Media Recovery, Inc. (Dallas, Texas), were compared to electronic data recorders for impacts in various types of boxcars. The comparison was conducted using boxcars with different types of undercarriages. The shocks developed during coupling were monitored. The shock durations varied as a function of the coupling. Results showed that these mechanical indicators are duration sensitive and show good results when the frequency of the shock pulse was approximately 10 Hz. Draft gears in boxcars that would generate shock pulses away from this frequency would produce an error, because of the change in duration.

There are different types of mechanical recorders and impact indicators that are used to measure dynamic levels in package shipments. This section describes the various kinds of recorders, and their functioning characteristics, that are most commonly used in the packaging industry and were tested in this study.

1.1 Mechanical Recorders.

Mechanical recorders generally work according to the "weights that sway" (Impact-O-Graph Manual) principle and give a registration on a moving paper slip. The result of an impact is shown as a curve with the registration as a function of time. One disadvantage in comparison with the PC instruments is that the results are more complex and involve considerable work. The main advantage of mechanical recorders is their ease of use.

1.2 Impact Indicators.

Impact Indicators are devices that use various concepts to indicate that an impact over a certain threshold has occurred. The various concepts include the use of magnetic forces, liquid suspended in a capillary tube, spring ball arrangement, etc. Some of these devices are re-settable and some are one time use only. The cost of these devices are relatively the lowest as compared to all shock monitoring instruments. However, these devices are duration sensitive and generally show higher errors when evaluating over a wide frequency range.

1.3 Study Objectives.

The purpose of this study was to determine the reliability and error associated with the two types of recorders and the four types of indicators (described later in 2.3 and 2.4) when they are exposed to shocks of varying levels and durations commonly seen in package impacts.

The major objectives of this study were as follows:

- Determine the error in each mechanical recorder and impact indicator.

- Determine the reliability of each mechanical recorder and impact indicator.

- Determine whether the recorders and indicators over or underestimated the shock level, and if they are consistent within type of unit.

2.0 EXPERIMENTAL DESIGN

In order to achieve the objectives of this study, tests were designed to accurately and consistently obtain shock pulses that were similar to those found in packaged products during handling. A programmable shock machine system and a free-fall drop tester were used to generate the shock pulses to the mechanical recorders and impact indicators. All testing was performed at standard laboratory conditions of 25° C and 50% Relative Humidity.

2.1 Instrumented Package Drop Tests.

A Lansmont PDT 56E Precision Drop Tester was used for all free-fall drops. This machine is equipped with a pneumatically actuated drop leaf system. The high velocity pneumatic system accelerates the drop leaf vertically downward with an acceleration greater than gravity. The package containing the mechanical shock recorders is dropped onto a concrete base. The package is also instrumented with a Dytran accelerometer (model 301 A05) to measure the acceleration levels.

The recorders were packaged in 200-pound C-flute corrugated regular slotted containers (RSC) using 2 inch and 4 inch thick polyethylene cushioning (Ethafoam, Dow Chemical Company) and 2 inch thick polyurethane cushioning. The recorder was encapsulated by these cushions in all six directions. Using three different types of cushions, data at three different duration levels can be obtained to determine the sensitivity of the recorder for various package frequencies.

The recorders were dropped on the three different orientations from five different heights. These were 12, 18, 24, 30, and 36 inch drop heights. At least two minutes between each drop was allowed for the cushions to recover and for the recorder's chart paper to advance. Ten repetitions were used in each set. Testing was stopped when the recorder reached its maximum level of 50 G (1 G = 32.2 ft/s^2)

The shock data measured by the accelerometer was analyzed using Lansmont's Test Partner data analysis software. These shock pulses were compared to the levels recorded on the chart paper of both types of mechanical recorders.

2.2 Impacts on Shock Indicators Using Shock Machine.

The purpose of this test was to determine the lowest input shock level on the shock machine that would trigger the impact indicators. This was done to determine the sensitivity of the mechanical indicator to a pre-programmed shock. The shock table was dropped on gas programmers from three different drop heights to develop consistent peak G shocks and also determine the effect of the duration of the shock. A Lansmont Shock Machine was used to perform the impacts. The shock data measured by the accelerometer was analyzed using

Lansmont's Test Partner software.

The impact-indicators were fixed on an aluminum block, which was bolted rigidly onto the shock table. The shock table was dropped from three different drop height levels that would produce different shock durations. The gas pressure was increased in 50 psi increments at each machine drop height level (approximately 2 to 7 peak G). The gas pressure level that resulted in a minimum shock level that first activated the indicator was determined. Ten different devices of the same type of indicator with the same threshold level were each dropped at these impact conditions (drop height and gas pressure) on the shock table. The resulting peak G levels varied slightly for each impact at these conditions. For each impact the corresponding acceleration levels measured by the accelerometer mounted on the shock table were measured. The average shock level that activated the indicators at these impact conditions was determined from a set of ten impacts.

The next section describes the various types of recorders and indicators used in this study and their detailed description for this study.

2.3 Mechanical Recorders.

Two types of commercially available mechanical shock recorders were studied. These are the Impact Register's RM-3WE (0-50 G) recorder and the Impact-O-Graph's M-4 (0-50 G) recorder. Both recorders use a set of three-axis pendulum arms that record on a constant speed driven chart paper. Impact Register's RM-3WE Accelerometer records acceleration in all three axes. Each stylus records its respective impacts on a 1 inch space on the chart paper. The recorder is pneumatically damped and is available in a wide range of frequencies and capacities. The dimensions of the RM-3WE are 6.5 inches wide by 10 inches long and 5.5 inches high, and it weighs 14 pounds. The chart shows accelerations in three axes and the time of occurrence. The chart provides a 1 inch space for records up to ±5 G for each axis. The chart speed is 1.5 inches per hour. The RM-3WE is driven by a Quartz motor powered by a "C" cell battery (1.5 volt DC). The accuracy is ± 0.5 seconds per day. The width of the trace made by the stylus is about 0.005 inches. Records are made on wax coated charts by stainless steel stylus points that remove wax from the chart. Figure 1 is a picture of the Impact Register's RM-3WE recorder.

The Impact-O-Graph model M-4 also records on chart paper the impacts in both magnitude and direction through three independently operating styli. The styli of the Impact-O-Graph are three independently operating spring-mass styli sensing elements, each of which is an angular vibration system that transforms longitudinal, lateral, and vertical motions into the same plane for convenient reading of graphs.

The Impact-O-Graph chart paper is pressure sensitive and is 4 inches wide and divided into 0.125 inch increments. The

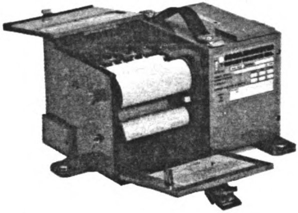

Figure 1: Impact Register's RM-3WE Mechanical Shock Recorder

chart paper length is marked in 1 hour intervals for each 24 hour day. Movement of the graph paper under the stylus is powered by a motor. Each impulse advances the take-up roll enough to separate each record on the chart paper from the one to follow. The chart speed is 0.5 inches per hour. The unit runs on a type "C" battery. Dimensions of this unit are 9.5 inches long by 5.25 inches wide by 3.75 inches high. The unit weighs 4 pounds and is contained in a polycarbonate case. Figure 2 is a picture of the Impact-O-Graph's M-4 (0-50 G) recorder used in this study.

The approximate cost of these types of recorders is $1,000. Both of the recorders compared in this study used a chart paper which was graduated in 10 G increments, up to the maximum range of ± 50 G. These recorders could be used continuously for approximately 30 days, based on the length of paper and battery life. The impacts are registered in the form of small spikes on paper which are indicated by the stylus as it is displaced due to a shock. The number of increments it moves across the paper describes the intensity (G level) of shock.

2.4 Impact Indicators.

Four impact indicators were compared in this study. The first type was the Impact-O-Graph's Omni-G impact indicator. Five different threshold level Omni-G indicators were studied. These were the 10, 25, 50, 75, and 100 G indicators. The

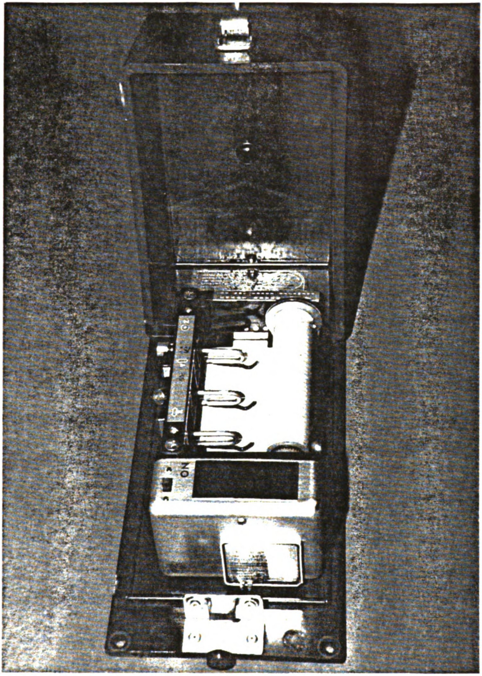

Figure 2: Impact-O-Graph's Model M-4 Mechanical Shock Recorder

Omni-G is a resettable impact indicator that is reset by unscrewing the cover and replacing balls and springs with special tweezers. The Omni-G consists of two sets of spring loaded steel balls nested within a rugged transparent plastic housing. The springs are calibrated to withstand forces up to the G rating of the unit. If impacts greater than the rated value are imposed, at least one set of balls will be dislodged and drop into the transparent dome. The dimensions of the Omni-G are 1.5 inches in height and a diameter of 2 inches. The Omni-G weighs approximately 2 ounces. Figure 3 is a picture of the Impact-O-Graph Omni-G impact indicator.

The second type of indicator studied was Media Recovery's Shockwatch series. Media Recovery's Shockwatch series uses a glass ampule tube that contains a liquid red dye on either end of the thin capillary tube. The middle section of the tube has air and is clear. Shockwatch labels are one-time impact indicators. They consist of a clear tube embedded in a 3.75 inch square label which is affixed to a package. When these types of indicators encounter shocks over their threshold levels, the surface tension forces between the colored liquid and the glass tube cause the liquid at either end to get displaced over the entire glass tube. If the package sustains a severe jolt, the clear tube turns red, providing a permanent record of potential damage. Figure 4 shows this type of indicator.

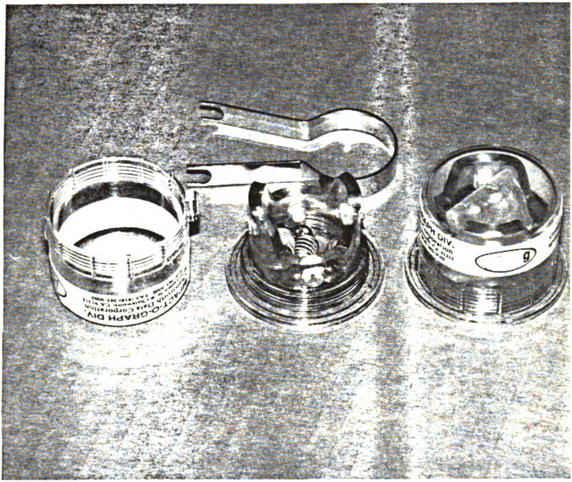

Figure 3: Impact-O-Graph's Omni-G Impact Indicator

Figure 4: Media Recovery's Shockwatch Label Impact Indicator

The third type of indicator is Media Recovery's Mag-2000. It utilizes two magnets. The bottom magnet is held rigidly in place in the unit while the upper magnetic disc is held in place due to the mutual magnetic fields of attraction. When the acceleration due to a shock is strong enough to create a force greater than the magnetic force, the upper magnet is forced off its "home" position and appears in a new visible position within the device. The Mag 2000 also indicates the angle of impact by the position in which the upper magnetic disc is located in its new position. The Mag 2000 is re-settable using a special key which is provided by Media Recovery. The upper magnetic discs are 0.125 inches thick, and 0.31 inches in diameter. The entire indicator unit itself is 1.33 inches in diameter and 0.60 inches high. Figure 5 describes the Mag 2000 indicator. The two indicators studied had a threshold level of 10 G and 25 G respectively.

The fourth type of indicator studied was Dallas Instruments' Shockranger. The Model R-1 Shockranger is an electronic, peak acceleration indicator which will display the highest of four different levels of shock that the unit may experience once it is placed in service. The Shockranger continuously samples the environment, and when a shock is received which exceeds any one of its four "latching" levels, the highest range reached is saved for subsequent readout. Readout of the highest shock level encountered by the shockranger is by illumination of one of the four built in LED lamps. The LED representing the latched level is momentarily activated when a recessed "read" push-button is pressed. The highest latching level reached is maintained until the shockranger is reset by pressing an adjacent button. The four threshold levels are 20, 40, 60, and 80 G. The Shockranger has an internal 50 Hz filter that will filter all shocks above 50 Hz before the raw data is processed for the individual levels. The Shockranger's lithium inorganic batteries have a minimum life of two years. Figure 6 is a picture of this type of recorder.

The R-1 Shockranger utilizes a piezoelectric transducer to measure acceleration, and a precision amplifier to insure stable operation over a wide temperature range. The size of the shockranger is 4.6 inches by 1.6 inches by 1.1 inches. It weighs approximately 6 ounces.

The data collected by the various devices for the various drop heights and impact conditions was analyzed, and the results are presented in the next chapter.

Figure 5: Media Recovery's Mag 2000 Impact Indicator

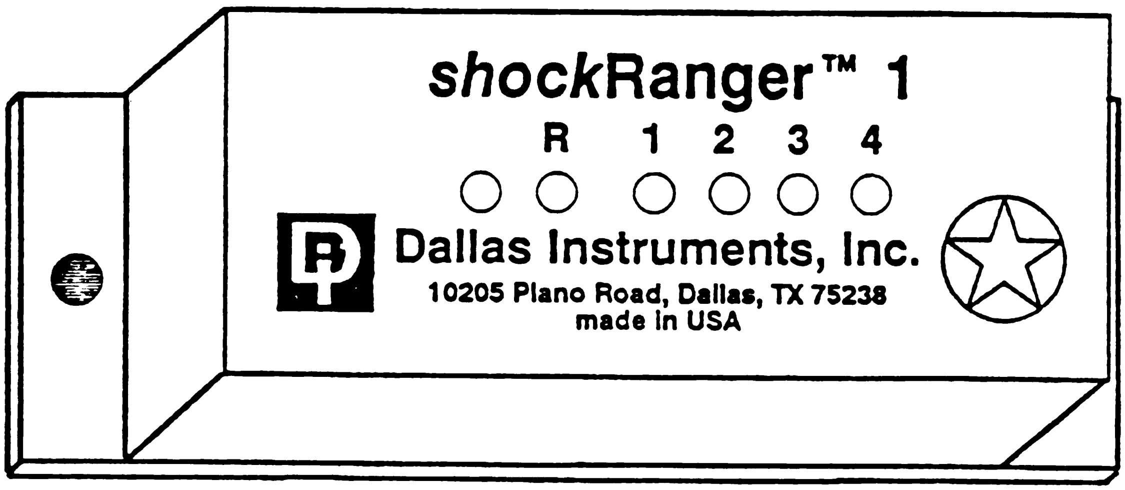

Figure 6: Dallas Instrument's Shockranger Impact Indicator

3.0 DATA AND RESULTS

The data collected for the different types of recorders and indicators is described in this chapter. The various input impact conditions and corresponding results indicated by the mechanical recorders was determined.

3.1 Mechanical Shock Recorders:

The Impact Register shock recorder was placed in C-flute corrugated board regular slotted containers with 2 inch Ethafoam on all six faces. An external accelerometer was placed on the outside of the shock recorder. The accelerometer was connected to a PC running Lansmont's Testpartner analytical software. Starting at a 12 inch drop height, the package containing the recorder was dropped from the Lansmont PDT 56E Precision Drop Tester on its X (lateral) axis. After each drop the shock pulse was recorded from the Lansmont Test Partner computer software. After 10 repetitions the drop height was increased to 18 inches. This procedure was repeated from 24, 30 and 36 inches. When all X axis tests were completed, the recorder was repositioned, along the Y axis in a new container and these tests were repeated.

Finally, the recorder was repositioned along the Z axis in a new container and the tests were repeated.

After completing the test plan for all three axes, the cushioning was changed to 4 inch Ethafoam and dropped on its

X, Y, and Z axes from 12, 18, 24, 30, and 36 inches with 10 repetitions at each drop height. The recorders were then tested in the same manner with 2 inch Urethane cushioning. Tables 1, 2, and 3 describe the results of the various tests performed on the X, Y, and Z axis of the Impact Register. Results from the mechanical recorders were compared to the true shock value obtained from the accelerometer mounted on the base of the recorder and connected to a personal computer. The error associated with the accelerometer and computer was ± 5%. The results of the recorders were analyzed for precision and accuracy. Precision is the repeatability of the recorders to record shock pulses; this is also called reliability. Accuracy is the agreement of the recorders shock pulses to the true values. The tables show that for a 24 inch drop height using a 4 inch Ethafoam cushion, the Impact Register measured 25 G whereas the accelerometer recorded 32.83 G for an average of ten impacts in the X axis. This shows that for these impact conditions the Impact Register had a Mean Percent Error of - 23.90%. The negative sign indicates that the unit underestimated the shock value. Overall from Table 1, the unit when compared to an accelerometer underestimated shock values by as much as -26% and overestimated by 9% in the X-axis. Similarly from Table 2, the unit underestimated values by as much as -42% and overestimates by 44% in the Y-axis. Table 3 shows that the Impact Register recorder underestimated values when compared

Table 1: Impact Register Test Results and Associated Errors (X-Axis)

Drop Height (inches)	Actual G	Recorded G	Duration (msec)	Error (%)
2 inch Ethafoam				
12	23.22	19.5	30.30	-16.00
18	31.44	30.0	28.95	-4.60
24	37.74	39.5	27.48	4.70
30	**	**	**	**
36	**	**	**	**
4 inch Ethafoam				
12	20.64	18.5	31.19	-10.40
18	27.54	20.5	29.67	-25.60
24	32.83	25.0	29.12	-23.90
30	36.37	28.0	27.95	-23.00
36	39.03	32.0	28.37	-18.00
2 inch Urethane				
12	25.32	27.5	22.52	8.60
18	**	**	**	**
24	**	**	**	**
30	**	**	**	**
36	**	**	**	**

** Impact Register recording >50G

Table 2: Impact Register Test Results and Associated Errors (Y-Axis)

Drop Height (inches)	Actual G	Recorded G	Duration (msec)	Error (%)
2 inch Ethafoam				
12	25.98	15.0	22.82	-42.30
18	33.95	20.0	22.03	-41.10
24	41.42	29.0	21.97	-30.00
30	52.34	35.0	21.70	-33.10
36	**	**	**	**
4 inch Ethafoam				
12	20.21	15.0	31.68	-25.80
18	25.94	18.5	31.52	-28.70
24	27.83	22.5	33.56	-19.20
30	29.00	27.5	32.01	-5.20
36	32.76	30.5	30.24	-6.90
2 inch Urethane				
12	*	*	*	*
18	23.65	34.0	27.98	43.80
24	**	**	**	**
30	**	**	**	**
36	**	**	**	**

* Test Partner would not trigger
** Impact Register recording >50G

Table 3: Impact Register Test Results and Associated Errors (Z-Axis)

2 inch Ethafoam				
Drop Height (inches)	Actual G	Recorded G	Duration (msec)	Error (%)
12	25.10	10.0	22.82	-60.20
18	30.02	15.0	24.61	-50.00
24	37.41	18.0	24.19	-51.90
30	43.01	41.0	23.32	-4.70
36	**	**	**	**
4 inch Ethafoam				
12	20.80	5.0	27.90	-76.00
18	25.04	11.0	28.87	-54.10
24	28.93	22.5	27.70	-22.20
30	29.17	22.5	31.00	-22.90
36	37.75	27.5	28.70	-27.20
2 inch Urethane				
12	**	**	**	**
18	**	**	**	**
24	**	**	**	**
30	**	**	**	**
36	**	**	**	**
** Impact Register recording >50G				

to an accelerometer in the Z-axis. The unit underestimated the values from - 5% to - 76% in the Z-axis. The Impact-O-Graph shock recorder was tested in a similar manner to the Impact Register shock recorder; but because the Impact-O-Graph weighed considerably less than the Impact Register recorder (four pounds compared to fourteen pounds), Ethafoam could not be used. Ethafoam proved to be too stiff, providing no cushion and excessive shock levels. To obtain three distinct levels of duration, the bearing area of the 2 inch Urethane cushion was changed instead of using the Ethafoam cushioning. The Impact-O-Graph was packaged in a 200 pound C-flute corrugated regular slotted container with 2 inch Urethane cushioning on all six faces. An external accelerometer was placed on the outside of the shock recorder. The accelerometer was connected to a personal computer running Lansmont's Testpartner analytical software. Starting at a 12 inch drop height, the package containing the recorder was dropped from the Lansmont PDT 56E Precision Drop Tester on its X (lateral) axis with a 0.05 PSI static loading. After each drop the shock pulse was recorded from the Lansmont Testpartner computer software. After 10 repetitions the drop height was increased to 18 inches. This procedure was repeated from 24, 30 and 36 inches. The shock recorders were then dropped on its X axis with a 0.09 PSI and 0.11 PSI static loading following the same procedure.

Next, the Impact-O-Graph recorder was dropped from a 12 inch drop height from the Lansmont PDT 56E Precision Drop Tester on its Y axis with a 0.06 PSI static loading. After each drop the shock pulse was recorded from the Lansmont Testpartner computer software. After 10 repetitions the drop height was increased to 18 inches. This procedure was repeated from 24, 30 and 36 inches. The shock recorders were then dropped on its Y axis with a 0.09 PSI and 0.11 PSI static loading following the same procedure.

Finally, the Impact-O-Graph recorder was dropped from a 12 inch drop height from the Lansmont PDT 56E Precision Drop Tester on its Z axis with a 0.03 PSI static loading. After each drop the shock pulse was recorded from the Lansmont Testpartner computer software. After 10 repetitions the drop height was increased to 18 inches. This procedure was repeated from 24, 30 and 36 inches. The shock recorders were then dropped on its Y axis with a 0.11 PSI and 0.16 PSI static loading following the same procedure. Tables 4, 5, and 6 describe the results of the various tests performed on the X, Y, and Z axis of the Impact-O-Graph. The table shows that for a 12 inch drop height using a 0.11 psi static loading, the Impact-O-Graph measured 38.8 G whereas the accelerometer recorded 37.7 G for an average of ten impacts in the X-axis. This shows that for these impact conditions the Impact-O-Graph had a Mean Error of 3.0%. Overall from Table 4, the unit when compared to an accelerometer underestimated shock values by as much as -0.3% and overestimated by 5.2% in the X-axis.

Similarly from Table 5, the unit when compared to an accelerometer overestimates shock values in the Y-axis. It overestimated values from 0.5% to 51%. Table 6 shows that the Impact-O-Graph recorder underestimated shock values by as much as -26% and overestimated values by as much as 32% when compared to an accelerometer in the Z-axis.

Among the mechanical shock recorders, the Impact-O-Graph is preferred over the Impact Register.

3.2 Mechanical Impact Indicators:

The mechanical indicators were evaluated using the shock table. The shock table was set on gas programmers. Starting at a low height (approximately 3 inches) the gas pressure was increased in small increments until reaching the minimum input threshold level required to trigger a given indicator. The indicator was subjected to ten different impacts that would just activate it. This process was repeated at various table heights and gas pressure conditions that provided the performance of the indicator in terms of the shock duration. The test data was analyzed and is discussed for each type of indicator in this chapter.

Impact-O-Graph's Omni-G was the first family of indicators tested. The 10 G Omni-G was dropped from a drop height of 3 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation.

Table 4: Impact-O-Graph Test Results and Associated Errors (X-Axis)

2 inch Urethane				
0.11 PSI Static Loading				
Drop Height (inches)	Actual G	Recorded G	Duration (msec)	Error (%)
12	37.67	38.8	20.46	3.0
18	**	**	**	**
24	**	**	**	**
30	**	**	**	**
36	**	**	**	**
0.05 PSI Static Loading				
12	*	*	*	*
18	28.90	30.4	28.02	5.2
24	**	**	**	**
30	**	**	**	**
36	**	**	**	**
0.09 PSI Static Loading				
12	20.58	20.5	30.98	-0.3
18	**	**	**	**
24	**	**	**	**
30	**	**	**	**
36	**	**	**	**
* Test Partner would not trigger ** Impact Register recording >50G				

Table 5: Impact-O-Graph Test Results and Associated Errors (Y-Axis)

2 inch Urethane				
0.06 PSI Static Loading				
Drop Height (inches)	Actual G	Recorded G	Duration (msec)	Error (%)
12	*	*	*	*
18	21.30	32.2	27.92	51.1
24	30.22	40.6	25.58	34.3
30	50.22	50.5	20.70	0.5
36	**	**	**	**
0.09 PSI Static Loading				
12	*	*	*	*
18	21.13	26.0	30.90	23.0
24	29.72	36.8	27.28	23.8
30	48.40	50.7	21.86	4.8
36	**	**	**	**
0.11 PSI Static Loading				
12	*	*	*	*
18	27.47	35.7	28.80	30.0
24	45.07	50.9	22.40	12.9
30	**	**	**	**
36	**	**	**	**
* Test Partner would not trigger ** Impact Register recording >50G				

Table 6: Impact-O-Graph Test Results and Associated Errors (Z-Axis)

2 inch Urethane				
0.03 PSI Static Loading				
Drop Height (inches)	Actual G	Recorded G	Duration (msec)	Error (%)
12	25.78	28.1	23.11	9.0
18	27.58	35.5	24.69	28.7
24	33.16	40.0	24.59	20.6
30	34.66	45.7	25.11	31.9
36	**	**	**	**
0.11 PSI Static Loading				
12	14.56	14.1	37.66	-3.2
18	25.12	27.8	26.91	10.7
24	37.70	42.6	21.87	13.0
30	**	**	**	**
36	**	**	**	**
0.16 PSI Static Loading				
12	27.66	20.6	23.97	-25.5
18	45.58	38.1	18.31	-16.4
24	48.77	39.6	21.30	-18.8
30	**	**	**	**
36	**	**	**	**
** Impact Register recording >50G				

The drop height was raised to 6 and 9 inches following the same procedure. Table 7 describes the data for an average of ten impacts. This shows that the 10 G indicator generally would not trigger until the input shock was as much as 39% above the model's given threshold.

The 25 G Omni-G was the next indicator tested. This indicator was first dropped from a 6 inch drop height. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 12 and 18 inches following the same procedure. Table 7 shows that the 25 G Omni-G model generally triggered when experiencing a shock value 21% less than the model's given threshold.

The 50 G Omni-G was initially dropped from 12 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 18 and 24 inches and followed the same procedure. Table 7 shows that the 50 G Omni-G model generally triggered when experiencing a shock value 6.2% less than the model's given threshold.

Both the 75 G and the 100 G Omni-G were first dropped from 18 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first

Table 7: Omni-G Test Results and Associated Errors

Shock Table Drop Height (inches)	10 G Model		
	G	Duration (msec)	Error (%)
3	13.88	21.71	38.80
6	13.09	32.60	30.90
9	13.67	43.57	36.70
	25 G Model		
	G	Duration (msec)	Error (%)
6	19.85	16.83	-20.6
12	20.67	23.54	-17.3
18	22.36	29.83	-10.6
	50 G Model		
	G	Duration (msec)	Error (%)
12	46.92	10.10	-6.2
18	46.97	12.13	-6.1
24	47.93	13.91	-4.1
	75 G Model		
	G	Duration (msec)	Error (%)
18	101.41	6.53	35.2
24	88.72	8.15	18.3
30	87.01	9.42	16.0
	100 G Model		
	G	Duration (msec)	Error (%)
18	108.22	6.75	8.2
24	114.83	7.10	14.8
30	114.79	8.02	14.7

activation. The drop height was raised to 24 and 30 inches and followed the same procedure. Table 7 shows that the 75 G Omni-G model generally triggered when shock values were as much as 35.2% over the model's given threshold, while the 100 G model generally triggered when shock values were as much as 15% over the model's given threshold. Media Recovery's Shockwatch labels were the second family of indicators to be tested. The 25 G model was initially dropped from 12 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 18 and 24 inches and followed the same procedure. Table 8 shows that the 25 G model generally would not trigger until the input shock value was as much as 124% higher than the model's given threshold. The 50 G Shockwatch label was initially dropped from 24 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 27 and 30 inches and followed the same procedure. Table 8 shows that the 50 G model would not trigger until the input shock value was as much as 105% over the model's given threshold.

The 75 G and 100 G models of the Shockwatch label did not activate using the highest drop height and the highest gas pressure so plastic programmers were used to trigger the

Table 8: Shockwatch Test Results and Associated Errors

GAS PROGRAMMER RESULTS			
Shock Table Drop Height (inches)	25 G Model		
	G	Duration (msec)	Error (%)
12	56.10	9.08	124.40
18	46.48	12.16	85.92
24	51.49	12.62	105.96
	50 G Model		
	G	Duration (msec)	Error (%)
24	112.15	6.55	124.3
27	102.46	7.15	104.92
30	103.70	7.24	107.4
PLASTIC PROGRAMMER RESULTS			
Shock Table Drop Height (inches)	75 G Model		
	G	Duration (msec)	Error (%)
10	255.08	2.53	240.1
13	292.76	2.46	290.4
16	324.82	2.46	333.1
	100 G Model		
	G	Duration (msec)	Error (%)
16	327.23	2.45	227.2
18	342.86	2.43	242.9
20	362.06	2.45	262.1

indicators. The indicators were dropped from a drop height below the threshold of the device. The drop height was then raised in 1 inch increments until the threshold was exceeded. Ten repetitions were then performed at this drop height using ten different indicators. The drop height was then raised three inches and then six inches, performing ten repetitions at each drop height.

The 75 G Shockwatch label first activated at a height of 10 inches. Ten repetitions were performed at this height. The drop height was then raised to 13 and 16 inches and 10 repetitions were performed at each drop height. Table 8 shows that the 75 G model would not trigger until the input shock value was as much as 333% above the model's given threshold.

The 100 G Shockwatch label first activated at a height of 16 inches. Ten repetitions were performed a this height. The drop height was then raised to 18 and 20 inches and 10 repetitions were performed at each drop height. Table 8 shows that the 100 G model would not trigger until the input shock was as much as 262% over the model's given threshold.

Media Recovery's Mag 2000 was the next indicator studied. The 10 G Model was initially dropped from 3 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 6 and 9 inches and followed the same procedure. Table 9 shows that the 10 G model would not trigger until the input shock level was as much as 39% above the model's given threshold.

The 25 G model was the last Mag 2000 studied. It was initially dropped from 12 inches. The gas pressure was raised in increments of 10 PSI until the indicator activated. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 18 and 24 inches and followed the same procedure. Table 9 shows that the 25 G model, when given an input shock, triggered as much as 18% under the model's given threshold. The Dallas Instruments Shockranger was the final impact indicator studied. The 20 G threshold was first activated when dropped from a height of 6 inches after increasing the gas pressure by increments of 10 PSI. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 12 and 18 inches and followed the same procedure. Table 10 shows that the 20 G threshold would not trigger when given an input shock until the shock level was as much as 33% above the 20 G threshold level.

The 40 G threshold was initially activated when dropped from 12 inches after increasing the gas pressure by increments of 10 PSI. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 12 and 18 inches and followed the same

Table 9: Mag 2000 Test Results and Associated Errors

Shock Table Drop Height (inches)	10 G Model		
	G	Duration (msec)	Error (%)
3	11.70	26.40	17.00
6	13.43	26.54	34.30
9	13.86	21.71	38.60
Shock Table Drop Height (inches)	25 G Model		
	G	Duration (msec)	Error (%)
12	23.73	20.45	-5.1
18	22.74	25.05	-9.0
24	20.53	33.81	-17.9

Table 10: Shock Ranger Test Results and Associated Errors 20 G Threshold

Shock Table Drop Height (inches)	20 G Threshold		
	G	Duration (msec)	Error (%)
6	26.53	13.85	32.65
12	26.44	20.93	32.20
18	26.21	26.16	31.05
	40 G Threshold		
	G	Duration (msec)	Error (%)
12	50.95	9.55	27.38
18	49.47	12.82	23.68
24	50.70	14.97	26.75
	60 G Threshold		
	G	Duration (msec)	Error (%)
18	86.15	6.97	43.58
24	72.59	9.61	20.98
30	76.36	10.53	27.27
	80 G Threshold		
	G	Duration (msec)	Error (%)
30	103.83	7.49	29.79
33	105.68	7.86	32.10
36	108.75	8.05	35.94

procedure. Table 10 shows that the 40 G threshold level would not trigger until the input shock level was as much as 27% above the 40 G threshold level.

The 60 G threshold was initially activated when dropped from 18 inches after increasing the gas pressure by increments of 10 PSI. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 24 and 30 inches and followed the same procedure. Table 10 shows that the 60 G threshold level would not trigger until the input shock was as much as 44% above the 60 G threshold level.

The 80 G threshold was initially activated when dropped from 30 inches after increasing the gas pressure by increments of 10 PSI. Ten repetitions were conducted at the height and gas pressure of first activation. The drop height was raised to 33 and 36 inches and followed the same procedure. Table 10 shows that the 80 G threshold level would not trigger until the input shock level was as much as 36% above the 80 G threshold level.

Table 11 lists the percentage of times that the indicators activated above the average threshold impact conditions. This shows the reliability of each model of indicator at the average threshold level that was needed to trigger the indicator. This shows that the shockranger triggered most of the times when shocks exceeded the true threshold level as measured by the accelerometer on the

Table 11: Percentage of Impacts that Triggered at the Given Threshold Level.

Threshold Level (G)	Shockwatch (%)	Omni-G (%)	Mag2000 (%)	Shockranger (%)
10	-	66.7	100.0	-
20	-	-	-	100.0
25	76.7	76.7	86.7	-
40	-	-	-	100.0
50	56.7	80.0	-	-
60	-	-	-	96.7
75	80.0	100.0	-	-
80	-	-	-	100.0
100	83.3	96.7	-	-

shock table. This is because the shockranger uses an internal accelerometer and thus it is not duration sensitive as compared to the other devices. The Shockwatch showed the lowest response. The order of preference among indicators is as follows:

- Omni-G
- Mag 2000
- Shockranger
- Shockwatch

4.0 CONCLUSIONS

The Impact Register showed a mean peak acceleration measurement error of -76% to 43.8% when compared to the input shock value using an accelerometer in package impacts.

The Impact-O-Graph showed a mean peak acceleration measurement error of -25.5% to 51.1% when compared to the input shock value using an accelerometer in package impacts.

The reason for the large error for the mechanical recorders is because the sensing mechanisms are too massive. The response of the recorders lags the actual shock because the sensing mechanisms have too much inertia. The mass of the recorder's sensing mechanisms are directly proportional to the error.

All of the mechanical indicators have rated threshold values. There are many different threshold values to choose from when ordering the indicators. The error associated with the mechanical indicators was calculated using the true shock value compared to the rated threshold value. The various indicators evaluated showed the following results:

- Omni-G showed a mean error of the threshold acceleration value from -20.6 to 38.8%.
- Mag 2000 showed a mean error of the threshold acceleration value from -17.9% to 38.6%.
- Shockranger showed a mean error of the threshold acceleration value from 23.68% to 43.58%.

- Shockwatch showed a mean error of the threshold acceleration value from 85.92% to 333.1%.

The results show that both the Shockranger and Shockwatch mechanical indicators never triggered at their rated thresholds.

5.0 OBSERVATIONS AND RECOMMENDATIONS

The industry seems to find numerous application areas for shock recorders and impact indicators. Many companies see the advantages of using shock recorders and impact indicators when evaluating their distribution environments and use these as a basis for quality control in their transportation and handling methods. Despite the large amount of error associated with using both the mechanical recorders and mechanical impact indicators, it is likely that most companies will continue to choose the mechanical devices over the electronic devices until the electronic devices become cost competitive.

It is hard to generalize the error amount with each recorder for a whole variety of shocks because of various factors such as duration sensitivity, variations in individual indicators, non-linear calibration, etc. The results may vary if different settings are used as compared to this study. The author used his best judgment in selecting representative applicable conditions for performing the test impacts.

APPENDIX

Table A1

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 12"			
Bearing Area: 120 square inches (12" X 10")			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	23.92	30	23.30
2	24.49	29	23.80
3	25.91	29	23.30
4	26.69	28	23.80
5	25.48	26	24.00
6	26.10	28	21.80
7	25.40	27	23.20
8	26.35	28	21.80
9	26.50	28	21.90
10	26.95	28	24.20
AVERAGE	25.78	28.1	23.11
STANDARD DEVIATION	0.97	1.10	0.94
MEAN PERCENT ERROR OF RECORDER = 9.0%			

Table A2

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 18"			
Bearing Area: 120 square inches (12" X 10")			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	29.10	37	23.60
2	25.79	36	24.70
3	25.99	36	24.20
4	26.13	35	24.40
5	27.04	35	24.90
6	27.97	35	24.80
7	29.14	35	24.60
8	28.13	35	25.20
9	28.47	35	25.10
10	28.01	36	25.40
AVERAGE	27.58	35.50	24.69
STANDARD DEVIATION	1.26	0.71	0.53
MEAN PERCENT ERROR OF RECORDER = 28.7%			

Table A3

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 24"			
Bearing Area: 120 square inches (12" X 10")			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	30.03	40	23.50
2	34.51	41	24.80
3	34.65	40	24.70
4	34.31	40	24.80
5	33.75	40	24.50
6	32.99	39	24.50
7	33.11	40	23.90
8	31.64	38	24.40
9	31.64	42	24.40
10	34.98	40	24.90
AVERAGE	33.16	40.00	24.59
STANDARD DEVIATION	1.62	1.05	0.66
MEAN PERCENT ERROR OF RECORDER = 20.6%			

Table A4

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 30"			
Bearing Area: 120 square inches (12" X 10")			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	33.32	44	23.70
2	32.37	47	24.00
3	31.79	48	24.90
4	31.79	46	24.90
5	36.58	45	25.40
6	37.04	45	25.30
7	36.27	45	25.60
8	35.68	46	25.80
9	36.46	46	25.60
10	35.25	45	25.90
AVERAGE	34.66	45.70	25.11
STANDARD DEVIATION	2.11	1.16	0.75
MEAN PERCENT ERROR OF RECORDER = 31.9%			

Table A5

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 12"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	15.74	15	38.30
2	14.23	14	38.10
3	14.61	14	39.00
4	14.79	13	37.30
5	14.66	14	37.20
6	14.55	14	37.70
7	14.45	15	37.20
8	14.25	14	38.40
9	13.85	14	37.00
10	14.51	14	36.40
AVERAGE	14.56	14.10	37.66
STANDARD DEVIATION	0.49	0.57	0.78
MEAN PERCENT ERROR OF RECORDER = -3.2%			

Table A6

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 18"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	19.30	21	33.50
2	23.44	26	30.70
3	23.80	28	26.40
4	25.79	29	26.10
5	25.31	29	26.80
6	25.60	29	25.90
7	25.35	29	25.60
8	29.76	29	24.30
9	26.45	29	24.70
10	26.43	29	25.10
AVERAGE	25.12	27.80	26.91
STANDARD DEVIATION	2.67	2.57	2.91
MEAN PERCENT ERROR OF RECORDER = 10.7%			

Table A7

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 24"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	33.00	35	24.20
2	35.70	42	22.20
3	37.24	42	21.70
4	38.09	44	21.70
5	40.29	44	21.40
6	39.16	44	21.30
7	38.85	44	21.50
8	38.24	43	21.50
9	37.54	43	21.30
10	38.90	45	21.90
AVERAGE	37.70	42.60	21.87
STANDARD DEVIATION	2.06	2.84	0.87
MEAN PERCENT ERROR OF RECORDER = 13.0%			

Table A8

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 12"			
Bearing Area: 25 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	17.75	11	34.00
2	23.88	19	28.30
3	24.39	20	24.30
4	25.83	20	24.70
5	26.33	21	24.20
6	29.14	22	21.90
7	30.54	22	21.10
8	35.67	23	19.50
9	31.70	24	20.80
10	31.41	24	20.90
AVERAGE	27.66	20.60	23.97
STANDARD DEVIATION	5.09	3.78	4.37
MEAN PERCENT ERROR OF RECORDER = -25.5%			

Table A9

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 18"			
Bearing Area: 25 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	35.44	30	20.80
2	42.26	36	18.50
3	45.88	36	17.90
4	50.25	39	16.20
5	52.78	40	16.30
6	51.42	40	16.00
7	30.43	35	26.90
8	44.29	41	17.70
9	49.62	42	16.60
10	53.44	42	16.20
AVERAGE	45.58	38.10	18.31
STANDARD DEVIATION	7.68	3.81	3.36
MEAN PERCENT ERROR OF RECORDER = -16.4%			

Table A10

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 24"			
Bearing Area: 25 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	37.12	34	24.20
2	48.18	39	21.80
3	45.44	39	23.20
4	47.94	40	21.40
5	50.34	40	20.20
6	51.95	40	20.60
7	51.33	40	20.60
8	52.74	42	20.40
9	51.00	42	20.20
10	51.65	40	20.40
AVERAGE	48.77	39.60	21.30
STANDARD DEVIATION	4.67	2.22	1.39
MEAN PERCENT ERROR OF RECORDER = -18.8%			

Table A11

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 18"			
Bearing Area: 72 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	18.50	34	28.60
2	19.73	32	28.60
3	20.42	32	28.40
4	21.38	32	28.20
5	21.98	32	28.20
6	22.22	32	28.00
7	21.47	32	27.00
8	22.51	32	27.80
9	22.38	32	26.80
10	22.43	32	27.60
AVERAGE	21.30	32.20	27.92
STANDARD DEVIATION	1.35	0.63	0.63
MEAN PERCENT ERROR OF RECORDER = 51.1%			

Table A12

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 24"			
Bearing Area: 72 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	24.82	38	28.20
2	29.82	40	24.80
3	29.93	40	25.00
4	30.19	41	25.20
5	30.65	41	25.80
6	31.26	42	25.40
7	31.22	42	25.00
8	31.38	41	25.20
9	31.76	41	25.20
10	31.18	40	26.00
AVERAGE	30.22	40.60	25.58
STANDARD DEVIATION	2.01	1.17	0.99
MEAN PERCENT ERROR OF RECORDER = 34.3%			

Table A13

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 30"			
Bearing Area: 72 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	38.16	50	24.40
2	48.47	50	20.60
3	50.59	50	20.40
4	51.68	50	20.60
5	51.50	50	20.20
6	52.77	51	20.20
7	53.93	51	19.80
8	50.27	51	20.40
9	51.10	51	20.40
10	53.69	51	20.00
AVERAGE	50.22	50.50	20.70
STANDARD DEVIATION	4.54	0.53	1.32
MEAN PERCENT ERROR OF RECORDER = 0.5%			

Table A14

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 18"			
Bearing Area: 46.75 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	19.96	26	31.20
2	19.56	26	32.20
3	20.39	26	31.40
4	20.49	26	31.00
5	20.90	26	30.80
6	21.12	26	31.20
7	21.69	26	31.00
8	21.98	26	30.00
9	22.51	26	30.20
10	22.65	26	30.00
AVERAGE	21.13	26.00	30.90
STANDARD DEVIATION	1.06	0.00	0.69
MEAN PERCENT ERROR OF RECORDER = 23.0%			

Table A15

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 24"			
Bearing Area: 46.75 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	25.92	32	28.60
2	28.76	35	27.80
3	30.28	37	27.40
4	31.22	37	26.80
5	30.15	37	27.00
6	29.68	37	27.00
7	30.95	38	26.80
8	28.72	37	28.40
9	30.83	39	26.60
10	30.70	39	26.40
AVERAGE	29.72	36.80	27.28
STANDARD DEVIATION	1.59	2.00	0.76
MEAN PERCENT ERROR OF RECORDER = 23.8%			

Table A16

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 30"			
Bearing Area: 46.75 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	42.72	48	24.00
2	46.42	51	22.40
3	49.10	51	21.80
4	50.42	51	21.40
5	48.71	51	21.80
6	47.34	51	21.80
7	47.38	51	21.60
8	51.49	51	21.20
9	49.41	51	21.40
10	51.05	51	21.20
AVERAGE	48.40	50.70	21.86
STANDARD DEVIATION	2.59	0.95	0.83
MEAN PERCENT ERROR OF RECORDER = 4.8%			

Table A17

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 18"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	23.96	32	31.60
2	25.62	35	29.40
3	26.31	26	30.00
4	27.29	37	28.20
5	27.44	38	28.40
6	28.33	38	28.20
7	28.43	38	28.20
8	29.22	38	28.00
9	28.68	37	28.00
10	29.43	38	28.00
AVERAGE	27.47	35.70	28.80
STANDARD DEVIATION	1.74	3.92	1.19
MEAN PERCENT ERROR OF RECORDER = 30.0%			

Table A18

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 24"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	40.52	50	24.60
2	42.20	51	23.80
3	48.50	51	22.20
4	37.01	51	23.40
5	50.37	51	21.40
6	38.70	51	23.00
7	52.74	51	21.00
8	40.45	51	23.00
9	50.56	51	20.20
10	49.63	51	21.40
AVERAGE	45.07	50.90	22.40
STANDARD DEVIATION	5.83	0.32	1.39
MEAN PERCENT ERROR OF RECORDER = 12.9%			

Table A19

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 12"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	28.79	33	28.40
2	32.16	35	21.40
3	38.77	38	18.60
4	29.53	35	27.80
5	38.73	41	20.00
6	37.91	41	17.80
7	42.66	41	16.60
8	44.09	41	19.20
9	42.03	41	17.60
10	42.05	42	17.20
AVERAGE	37.67	38.80	20.46
STANDARD DEVIATION	5.60	3.29	4.27
MEAN PERCENT ERROR OF RECORDER = 3.0%			

Table A20

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 18"			
Bearing Area: 80.7 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	23.49	22	29.80
2	26.45	22	29.40
3	28.20	30	28.60
4	29.43	30	28.00
5	29.67	33	28.20
6	30.16	32	28.20
7	30.09	33	27.40
8	29.82	33	27.00
9	31.20	35	26.80
10	30.49	34	26.80
AVERAGE	28.90	30.40	28.02
STANDARD DEVIATION	2.32	4.70	1.05
MEAN PERCENT ERROR OF RECORDER = 5.2%			

Table A21

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 24"			
Bearing Area: 80.7 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	41.65	48	23.60
2	45.80	50	22.60
3	51.59	50	21.00
4			
5			
6			
7			
8			
9			
10			
AVERAGE	46.35	49.33	22.40
STANDARD DEVIATION	4.99	1.15	1.31
MEAN PERCENT ERROR OF RECORDER = 6.4%			

[illegible]

Table A22

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 12"			
Bearing Area: 46.75 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	17.11	18	35.20
2	20.40	20	30.80
3	20.13	20	31.40
4	19.53	20	32.00
5	20.01	18	31.40
6	19.54	18	30.60
7	23.52	25	29.00
8	20.88	20	30.40
9	23.67	25	29.20
10	21.01	21	29.80
AVERAGE	20.58	20.50	30.98
STANDARD DEVIATION	1.92	2.59	1.77
MEAN PERCENT ERROR OF RECORDER = -0.3%			

Table A23

IMPACT-O-GRAPH TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 18"			
Bearing Area: 46.75 square inches			
DROP	ACTUAL G (G)	IMPACT-O-GRAPH (G)	DURATION (milliseconds)
1	27.23	34	23.40
2	45.22	54	18.80
3	50.94	54	18.60
4			
5			
6			
7			
8			
9			
10			
AVERAGE	41.13	47.33	20.27
STANDARD DEVIATION	12.37	11.55	2.72
MEAN PERCENT ERROR OF RECORDER = 15.1%			

TESTING STOPPED DUE TO HIGH G-LEVEL

Table A24

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Z			
Drop Height: 12"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	26.07	10	22.10
2	25.70	10	24.20
3	24.75	10	20.80
4	25.01	10	24.60
5	24.46	10	20.70
6	25.21	10	21.10
7	24.80	10	25.30
8	25.49	10	24.50
9	24.88	10	24.10
10	24.63	10	20.80
AVERAGE	25.10	10.00	22.82
STANDARD DEVIATION	0.51	0.00	1.88
MEAN PERCENT ERROR OF RECORDER = -60.2%			

Table A25

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Z			
Drop Height: 18"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	28.38	15	25.80
2	30.14	15	25.00
3	29.70	15	24.90
4	29.62	15	24.90
5	30.84	15	24.50
6	30.34	15	24.80
7	30.26	15	24.30
8	30.31	15	24.90
9	30.62	15	22.90
10	30.01	15	24.10
AVERAGE	30.02	15.00	24.61
STANDARD DEVIATION	0.69	0.00	0.76
MEAN PERCENT ERROR OF RECORDER = -50.0%			

Table A26

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Z			
Drop Height: 24"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	36.33	20	23.60
2	37.14	20	24.10
3	36.67	20	23.80
4	37.48	15	24.40
5	37.23	15	24.70
6	37.11	15	23.90
7	37.43	20	24.20
8	38.40	20	24.50
9	37.97	20	24.40
10	38.31	15	24.30
AVERAGE	37.41	18.00	24.19
STANDARD DEVIATION	0.67	2.58	0.34
MEAN PERCENT ERROR OF RECORDER = -51.9%			

Table A27

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Z			
Drop Height: 30"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	44.34	25	22.90
2	43.35	30	24.10
3	41.89	35	23.90
4	43.88	40	23.60
5	43.84	45	23.30
6	42.18	40	23.70
7	42.13	45	23.60
8	43.61	50	22.60
9	42.30	50	22.40
10	42.60	50	23.10
AVERAGE	43.01	41.00	23.32
STANDARD DEVIATION	0.89	8.76	0.56
MEAN PERCENT ERROR OF RECORDER = -4.7%			

Table A28

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Y			
Drop Height: 12"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	24.52	15	22.90
2	25.49	15	22.80
3	25.43	15	22.60
4	25.20	15	22.70
5	30.21	15	24.50
6	26.15	15	22.40
7	25.41	15	22.70
8	25.82	15	23.10
9	25.86	15	22.40
10	25.74	15	22.10
AVERAGE	25.98	15.00	22.82
STANDARD DEVIATION	1.55	0.00	0.65
MEAN PERCENT ERROR OF RECORDER = -42.3%			

Table A29

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Y			
Drop Height: 18"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	31.89	20	22.30
2	32.93	20	22.50
3	33.80	20	22.00
4	34.89	20	21.50
5	33.74	20	22.40
6	33.75	20	21.90
7	34.21	20	21.90
8	35.25	20	21.30
9	34.20	20	22.50
10	34.79	20	22.00
AVERAGE	33.95	20.00	22.03
STANDARD DEVIATION	0.99	0.00	0.41
MEAN PERCENT ERROR OF RECORDER = -41.1%			

Table A30

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Y			
Drop Height: 24"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	39.11	30	22.30
2	40.44	30	22.20
3	42.42	30	21.50
4	42.02	30	21.70
5	41.90	30	21.50
6	41.94	25	22.10
7	41.14	30	22.00
8	41.20	25	22.30
9	42.53	30	21.90
10	41.53	30	22.20
AVERAGE	41.42	29.00	21.97
STANDARD DEVIATION	1.03	2.11	0.31
MEAN PERCENT ERROR OF RECORDER = -30.0%			

Table A31

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: Y			
Drop Height: 30"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	45.34	30	23.00
2	50.16	35	22.00
3	52.06	35	22.50
4	53.50	35	21.50
5	53.62	35	21.00
6	54.53	35	21.00
7	53.44	35	21.50
8	54.06	35	21.50
9	53.46	40	21.50
10	53.18	35	21.50
AVERAGE	52.34	35.00	21.70
STANDARD DEVIATION	2.74	2.36	0.63
MEAN PERCENT ERROR OF RECORDER = -33.1%			

Table A32

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: X			
Drop Height: 12"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	20.67	15	30.00
2	23.61	20	30.50
3	23.05	20	30.00
4	23.46	20	29.50
5	23.12	20	30.50
6	23.19	20	30.00
7	23.96	20	31.00
8	24.05	20	30.00
9	23.57	20	31.00
10	23.50	20	30.50
AVERAGE	23.22	19.50	30.30
STANDARD DEVIATION	0.95	1.58	0.48
MEAN PERCENT ERROR OF RECORDER = -16.0%			

Table A33

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: X			
Drop Height: 18"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	30.03	30	29.00
2	32.05	30	27.50
3	32.24	30	29.00
4	31.57	30	29.00
5	32.08	30	29.00
6	32.10	30	28.50
7	31.55	30	29.50
8	31.59	30	29.00
9	30.03	30	29.00
10	31.16	30	30.00
AVERAGE	31.44	30.00	28.95
STANDARD DEVIATION	0.81	0.00	0.64
MEAN PERCENT ERROR OF RECORDER = -4.6%			

Table A34

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Ethafoam			
Axis: X			
Drop Height: 24"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	36.29	35	26.50
2	38.73	40	27.00
3	38.08	40	28.00
4	37.78	40	27.50
5	37.61	40	28.50
6	37.39	40	27.50
7	38.68	40	27.00
8	37.50	40	28.50
9	37.76	40	28.50
10	37.54	40	28.50
AVERAGE	37.74	39.50	27.48
STANDARD DEVIATION	0.69	1.58	0.92
MEAN PERCENT ERROR OF RECORDER = 4.7%			

Table A35

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Z			
Drop Height: 12"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	21.62	5	28.20
2	20.99	5	28.40
3	21.05	5	28.60
4	20.79	5	27.70
5	21.23	5	28.20
6	19.02	5	29.40
7	20.75	5	27.30
8	20.79	5	26.20
9	20.92	5	29.00
10	20.84	5	26.00
AVERAGE	20.80	5.00	27.90
STANDARD DEVIATION	0.68	0.00	1.12
MEAN PERCENT ERROR OF RECORDER = -76.0%			

Table A36

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Z			
Drop Height: 18"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	23.18	5	29.00
2	25.87	10	28.80
3	24.54	10	28.50
4	26.76	15	29.00
5	24.54	10	28.10
6	26.07	15	29.50
7	22.67	10	28.80
8	26.06	15	28.06
9	24.90	10	29.20
10	25.82	15	29.70
AVERAGE	25.04	11.5	28.87
STANDARD DEVIATION	1.33	3.37	0.54
MEAN PERCENT ERROR OF RECORDER = -54.1%			

Table A37

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Z			
Drop Height: 24"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	23.81	20	30.60
2	30.65	20	28.20
3	31.20	25	25.80
4	29.47	20	26.40
5	28.86	25	26.10
6	29.56	25	26.90
7	24.74	15	28.20
8	30.34	25	29.10
9	30.73	25	29.10
10	29.89	25	26.60
AVERAGE	28.93	22.5	27.70
STANDARD DEVIATION	2.55	3.54	1.58
MEAN PERCENT ERROR OF RECORDER = -22.2%			

Table A38

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Z			
Drop Height: 30"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	31.50	20	31.60
2	30.76	25	32.30
3	31.24	25	31.30
4	30.61	25	30.60
5	26.03	20	30.40
6	27.17	20	29.30
7	29.22	20	32.00
8	28.46	25	32.40
9	27.75	20	28.00
10	28.91	25	32.10
AVERAGE	29.17	22.5	31.00
STANDARD DEVIATION	1.85	2.64	1.44
MEAN PERCENT ERROR OF RECORDER = -22.9%			

Table A39

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Z			
Drop Height: 36"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	38.25	25	31.40
2	38.49	35	32.00
3	37.68	30	32.10
4	38.52	30	31.50
5	37.78	25	25.80
6	36.60	25	26.90
7	38.57	25	26.20
8	37.54	30	27.30
9	35.77	25	27.40
10	38.29	25	26.40
AVERAGE	37.75	27.5	28.70
STANDARD DEVIATION	0.92	3.54	2.68
MEAN PERCENT ERROR OF RECORDER = -27.2%			

Table A40

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Y			
Drop Height: 12"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	17.03	15	31.30
2	18.58	15	31.30
3	18.04	15	31.20
4	20.10	15	31.60
5	19.57	15	32.10
6	23.15	15	32.00
7	21.34	15	32.20
8	21.40	15	31.70
9	22.25	15	31.80
10	20.63	15	31.60
AVERAGE	20.21	15	31.68
STANDARD DEVIATION	1.93	0.00	0.35
MEAN PERCENT ERROR OF RECORDER = -25.8%			

Table A41

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Y			
Drop Height: 18"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	29.09	20	30.70
2	28.60	20	30.40
3	26.37	20	31.00
4	28.66	15	27.50
5	27.08	20	31.40
6	24.57	15	33.30
7	23.80	20	32.30
8	23.41	20	32.60
9	24.29	20	32.30
10	23.52	15	33.70
AVERAGE	25.94	18.5	31.52
STANDARD DEVIATION	2.29	2.42	1.78
MEAN PERCENT ERROR OF RECORDER = -28.7%			

Table A42

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Y			
Drop Height: 24"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	28.37	20	33.10
2	27.70	25	33.10
3	29.95	25	32.40
4	28.83	20	32.60
5	28.44	20	33.10
6	27.95	20	33.70
7	26.12	20	34.20
8	26.84	25	34.70
9	26.56	25	34.90
10	27.53	25	33.80
AVERAGE	27.83	22.5	33.56
STANDARD DEVIATION	1.14	2.64	0.85
MEAN PERCENT ERROR OF RECORDER = -19.2%			

Table A43

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Y			
Drop Height: 30"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	32.56	25	31.80
2	31.68	30	32.20
3	28.20	30	33.10
4	28.06	30	31.60
5	27.65	30	31.10
6	28.09	30	32.10
7	28.96	25	33.30
8	27.02	25	29.00
9	29.68	25	33.00
10	28.05	25	32.90
AVERAGE	29.00	27.50	32.01
STANDARD DEVIATION	1.80	2.64	1.28
MEAN PERCENT ERROR OF RECORDER = -5.2%			

Table A44

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: Y			
Drop Height: 36"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	34.09	30	29.20
2	33.13	30	29.80
3	35.28	30	29.80
4	33.20	30	29.50
5	32.52	30	30.10
6	33.93	30	30.30
7	31.70	30	30.40
8	30.57	35	31.00
9	31.78	30	31.00
10	31.42	30	31.30
AVERAGE	32.76	30.50	30.24
STANDARD DEVIATION	1.44	1.58	0.69
MEAN PERCENT ERROR OF RECORDER = -6.9%			

Table A45

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: X			
Drop Height: 12"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	19.28	15	31.00
2	18.55	15	31.80
3	19.28	15	32.30
4	22.60	20	31.00
5	19.43	20	31.80
6	22.89	20	30.30
7	20.68	20	30.80
8	19.95	20	31.30
9	21.88	20	31.30
10	21.84	20	30.30
AVERAGE	20.64	18.50	31.19
STANDARD DEVIATION	1.56	2.42	0.65
MEAN PERCENT ERROR OF RECORDER = -10.4%			

Table A46

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: X			
Drop Height: 18"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	28.77	25	29.50
2	25.50	20	30.30
3	26.90	20	29.90
4	27.32	20	29.90
5	29.10	20	29.20
6	27.81	20	28.80
7	27.58	20	30.00
8	27.74	20	29.80
9	27.17	20	29.90
10	27.46	20	29.40
AVERAGE	27.54	20.50	29.67
STANDARD DEVIATION	0.99	1.58	0.44
MEAN PERCENT ERROR OF RECORDER = -25.6%			

Table A47

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: X			
Drop Height: 24"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	31.88	25	29.90
2	30.83	25	29.20
3	33.16	25	29.50
4	32.55	25	29.40
5	33.35	25	29.40
6	33.21	25	28.40
7	33.67	25	29.30
8	34.06	25	28.50
9	32.58	25	28.50
10	33.02	25	29.10
AVERAGE	32.83	25.50	29.12
STANDARD DEVIATION	0.93	0.00	0.50
MEAN PERCENT ERROR OF RECORDER = -23.9%			

Table A48

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: X			
Drop Height: 30"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	36.88	30	28.10
2	34.64	25	28.30
3	34.93	25	28.20
4	36.83	30	27.80
5	35.48	25	28.20
6	35.48	25	28.10
7	36.75	30	27.70
8	38.01	30	27.90
9	36.90	30	27.70
10	37.83	30	27.50
AVERAGE	36.37	28.00	27.95
STANDARD DEVIATION	1.17	2.58	0.27
MEAN PERCENT ERROR OF RECORDER = -23.0%			

Table A49

IMPACT REGISTER TEST RESULTS			
Cushion: 4" Ethafoam			
Axis: X			
Drop Height: 36"			
Bearing Area: 12 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	40.31	35	29.20
2	36.21	30	29.20
3	36.29	30	29.20
4	38.86	30	27.80
5	39.04	30	28.20
6	39.93	30	28.50
7	40.29	35	27.90
8	40.29	35	27.80
9	39.18	30	27.90
10	39.93	35	28.00
AVERAGE	39.03	32.00	28.37
STANDARD DEVIATION	1.56	2.58	0.61
MEAN PERCENT ERROR OF RECORDER = -18.0%			

Table A50

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Urethane			
Axis: Z			
Drop Height: 18"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	13.03	50	25.30
2	18.73	50	27.90
3	19.63	50	27.50
4	19.86	50	27.90
5			
6			
7			
8			
9			
10			
AVERAGE	17.81	50.00	27.15
STANDARD DEVIATION	3.23	0.00	1.25
MEAN PERCENT ERROR OF RECORDER = 180.7%			

TESTING STOPPED DUE TO HIGH G-LEVEL

Table A51

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 12"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	16.07	15	20.02
2	18.02	20	23.90
3	21.85	25	21.40
4	24.07	25	23.30
5	26.24	30	21.80
6	27.22	30	22.40
7	28.61	30	23.30
8	31.61	35	23.20
9	29.56	30	23.20
10	29.88	35	22.70
AVERAGE	25.32	27.50	22.52
STANDARD DEVIATION	5.22	6.35	1.16
MEAN PERCENT ERROR OF RECORDER = 8.6%			

Table A52

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Urethane			
Axis: X			
Drop Height: 18"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	49.78	50	18.00
2			
3			
4			
5			
6			
7			
8			
9			
10			
AVERAGE	49.78	50.00	18.00
STANDARD DEVIATION			
MEAN PERCENT ERROR OF RECORDER = 0.4%			

TESTING STOPPED DUE TO HIGH G-LEVEL

Table A53

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 18"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	21.86	35	28.40
2	23.16	35	28.20
3	22.62	30	28.60
4	22.12	35	28.10
5	24.60	35	27.70
6	21.24	30	29.00
7	26.92	35	27.00
8	23.34	35	28.30
9	25.90	35	27.10
10	24.76	35	27.40
AVERAGE	23.65	34.00	27.98
STANDARD DEVIATION	1.85	2.11	0.66
MEAN PERCENT ERROR OF RECORDER = 43.8%			

Table A54

IMPACT REGISTER TEST RESULTS			
Cushion: 2" Urethane			
Axis: Y			
Drop Height: 24"			
Bearing Area: 36 square inches			
DROP	ACTUAL G (G)	IMPACT REGISTER (G)	DURATION (milliseconds)
1	29.79	45	25.90
2	39.31	50	22.50
3	37.00	50	22.60
4			
5			
6			
7			
8			
9			
10			
AVERAGE	35.37	48.33	23.67
STANDARD DEVIATION	4.97	2.89	1.93
MEAN PERCENT ERROR OF RECORDER = 36.6%			

TESTING STOPPED DUE TO HIGH G-LEVEL

Table A55

SHOCKWATCH L-65 INDICATOR (25 G)				
DROP HEIGHT: 12 inches				
GAS PRESSURE: 650 PSI				
FILTER: 200 Hz				
DROP	G	DURATION (msec)	VELOCITY CHANGE (in/sec)	ACTIVATION (Y/N)
1	55.13	9.20	149.38	YES
2	55.09	9.30	150.17	YES
3	56.78	9.40	153.89	YES
4	56.47	8.90	148.84	NO
5	55.97	8.90	148.61	YES
6	56.42	8.90	148.99	YES
7	56.27	9.10	149.40	YES
8	56.19	9.00	149.53	YES
9	56.27	9.10	150.25	YES
10	56.41	9.00	150.20	YES
AVERAGE	56.10	9.08	149.93	90%
STANDARD DEVIATION	0.56	0.18	1.51	

Table A56

OMNI-G IMPACT INDICATOR (25 G)				
DROP HEIGHT: 6 inches				
GAS PRESSURE: 210 PSI				
FILTER: 300 Hz				
DROP	G	DURATION (msec)	VELOCITY CHANGE (in/sec)	ACTIVATION (Y/N)
1	19.62	17.10	111.61	YES
2	19.78	16.90	111.50	NO
3	20.00	16.90	114.02	NO
4	20.10	17.10	116.11	NO
5	19.87	16.80	112.08	NO
6	19.67	16.90	113.34	NO
7	19.95	16.60	111.75	NO
8	19.61	16.60	110.44	NO
9	19.90	16.70	112.52	YES
10	19.97	16.70	111.44	YES
AVERAGE	19.85	16.83	112.48	30%
STANDARD DEVIATION	0.17	0.18	1.63	

Table A57

MAG-2000 IMPACT INDICATOR (25 G)				
DROP HEIGHT: 12 inches				
GAS PRESSURE: 250 PSI				
FILTER: 150 Hz				
DROP	G	DURATION (msec)	VELOCITY CHANGE (in/sec)	ACTIVATION (Y/N)
1	23.20	20.70	157.00	NO
2	23.15	20.20	153.26	YES
3	24.60	20.10	160.09	YES
4	24.05	20.30	157.09	YES
5	24.09	20.00	154.09	YES
6	23.61	20.80	159.27	YES
7	24.89	21.00	170.66	YES
8	22.90	20.30	152.71	YES
9	23.74	20.70	159.14	YES
10	23.11	20.40	154.39	YES
AVERAGE	23.73	20.45	157.77	90%
STANDARD DEVIATION	0.67	0.33	5.25	

Table A58

SHOCKRANGER IMPACT INDICATOR (20-40 G)				
DROP HEIGHT: 6 inches				
GAS PRESSURE: 250 PSI				
FILTER: 150 Hz				
DROP	G	DURATION (msec)	VELOCITY CHANGE (in/sec)	ACTIVATION (Y/N)
1	26.34	14.30	113.76	YES
2	26.64	14.20	112.61	YES
3	26.64	14.10	112.96	YES
4	26.50	13.60	108.90	YES
5	26.55	13.90	110.35	YES
6	26.19	13.80	108.56	YES
7	26.64	13.80	110.04	YES
8	26.59	13.60	108.75	YES
9	26.68	13.40	107.11	YES
10	26.56	13.80	109.07	YES
AVERAGE	26.53	13.85	110.21	100%
STANDARD DEVIATION	0.15	0.28	2.20	

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