Problem Description

The original safety helmet was created in 1898. Since then, the safety helmet has evolved and found purpose into specific applications such as a fire helmet. The next step in Bullard’s fire helmet evolution is to decrease the ride height of the fire helmet as pictured below in Figure 1. This will improve the functionality of the helmet while maintaining necessary impact requirements for firefighters.

A study that was conducted involving over 100 firefighters and it was noted that the problem with the existing strap impact absorption system is twofold. Firstly, the helmet has a ride height that makes it cumbersome for the user to wear. This elevated ride height causes unstable movement due to its high center of gravity. Secondly, there is a need for a dual-phase shock absorption system. The current nylon-strap suspension system only provides one phase of shock absorption. The objective is to redesign this shock absorbing system in a way that absorbs force at two separate phases. Furthermore, the current design does not provide side impact absorption, which is a very important safety concern. Based on market research, Bullard has concluded that if they could incorporate a dual-phase shock absorption system and lower the ride height of the helmet by 0.5 inch, they would become a distinguisher in the market of fire helmet technology.

Product Design Specifications

To accomplish ride height reduction it will be necessary to redesign the existing shock absorbing system that Bullard is using in their fire helmet. The new design should incorporate a dual-phase shock absorbing system that will reduce the ride height of the helmet by 0.5 inch.

The dual phase shock absorber shall meet performance requirements demanded by Bullard and any, and all, state or national safety standards set by entities such as the NFPA. This includes a phase one impact absorption of up to 40ft-lb and 8500lbs transferred to the spine across 0.9 inch of phase one displacement. A phase two impact absorption of up to 66ft-lb and 16500lbs transferred to the spine across 0.4 inch of phase two displacement. The system shall also be heat and freeze resistant, where the absorbers may be able to withstand from -25°F to 350°F for fifteen minutes.

Furthermore, the first phase of the absorber shall not exceed a height of 1.5 inch, radius of 1.25 inch, a wall angle of 60° and wall thickness of 0.09 inch. Additionally, phase two shall not exceed a height of 0.6 inch, radius of 0.6 inch, wall angle of 75° and wall thickness of 0.9 inch.

Material Testing

To construct the shock absorbers, the team will be using a Elastosil LR 3003 series silicone rubber made by Wacker Silcones. This type of silicone holds its material properties in extreme temperatures and is particularly suitable for the economical production in large series injection moldings.

The team went to Bullard to test several silicone samples in order to achieve material data for ANSYS modeling. Bullard’s Instron machine was used to conduct a compression and tensile test, generating two stress-strain curves. From the compression test, the first trial experienced a break-in phase. The following trials generated repeatable data. The tensile test concluded that the material would produce a strain value of approximately 2 before its breaking point, indicating that the silicone should have no issues in tension or in bending, especially considering the stress concentrations at parting lines and corners at the top and base.

Figure 1: Current Ride Height (left) vs. Desired Ride Height (right)

FEA and Product Architecture Analysis

Using the results from materials importing the uniaxial preliminary test data and using the anisotropic materials feature, the team analyzed the datum, hex and the accordion concepts comparing the relative deformation between the two under constant loads.

A three factor, two level experiment was generated. The three factors consist of wall thickness, radius, and wall angle. Each factor was analyzed at a high and low value. Thus, the test matrix generated eight unique variations of each concept. Each variation, for both phase 1 and 2, was then analyzed within ANSYS to determine its deflection relative to the others. The results were then analyzed and it was determined that wall angle and wall thickness had the largest impact on the shock absorbers deflection, whereas puck radius had little effect. The results were conclusive for both phase 1, the accordion, and phase 2, the hex design.

Final Concept Selection

Figure 4 below shows CAD models of the final concepts selected for the phase 1 and phase 2 shock absorbers. These concepts were selected based on the factors previously mentioned, which are wall angle, wall thickness, and radius. In addition, each shock absorber concept will add the needed rigidity that previous ideas have not been able to accommodate. Each concept has been designed to optimally meet the force standards mentioned in the PDS.

In order to aid in manufacturability, an open bottom construction has been added to each design which will allow the core to be removed during production. Air holes have also been added to each concept. This was done to ensure that the pressure built-up upon compression within each shock absorber doesn’t exceed the limitations of the material and cause the puck to burst.

Throughout the remainder of semester, these final concepts will be further analyzed and refined based on prototype testing.

Figure 2: Silicone Material Being Tested on an Instron Machine

Figure 3: Phase 1 (top) and Phase 2 (bottom) Shock Absorbers in Nominal and Displacement Positions

Prototyping and Moving Forward

With a prototype arrival date anticipated for the week of February 29th, the team has planned and prepared necessary procedures for testing. With 80 samples of both phase 1 and phase 2 shock absorbers, many variations of the selected baseline test will also be used to collect data for analysis.

One test the team will be running is known as a drop test. It involves dropping a selected weight from a specified height along a guided vertical channel. As it impacts the shock absorber, data will be collected and analyzed for further interpretation. The results the team hopes to see pertains mainly to the stress-strain curve, optimally with largest area under the curve as possible. The way this is achieved is through a dual phase impact absorption process. The graph should initially spike steeply upward during phase 1 impact, then level off, then spike upward again during the phase 2 impact, and then finally level off to complete the curve.

Another test planned to take place is known as a compressive testing, displacing the absorbers at a rate ranging from 5 inches per minute to 20 inches per minute. This will aid the team in evaluating the stress induced on the absorbers at specific displacement values.