Introduction

360° Testing Service has been retained to conduct impact testing of the client's athletic cups plus cups from two competitors; see the photo to the right. From left to right:

- Brand - 1 cup - A
- Brand - 2 cup - B
- Brand - 3 cup - C

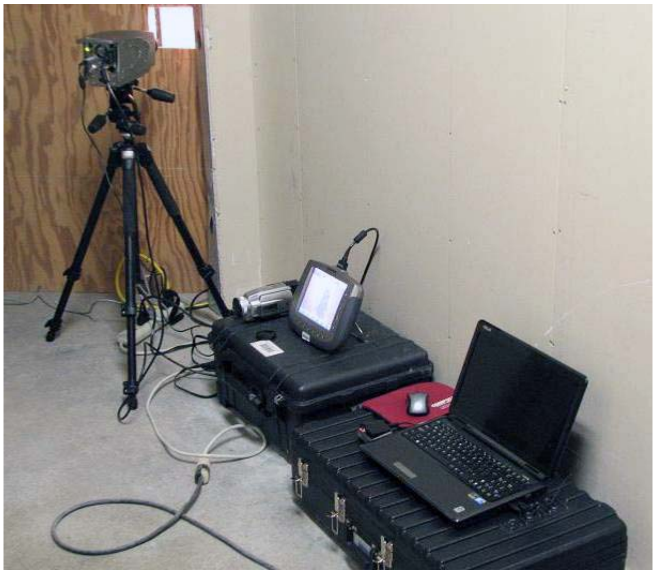
All three products were Adult size.

The following describes how we conducted the tests, and the results of our testing.

Test Setup

Impact testing was performed by mounting the subject cup over a foam holding fixture (to simulate the human body behind the cup), with the foam fixture secured to a concrete block wall. Ruled paper was mounted behind the cups to provide a deflection measurement reference. A Jugs 101™ Pitching Machine shot standard 5-ounce baseballs at each subject cup, while a Olympus iSpeed 3 high-speed video camera recorded the reaction of the cup to being struck by the baseball. Trials were conducted at 30 and 60 mph ball speeds, as determined by the speed setting on the pitching machine. Three high-intensity quartz-halogen lamps illuminated the target area for the camera. The following photo shows the equipment used for the tests.

The camera was protected from baseball ricochets by being located behind a sheet of plywood, looking out into the target area through a sheet of clear impact-resistant Lexan plastic. The camera's Camera Display Unit (CDU) and a laptop computer, on which the camera movies were reviewed and stored, were located with the camera behind the plywood (pictured below left).



The camera setup. Note the small, Lexan-covered window through which the camera photographed the baseball hitting tested cups.

Looking downrange from behind the Jugs pitching machine. A third high-intensity lamp to the right side of the target is barely noticeable in this photo.

Impact Testing

Impact testing was performed first at 30 mph, then at 60 mph.[1] Balls were shot at the athletic cups until a ball was photographed hitting the center of a new cup.

If a ball did not strike a Brand - 1 cup - A exactly center, the spinning ball would tend to roll over the side of the cup (i.e.: th e baseball would have impacted the cup wearer's body). When the ball rolled over the side of a cup, it usually left "plastic burn" marks from the ball stitches as they rolled against the plastic cup surface. This rolling off to the side appears to be because of the shape in the center of the cup - A; this shape is relatively sharp and so tends to direct the ball off to the side. Only with these cup - As did we experience uncontrollable ricocheting balls that damaged various camera lights.

cup - Cs™, on the other hand, appeared to "throw" the ball back off; balls rarely appeared to continue to "roll down" the shape of the cup and impact the backstop behind the cup. In addition, both the cup - C and cup - A appear to be made of stiffer plastic which did not deform as easily, compared to the Brand - 2 cup.

The fact that balls normally left some kind of mark on the exterior of the cup - C and cup - A allowed us to examine the cup's exterior surface to see exactly where it was actually struck. This was less true of the Brand - 2 cups, however.

We found that when struck by a baseball, cups tended to react in the following manner:

- When struck on the relatively flat upper surface of the cup, Brand - 3 cup - C compressed within the area struck by the ball and usually showed stress marks visible

[1] Jugs machine was positioned 19' from the target.

on the inside of the cup where it had deformed. The ball would often leave a visible mark on the exterior surface of the cup, on the opposite side of the stress mark. Stress marks were not generally visible on the outside of the cup except around ventilation holes. One cup appeared to crack but the cracks appear to be inside the plastic; no break in the material can be felt on either the inside or outside. What appears to be a small crack in one cup may not actually be a crack, however, since there is neither any feeling of a break in the plastic, nor a stress mark around the crack. As seen in the photo on the following page, most of the Brand - 3 cups, after being struck at 60 mph, show highly visible stress marks on the interior surface.

Impact stress marks on Brand - 3 cups struck at 60 mph

- Brand - 1 cups have a relatively-flat surface on the “upper” portion of the cup, but with a sharper “ridge” on the lower portion of the cup compared to the Brand - 3 cup - C (below).

In the photo above, note the sharper “ridge” in the center of the lower portion of the Brand - 1 cup - A on the left, compared to the relatively-blunt “ridge” on the Brand - 3 cup - C on the right. Note, too, that the upper portion of each of these two cups is relatively “flat”. This allows a ball, striking the center of the upper portion of either cup, to continue to compress the cup rather than rolling off to either side. Note, for example, in the following photo series, how the ball compressed into the Brand - 1 cup before finally rolling off and down the side of the cup. A Brand - 3 cup - C also deformed but the ball would then tend to “bounce” away from the cup rather than roll down the side.

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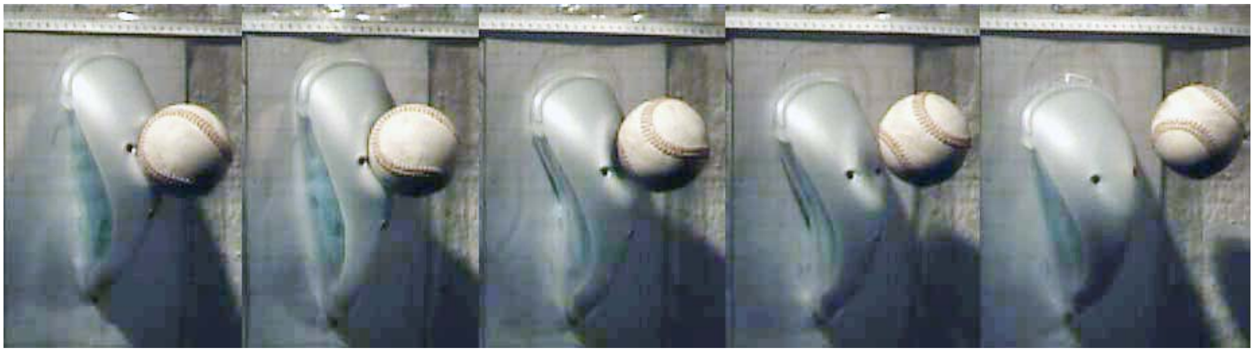
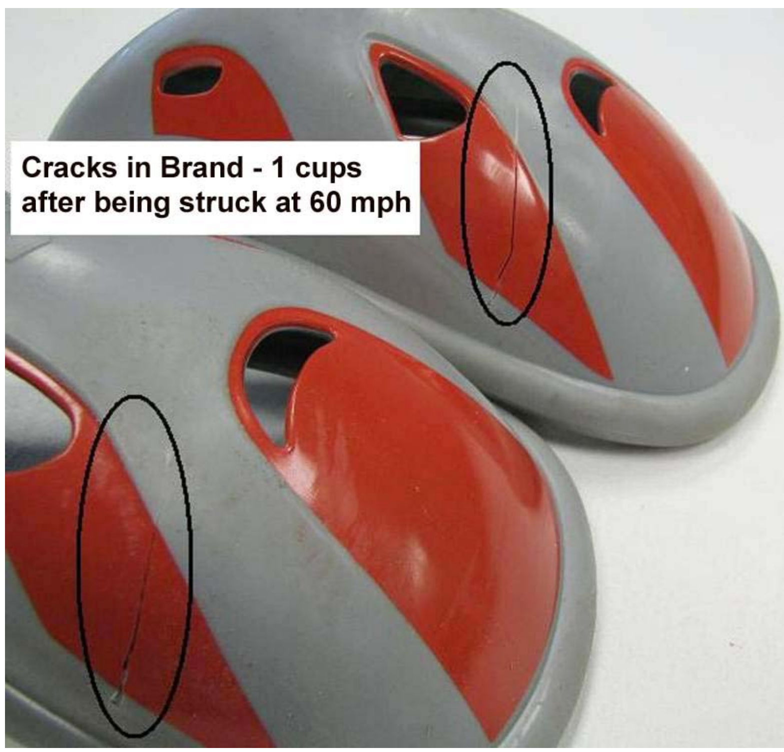


Deformation of a Brand - 1 cup - A (top) and Brand - 3 cup - C (bottom) when struck near the center at 60 mph. This particular impact cracked this cup - A, as seen in following photos. The cup - C exhibited stress marks on the inside; this particular cup was labeled "60 #11" and the resulting stress marks can be seen in the photo at the bottom of page 3.

- Two Brand - 1 cup - A cups cracked when struck at 60 mph; the photo series above shows one of those two cups. The ball struck each cup at almost the same location, just to the right and slightly above the center. The photo at right shows the almost-identical cracks in the two Brand - 1 cups.



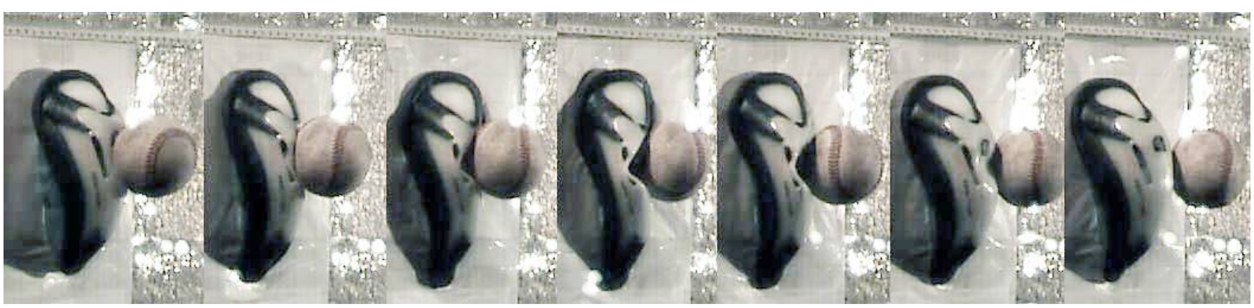
- When struck at only 30 mph, the Brand - 2 cup - B noticeably deformed, as seen in the following photo sequence.

- A 60 mph strike in the center of a Brand - 2 appeared to flatten the cup completely, as seen in the next photo sequence.

A Brand - 2 cup being struck in the center at 60 MPH. Note, in the 4th photo of the sequence, how the cup appears to flatten completely.

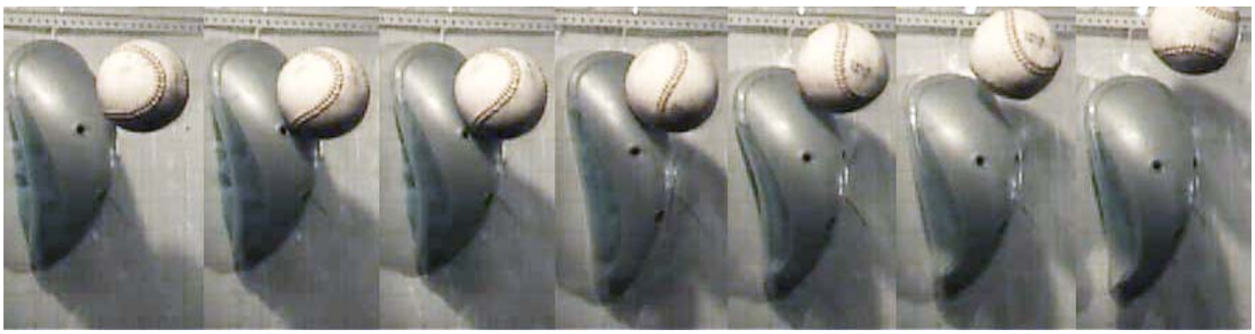
However, no damage of any kind was found on a struck Brand - 2 cup other than some "plastic burn" resulting from the ball spinning on the surface of the cup.

- Another 60 mph strike on a Brand - 2 cup, slightly off center, caused the cup to deform inward where it was struck, as seen in the following photo sequence. The ball is clearly following the shape of the cup and rolling off to the side, where it might have struck the cup-wearer's body.



- When struck at 30 mph, a Brand - 1 cup - A barely deformed inward, as seen in the 2nd and 3rd photos of the following sequence. The ball struck this cup slightly off-center toward the far side, compressing that portion of the cup, then rolled down the side of the cup until it struck the backstop behind the cup. Part of this rolling is clearly due to the very fast spinning of the ball but part is also due to striking the cup slightly off-center.

- The following photo sequence shows a cup - C being struck at 30 mph slightly above the center of the cup, on the upper flat surface (2nd, 3rd and 4th photos in the sequence). Note how the cup deforms slightly, and then appears to shove the ball off. The ball does continue rolling "up" the flat surface but is repelled from the cup before contacting the cup wearer's body.



This particular strike left a barely-discernable stress mark on the inside of the cup. The ball left a much-more-visible "wear mark" on the outside (pictured below).

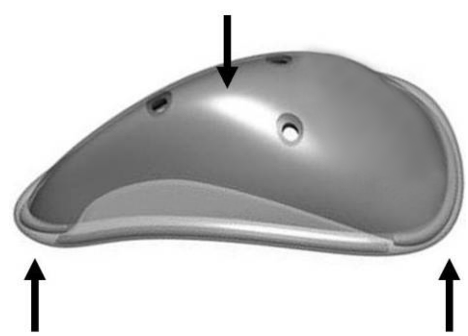
- A second 30 mph strike on a Brand - 3 cup - C, this time slightly to the left of center, appears to have caused slightly more inward compression of the cup, as seen below in the 3rd photo of the sequence. Note that again, the ball is thrown back off the cup before it has had a chance to roll down onto the cup wearer's body.

Load Cell Impact Testing

Load-cell impact testing was done by applying known weights to the cups at measured height intervals, and measuring the resulting impact force(s).

I. Static weight distribution

Measured: Using the calibrated data collection, a known weight was placed on the product (C) and the weight at each end was measured. The narrow end (A) of the device measured 53%, and the wide end (B) of the device measured 47%. This is within the expected margin of error for equal 50-50 weight distribution.



Note: For all testing, the wide end (B) was measured on Channel 1, and the narrow end (A) was measured on Channel 2 of the test equipment.

II. Conservation of Impact Energy

Theory: The desired impact of a 5 ounce (0.3125 pound) ball traveling at 60 miles per hour (88 feet per second) is analyzed. A ball can achieve 60 miles per hour when dropped under free-fall from 120.3 feet (1444.1 inches) [Height = Velocity^2 / (2*Gravity) = 88^2 / (2*32.174)]. Dropping a ball with repeated precision from 120.3 feet is very challenging. Therefore, an equivalent drop was done with a greater mass (12 pounds). The impact energy from the 5 ounce (0.3125 pound) ball is 451 inch-pounds [height*mass = 1444 * 0.3125]. The equivalent drop heights for 20, 40, and 60 mph ball speeds are summarized in the below table.

Speed (mph)	Speed (ft/sec)	FreeFall Height (ft)	Baseball Mass (lb)	Impact Energy (ft-lbs)	Impact Energy (in-lbs)	Experimental Weight (lbs)	Experimental Drop Height (in)
20	29.3	13.4	0.3125	4.2	50.1	12	4.18
40	58.7	53.5	0.3125	16.7	200.6	12	16.71
60	88.0	120.3	0.3125	37.6	451.3	12	37.61

Test Setup
A calibrated piezo-electric load cell was placed below each end of the product, and a fixed weight was dropped from a measured height onto the product. The voltage signal that was output from each load cell was then measured on a digital storage oscilloscope. The peak impact is then recorded and converted to a force using the calibration coefficient for each respective load cell.

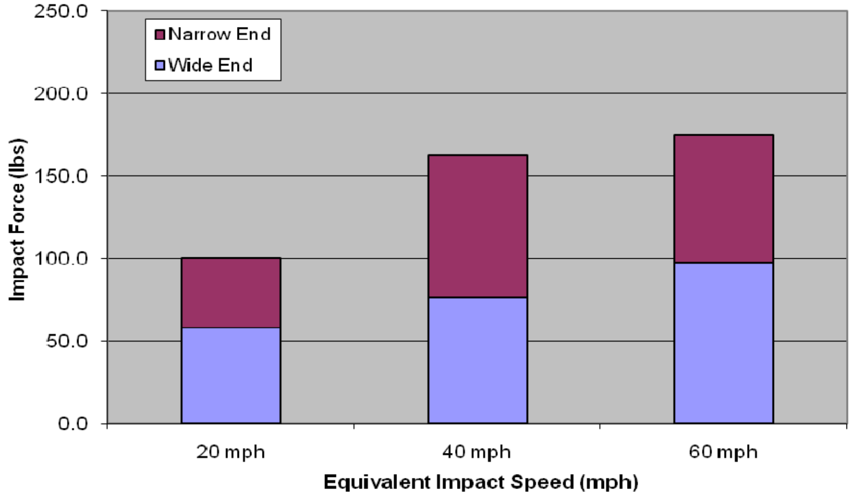
We encountered a “testing challenge” whereby the large impact forces occasionally caused the product to bounce off of the load cells before the full impact energy could be measured; thus, occasionally, repeated load-impact strikes were necessary in order to collect good data.

The same weighted object was dropped from various heights onto each athletic cup. The measured heights correspond to the impact energy of an equivalent speed baseball.

Brand - 3: Data Summary
There was no observable damage from the 20mph impact simulations. The highlights of the product damage resulting from various impacts are summarized below.

Typical 40mph damage: The most common damage found was from the impact with the sharp edges of the load cells, and not due to performance of the protective device. In most cases there was no structural damage noted; except as described below.	
60mph damage: The plastic regions near and between the ventilation holes show signs of plastic strain. These areas are the higher stress points that will likely be the first points of any failure or cracking.	
60mph damage: The second gray sample, after three (3) impacts at 60 mph, suffered a crack along the centerline from the lowest hole toward the narrow tip.	

Brand - 3

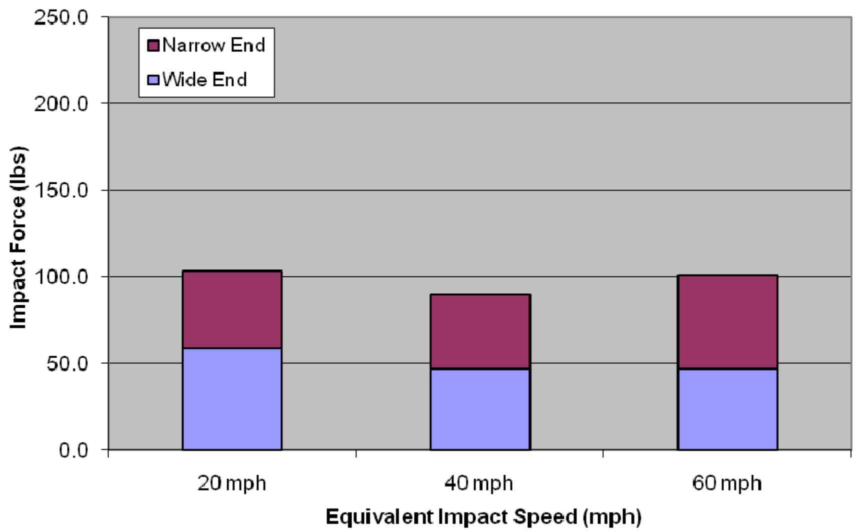


Brand - 2 Data Summary

The same weighted object was dropped from various heights onto the Brand - 2 sample cups. The measured heights correspond to the impact energy of an equivalent speed baseball. There was no observable damage from any of the impact simulations. The highlights of the product damage are summarized below.

After three (3) impacts at the equivalent 60 mph setting, the Brand - 2 cupl did not show any signs of fatigue, stress, or cracking.	

Brand - 2

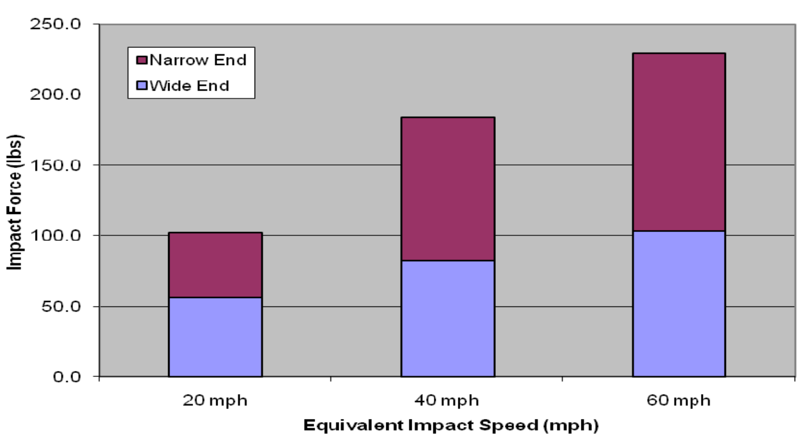


Brand - 1: Data Summary

The same weighted object was dropped from various heights onto the protective device. The measured heights correspond to the impact energy of an equivalent speed baseball. There was no observable damage from the 20mph or 40mph impact simulations. The highlights of the product damage are summarized below.

60mph damage: After one hit on the first sample, very visible stress fatigue marks appeared between the ventilation holes. The plastic stress marks are visible on both the inside and outside of the cup. The 60 mph baseball impact created the same fatigue pattern.	
60mph damage: The single impact on the second sample landed slightly lower. The same behavior of the plastic stress mark immediately appeared between the lower ventilation holes.	
60mph damage: The single impact on the third sample landed slightly lower than the impact on the second sample; but the stress marks that appeared look almost identical to those on the second sample.	

Brand - 1



Absorbed Energy
The absorbed energy is estimated from the force compressing the device through a distance. The maximum force is when the device has zero deflection, then as the device deflects, the force decreases to zero. Therefore, the absorbed energy is approximated as half the force multiplied by the compressed distance. The absorbed energy is compared to the maximum theoretical impact energy presented above. The remaining energy that is not absorbed by the plastic device is then passed on to the wearer. Additionally, the excess energy is spread across a larger area on the wearer, which reduces the perceived impact.

	Force (lbs)	Compression Distance (in)	Work (in-lbs)	Max. Theoretical Work (in-lbs)	Percent Absorbed Energy (%)
Brand – 1	229.6	0.69	78.9	451.3	**17.5%**
Brand – 2	101.2	0.94	47.4	451.3	**10.5%**
Brand – 3	175.0	0.63	54.7	451.3	**12.1%**

Video Observations
The slow motion video data confirms the behavior of the impact drop testing. The impact drop testing tends to show a double-hit type of behavior. The slow motion data demonstrates that the typical impact time is approximately eight milliseconds. This data aligns well with the oscilloscope first impact. Using the confirmed impact time provides more accurate data interpretation.

The black and white Brand - 2 has a greater deflection distance. However, this greater distance is fully extended with a lesser force than the other two brands. The lesser force leads to less overall energy absorption.

The red and gray Brand - 1 cup - A consistently displays stress flexure marks between ventilation holes when impacted by a 60 mph ball (or equivalent). This is due to the local plastic area exceeding the plastic strength. This can be improved with slightly additional thickness or plastic additive. This device generally absorbs the most energy of the products tested.

The gray cup - C did not demonstrate any abnormal behavior from the impacts. A few stress marks are easily induced. The clear supports along the side provide a good balance of restraining the elongation of the product during the impact while also absorbing the impact energy.

Each of the protective products demonstrated a good ability to return to the original shape after the impact load is removed. This allows the bounce rebound aid in pushing the ball out in a safe direction away from the wearer.

Additionally, the slow motion data visualizes the mode of deflection of the protective devices. As the ball impacts the device, the center region bows inward and causes the significant expansion downward toward the narrow end.

Summary, Load Cell Impact Testing

The impact forces were measured for a variety of equivalent impact speeds. The above data demonstrates that the Brand - 1 cup - A protective device absorbs the most energy. This was also the product that exhibited the most catastrophic damage by cracking when struck directly by a baseball at 60 mph.

The graphs below each product (data sections) represent the total force measured from the protective devices. Once the maximum force required to collapse the device is achieved, then the next increasing impacts does not increase the absorbed forces. The device has absorbed all of the energy possible, and all excess impact energy is passed onto the wearer.

Conclusion

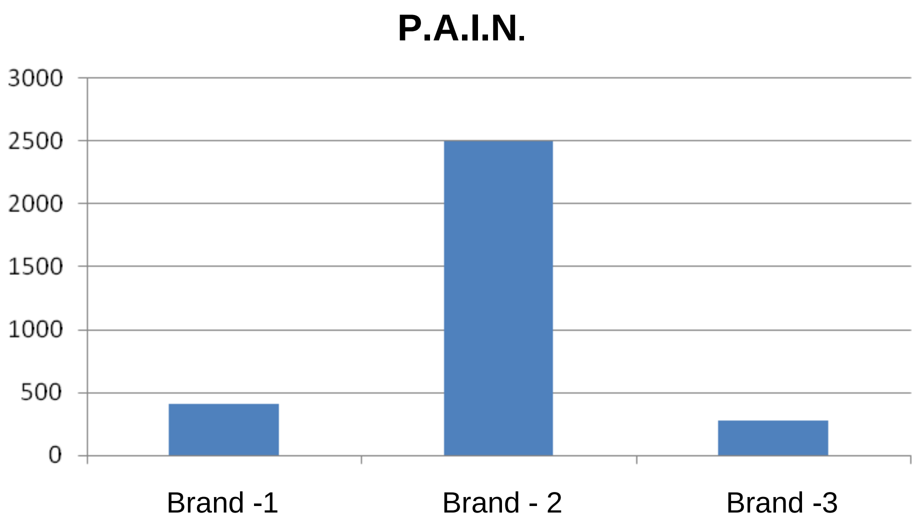
The videos clearly show that the Brand - 2 cup - B athletic cups deform noticeably inward when struck at even low speeds such as 30 mph. A 60 mph impact in the center has been shown to almost-completely collapse the Brand - 2 cup. On the other hand, both the Brand - 3 cup - C and Brand - 1 cup - A show minimal deformation when struck in the center at 60 mph by a baseball. Both do, however, show plastic stress marks with such impacts, and two Brand - 1 cups cracked significantly. A cup - C cracked after three static weight impacts but until then, only showed stress marks.

Pain **A**nd **I**njury **N**umber (**P.A.I.N.**)

From the slow motion camera video captures, the diameter of the impact area that the ball depressed is measured for each brand. From the diameter of the deflected device and with the known diameter of the ball, the penetration depth is calculated. The impact force from the above table is divided by the penetration depth to achieve the developed P.A.I.N.

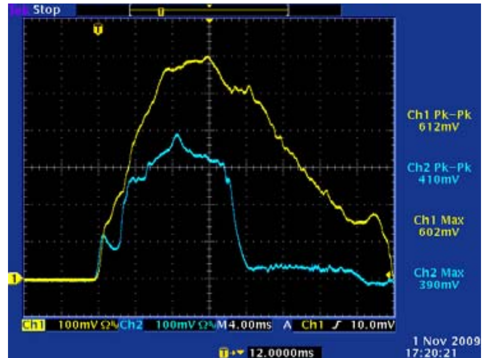
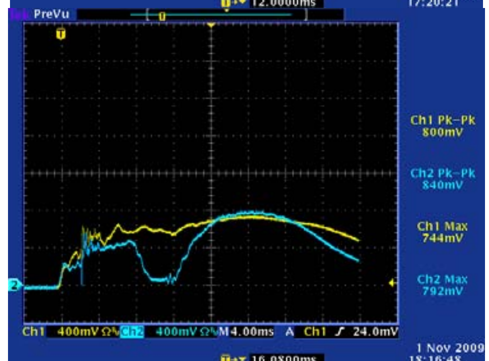
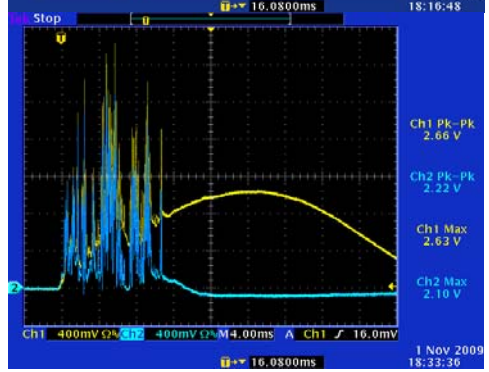
	Impact Dia (in)	*Depth (in)*	*Measured Force (lbs)*	***P.A.I.N.***
Brand – 1	2.348	0.566	229.6	**406**
Brand – 2	0.692	0.040	101.2	**2500**
Brand – 3	2.444	0.630	175.0	**278**

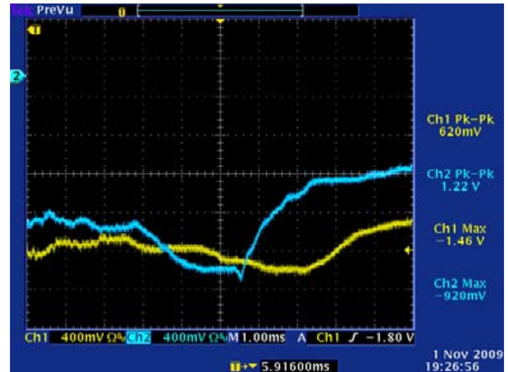
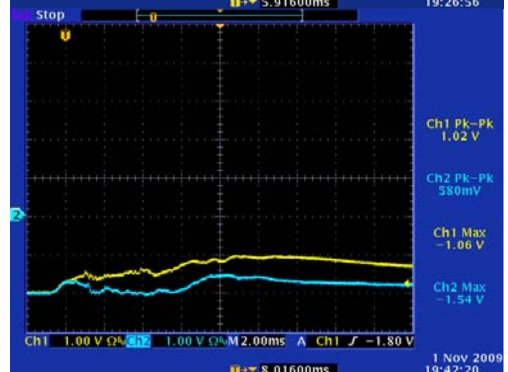
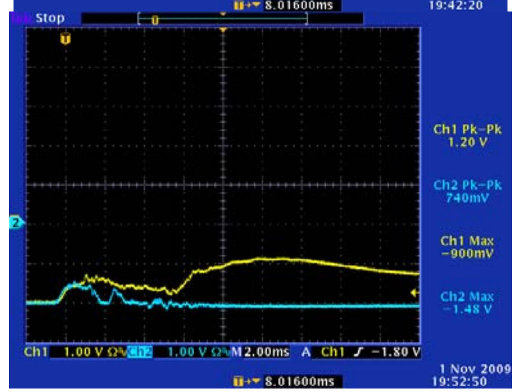


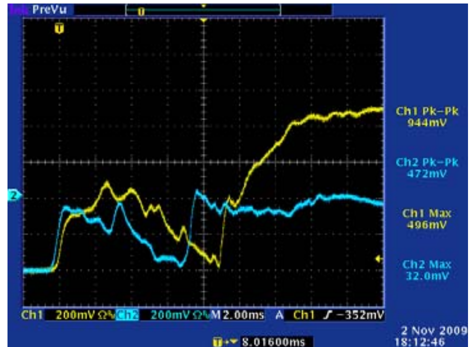
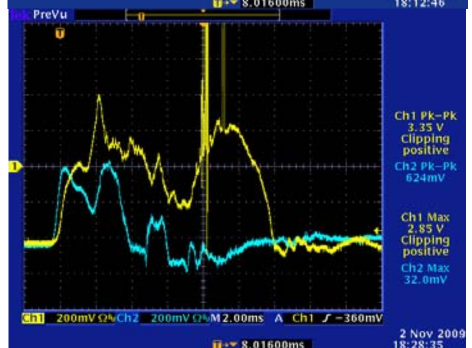
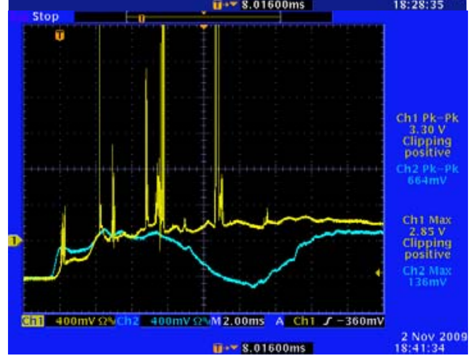


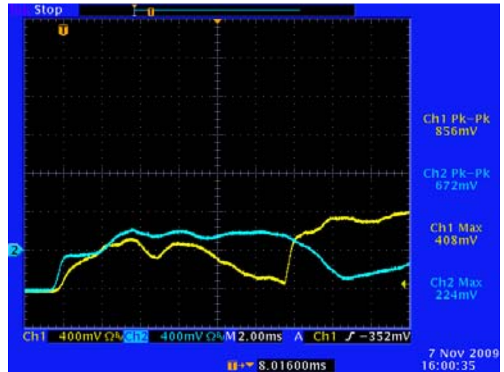
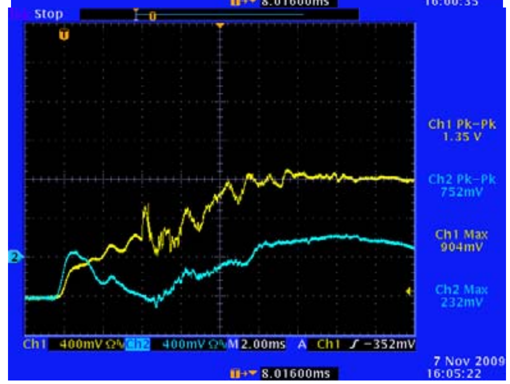
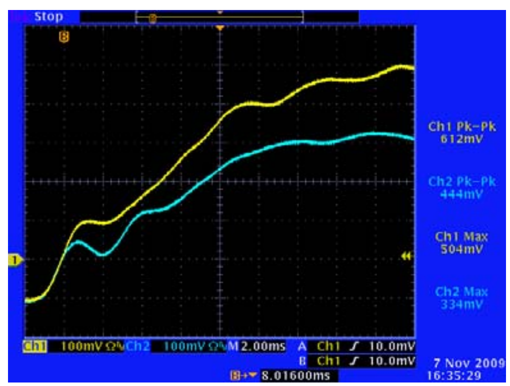
The developed P.A.I.N. demonstrates that the lower force through the very small surface displacement can yield significant impact to the wearer.

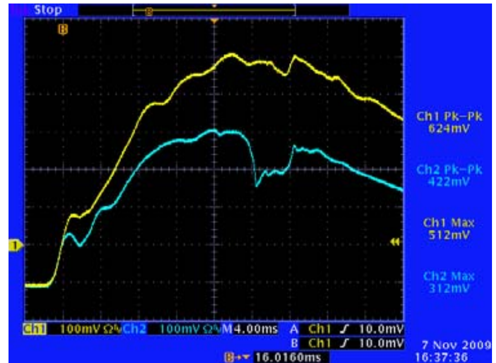
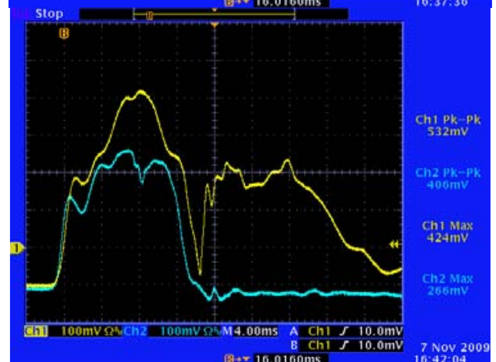
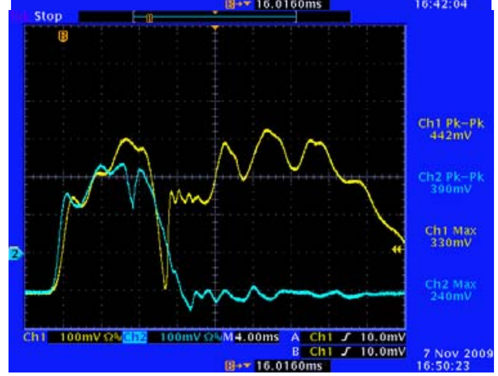
Measurement Data

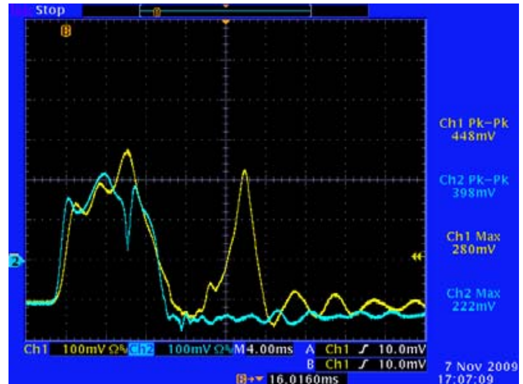
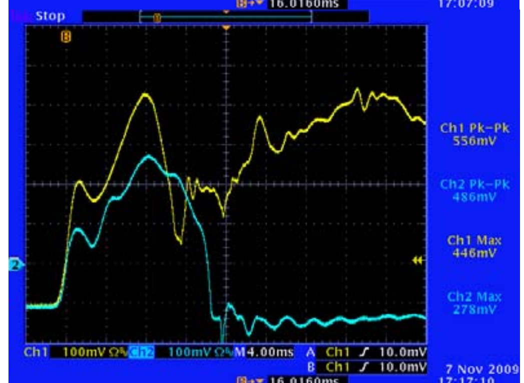
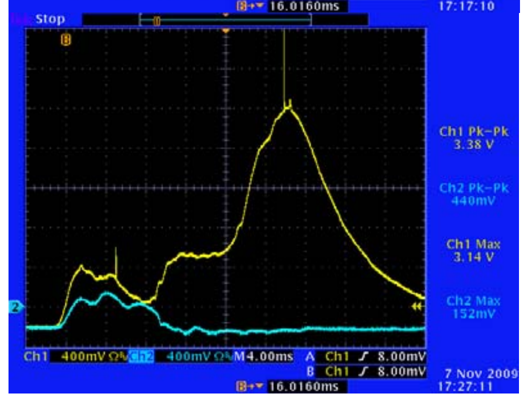
<table>
<tr><th>Drop #</th><th>Type</th><th>Equiv Speed</th><th>Ch. 1 Force (lbs)</th><th>Ch. 2 Force (lbs)</th><th>Sensor Data Image</th><th>Comments</th></tr>
<tr><td>1</td><td>Brand - 3 #1</td><td>20 mph</td><td>58.3</td><td>42.1</td><td>
</td><td>No damage</td></tr>
<tr><td>2</td><td>Brand - 3 #1</td><td>40 mph</td><td>76.2</td><td>86.2</td><td>
</td><td>No structural damage; slight abrasion w/load cell</td></tr>
<tr><td>3</td><td>Brand - 3 #1</td><td>40 mph</td><td>253.3</td><td>227.7</td><td>
</td><td>Oscillating impact frequency. Test setup vibration.</td></tr>
</table>

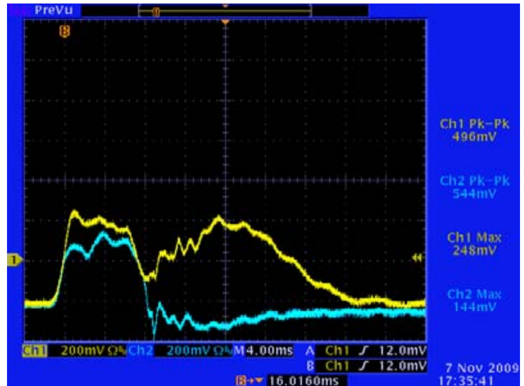
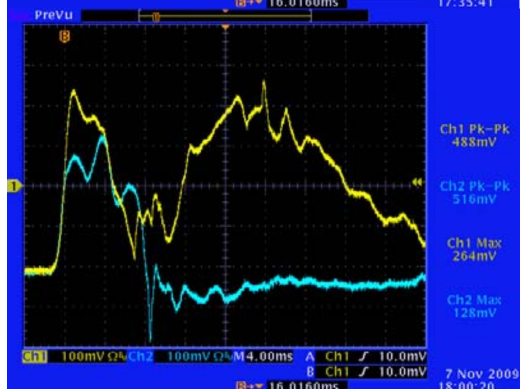
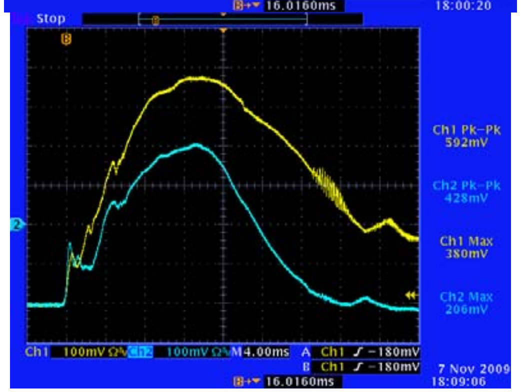
Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
4	Brand - 3 #1	60 mph	59.0	125.1		Off-center target, No structural damage. Short time-period capture window.
5	Brand - 3 #1	60 mph	97.1	59.5		Lower results than expected.
6	Brand - 3 #2	60 mph	114.3	75.9		Plastic stress discoloration between holes
7	Brand - 3 #2	60 mph	No data	No data	No data	Test fixture center brace was not installed. Bent load cell mounting. No data was recorded.

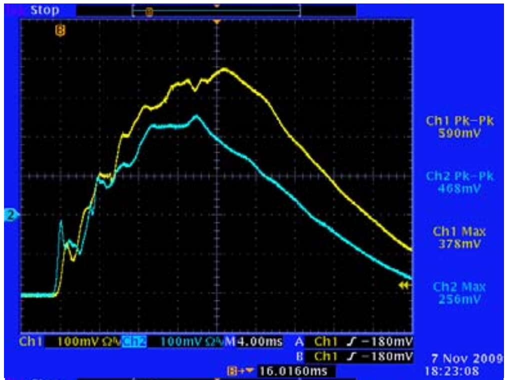
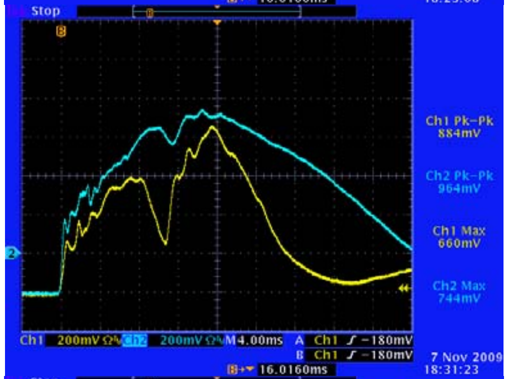
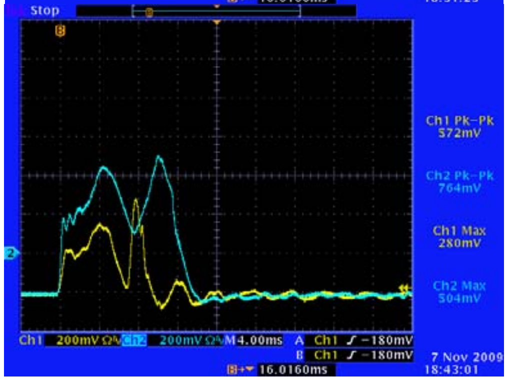
Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
8	Brand - 3 #2	60 mph	89.9	48.4		Crack down center of narrow end (hole to narrow tip) [photo]
9	Brand - 3 #3	60 mph	319.0	64.0		Clipped output from vibration spikes.
10	Brand - 3 #3	40 mph	314.3	68.1		Clipped output; sensor vibration

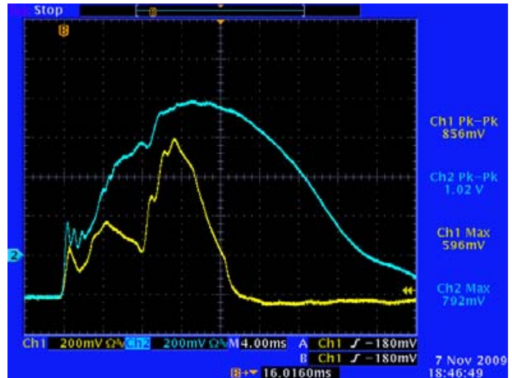
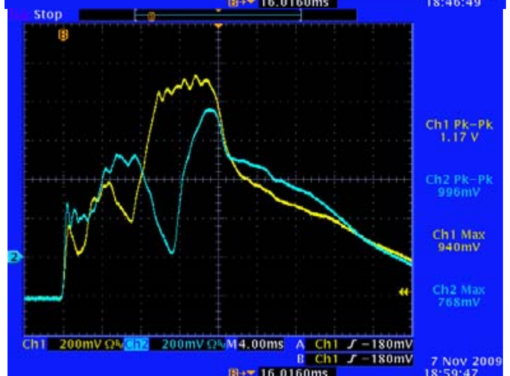
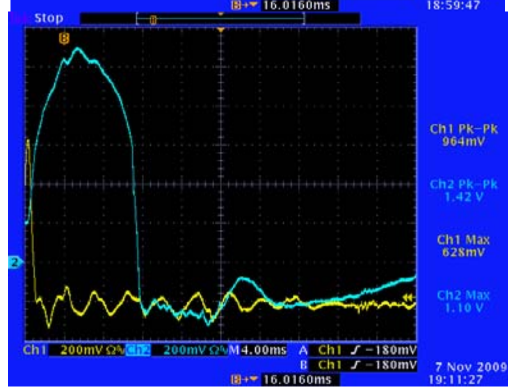
Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
11	Brand - 3 #3	40 mph	81.5	68.9		No visible damage.
12	Brand - 3 #3	60 mph	128.6	77.1		Photo; Damage by load cells. Plastic Stress near center hole.
13	Calibration Weight		12.4	12.0	none	Static sensor re-calibration with 12 lb weight
14	Brand - 2 #1	20 mph	58.3	45.5		No visible damage.

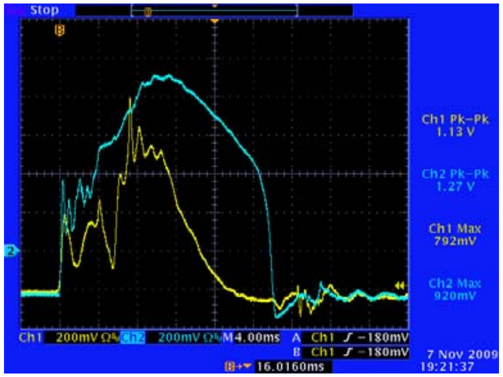
Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
15	Brand - 2 #1	20 mph	59.4	43.3		No visible damage.
16	Brand - 2 #1	40 mph	50.7	41.6		No visible damage.
17	Brand - 2 #1	40 mph	42.1	40.0		No visible damage.

Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
18	Brand - 2 #1	40 mph	42.7	40.8		No visible damage.
19	Brand - 2 #1	40 mph	53.0	49.8		No visible damage.
20	Brand - 2 #2	60 mph	321.9	45.1		After product bounced off load cells, the weight landed on load cell causing larger spike.

Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
21	Brand - 2 #2	60 mph	47.2	55.8		No visible damage.
22	Brand - 2 #2	60 mph	46.5	52.9		No visible damage. [photo]
23	Brand - 1 #1	20 mph	56.4	43.9		No visible damage.

Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
24	Brand - 1 #1	20 mph	56.2	48.0		No visible damage.
25	Brand - 1 #1	40 mph	84.2	98.9		No visible damage; taped to load cell sensor for better data.
26	Brand - 1 #1	40 mph	54.5	78.4		Off-center hit; glancing blow.

Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
27	Brand - 1 #1	40 mph	80.6	104.6		Perfect hit. No structural damage.
28	Brand - 1 #2	60 mph	111.4	102.2		Good hit. [Photo] Plastic stress on front between middle holes.
29	Brand - 1 #3	60 mph	91.8	145.6		Slightly off-center toward Channel 2 (narrow tip). [Photo]. Plastic stress mark between lower holes.

Drop #	Type	Equiv Speed	Ch. 1 Force (lbs)	Ch. 2 Force (lbs)	Sensor Data Image	Comments
30	Brand - 1 #1	60 mph	107.6	130.3		Plastic stress discoloration between lower holes. [Photo]