

# High Speed Force Measurement System for Evaluation of Helmet Impact Load Distribution



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## Introduction

Despite well established international helmet testing standards and the requirement of competitive athletes to wear protective head gear, an estimated 1.6-3.8 million sports related mTBI's occur each year[1]. The primary purpose of a helmet is to reduce the severity of a head injury. To assess this impact severity most standards are based on human tolerance curves for head trauma[2]. By increasing the duration of contact and lowering the peak acceleration, the helmet reduces the risk associated with of blunt force trauma. The certification standards used to approve helmet performance (CSA, ASTM, ISO) rely on metrics of global acceleration and puncture prevention. However, there exist situations where high velocity, low mass projectiles (e.g. a hockey puck) can cause extremely high focal forces at the impact site while global acceleration remains relatively low[3]. Finite element modeling can be used to estimate these focal force values, although little work has been done to asses these measures directly. To capture this helmet-to-head force transfer, conventional force sensor 'mats' provide high spatial resolution; however, they typically lack the necessary sampling rates, conformity and durability for multiple impact measurement of a curved surface. Hence, the purpose of this study was to design a flexible, cost-effective and durable high speed force measurement system and conduct pilot testing to examine blunt and projectile impact scenarios.

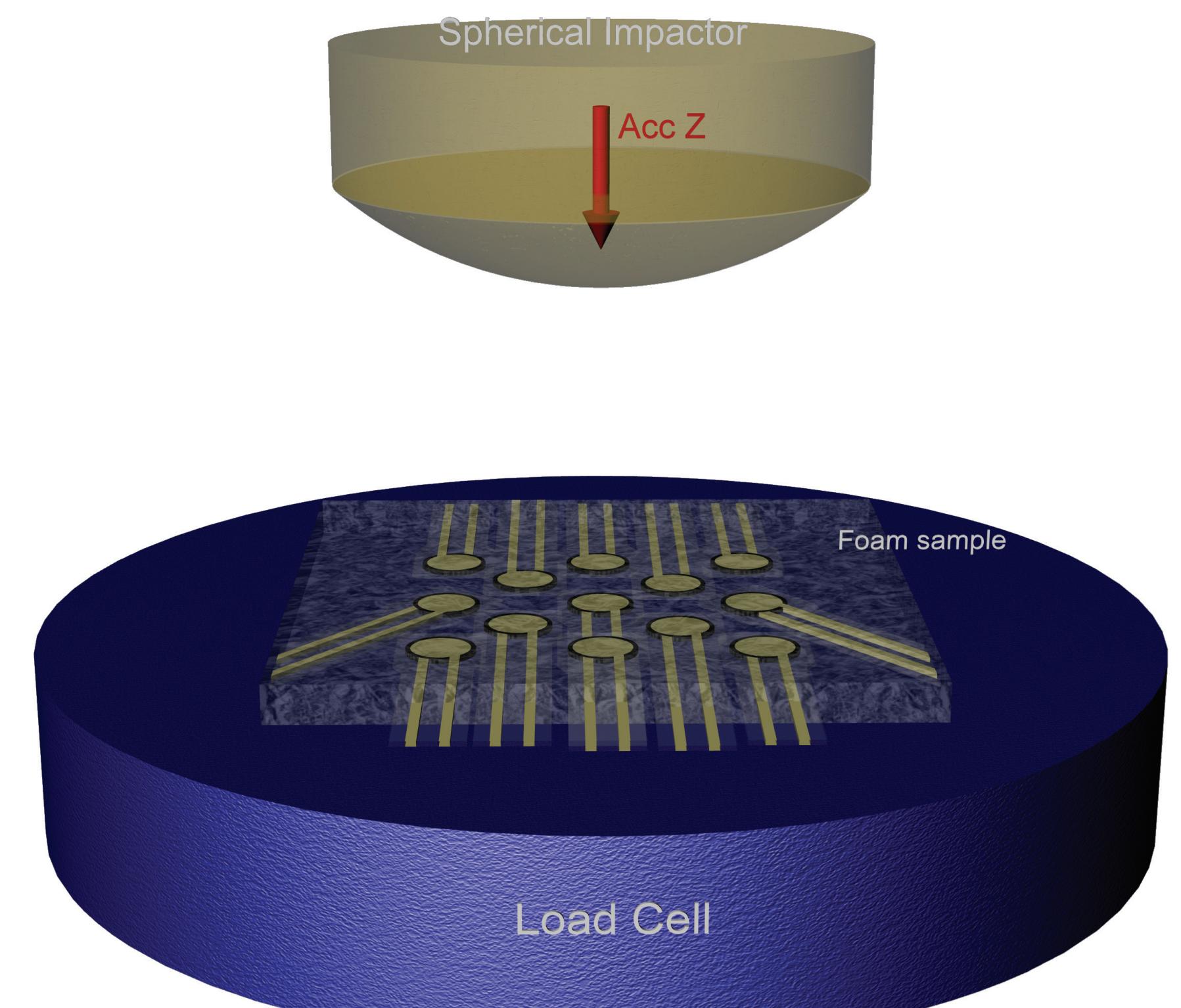


Figure 1: Testing apparatus for helmet foam samples. 13 Flexiforce® sensors are arranged in a 10x10cm array. Vertical acceleration is measured at the spherical impactor and global force is measured at the load cell.



Figure 2: Force sensor array on a NOCSAE full face headform (left) and laser alignment of the puck cannon to the central sensor (right)

## Methods

### System Design and Calibration

A compact amplifier was designed and built to power an array of 16 Flexiforce® sensors (A201-100 Tekscan, Boston, MA). A USB data acquisition device (NI USB-6210, NI, Austin, TX) powered by a portable laptop recorded synchronized force readings providing higher speed (15KHz/Sensor) and signal resolution (16-bit) than many available systems. Power for the amplifier is obtained through the laptop USB port hence the unit is portable for field testing. Prior to use, each sensor is conditioned at 110% load and dynamically calibrated from 0-1000N using a material testing machine at a load rate of 1000N/sec. Five individual calibrations were performed for each of the 16 sensors and corresponding voltage signals correlated to force.

### Drop Testing (High mass, Low Velocity)

A force plate was instrumented with a 10x10cm array of 13 Flexiforce® sensors (Figure 1). Several types of 10x10cm foam samples were tested on top of the array and impacted with 10J of energy by a 5kg spherical impactor. Vertical acceleration was recorded at the CoM of the impactor.

### Projectile Testing (Low Mass, High Velocity)

To test the response of the system during high velocity impacts a NOCSAE full face headform was instrumented with 13 Flexiforce® sensors at the front location (Figure 2). A medium sized EPP hockey helmet was placed on the headform and a pneumatic cannon was used to fire a hockey puck at 28m/s toward the central sensor.

## Results

### Calibration and System Accuracy

Raw voltage signals from the Flexiforce® sensors recorded during the 5 individual calibrations were pooled and correlated to applied force using linear regression. The average (mean  $\pm$ standard deviation) linear correlation across all sensors was acceptable ( $R^2=0.995\pm0.003$ , RMSE=16.3 $\pm$ 4.69N), however using 3rd order polynomials this improved to ( $R^2=0.9997\pm0.0002$ , RMSE=4.58 $\pm$ 1.18N).

### Drop Testing Results

A sample 10J foam impact with metrics of acceleration and load distribution is shown in Figure 3. Average acceleration values were nearly identical between foam samples however measurement of load distribution showed a two-fold difference in peak focal force between two different foam types.

### Projectile Testing Results

Peak force distribution for a 28 m/s puck impact to the helmeted forehead is presented in Figure 3. Peak force values were upwards of 425N, which converts to ~6 MPa. Bishop and Arnold (1993) measured pressures in the range of 10-15MPa at the same impact velocity to an area with typically less padding (temple) using pressure sensitive film.

This system was shown to be repeatable and accurate for the selected measurement range. The Flexiforce® sensors allow conformity to the curved surfaces of the head and are capable of measuring impact dynamics. Sensor life was impressive; during 600 recorded impacts replacement of the central sensor was required only once. When sensor replacement was necessary the process was simple and cost effective. The measure of acceleration as the primary predictor for helmet performance does not capture differences in focal forces as demonstrated (Figure 3). These differences could be attributed to factors such as foam stiffness, overall contact area and shell geometry. This system provides empirical data for use in direct assessment of helmet performance. In turn, this could aid in design of protective equipment through analysis of the load distributions and could provide additional data to aid in computation of finite element models.

### Literature Cited:

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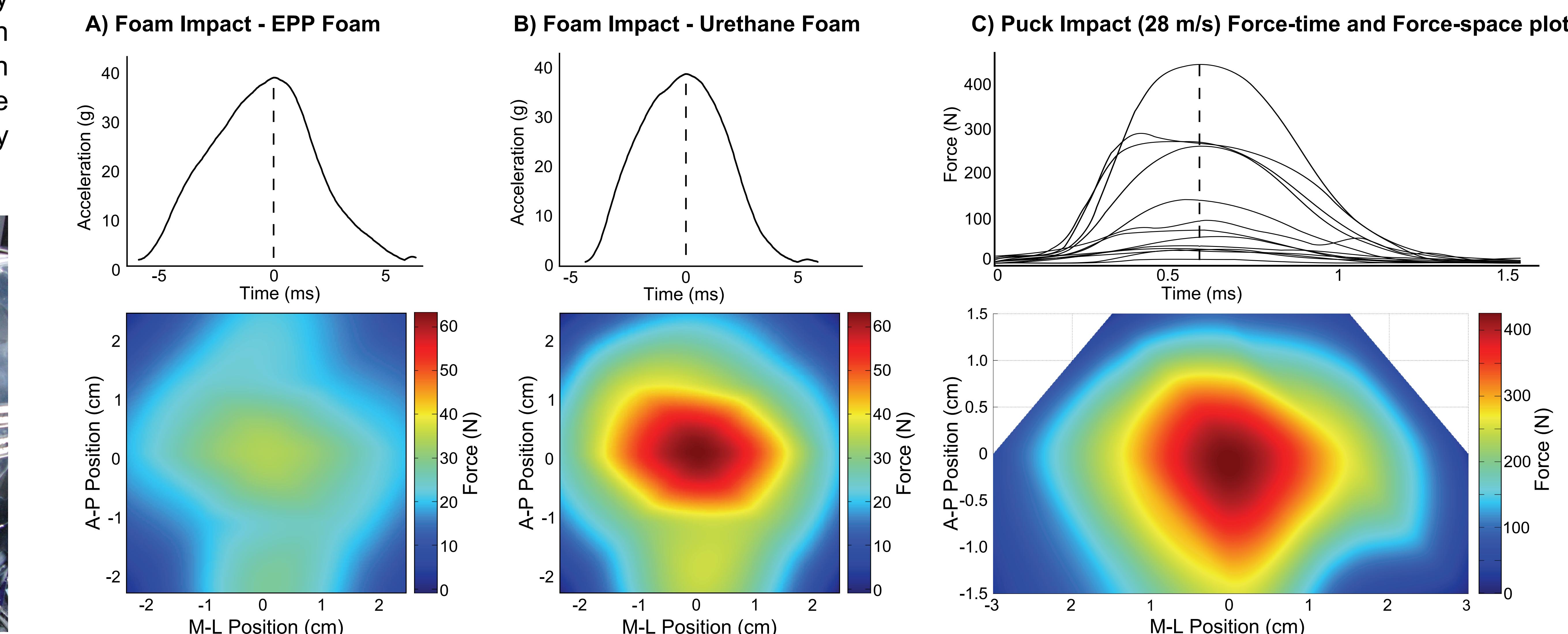


Figure 3: A) Acceleration and peak load distribution of a 12.5mm EPP foam during a 10J impact. B) Acceleration and peak load distribution of a 12.5mm urethane foam during a 10J impact. C) Force vs time and peak load distribution for a 28 m/s impact of a hockey puck to forehead of an EPP type helmet.