elastically to protect the user. This elastic deformation will cause a change in the materials shape, effecting the form system.

1.3.8 Function Resolution

After going through our data generation, the hierarchy chart and the cross-reference table, this product must protect the user from blunt force trauma and form accordingly to prevent injury.

1.4 Targets and Metrics

1.4.1 Target Summary

Functions were established from the information deciphered within the customer needs and function decomposition. The two main functions are protect and form. Following the two main functions are three individual sub-functions branching off each main function. Targets and metrics are used to validate concepts later in the design process. Targets is defined as the specific value used for validation while a metrics is defined as a method to validate a function. Table 3 shows the breakdown of the functions into its targets and metrics. Three functions with the corresponding targets and metrics, highlighted in yellow, are determined to be the critical functions of the project.

Table 3. Targets and Metrics Table

Function	Metric	Target
Absorb Direct Impact	G-Force (G)	Decelerates impacts by at least 75%
Disperse Incoming Energy	Force (lbf)	Less than 740 lbf
Reacts Elastically	Volume (in^3)	No loss of volume

Remains Lightweight	Weight (lbs)	5 lbs or less
Adapts to Fit	Regulations (in)	½ in gaps
Cost to Produce	US dollars ($)	No more than 10% increase in production cost over current products
Compact Size	Volume (in^3)	Less than 10% bigger than current products
Comfortability	Rating: 1 to 10	At least 7 out of 10

1.4.1 Derivation of Functions Targets and Metrics

Remains Lightweight - Weight

Remaining lightweight is a function important in the design of the project. Many football players are playing with the least amount of padding in the shoulder pads because it limits their range of motion and hand eye coordination. The metric associated with this function is weight. The target that is being used to measure this metric is lbs. Shoulder pads currently range from 3 lbs – 6 lbs. The increase in padding is likely to increase the weight of the shoulder pads, which is what athletic trainers are doing now, but installing a different material into the shoulder pads may decrease the weight of the pads while keeping the players safe and agile. The range of weight this product should be is 2 lbs - 5lbs.

Adapts to Fit – Regulations and Young's Modulus

The function to adapt to fit allows this product to not have a set shape or structure which aids in the versatility of incorporating into other existing products along with the user. There are no set regulations for should pad fitting except for the cantilever pad extending past the shoulder by ½ inch and the collar being ½ inch from the neck. It is also recommended that the fit is snug with any looseness being less than ½ inch gap. Determining the fit of the padding onto the user depends on the flexibility of the material, determined by the elastic modulus. Elastic modulus varies depending on the properties of a material which directly affects the Young's Modulus value. The property of a negative Poisson's ratio within auxetic foam is an example of a property that can change a Young's Modulus value. Due to this, a specific modulus value was not assigned for a target within Table 3.

Cost to Produce – US Dollars

Cost to produce is emphasized for the product as it is meant to be sold on the market. Also, the goal is to improve an existing product meaning that the price point needs to be comparable to current prices even with improvements being made. Based market research a 10% increase in price is accepted for an improved product.

Compact Size – Volume

An increase in padding volume directly relates to the increase in movement restriction for the user. Any restrictions of movement can hinder performance along with promoting incorrect form from the user during use. A user's overcorrection of overcoming a movement restriction can lead to more injury or harm, thus the volume of the padding product is required to reflect the same sizes of current paddings on market. The target volume sizes for the product are at most, a 10% increase of current volume sizes to account for improvements of paddings, but the goal is to decrease the necessary volume size as best as possible. The main factor of measurement highlighted is the thickness of the padding. While padding thicknesses vary depending on current available products, the common width of current paddings is under 2 inches in thickness.

Comfortability– Rating Scale

Confirmed feedback from humans is the standard metric of comfortability. While this quality does not directly impact the protective function of the product, the wearing comfortability of the shoulder pads affects the market's preference for the product. Discomfort for the user caused by the product will deter product use even if the padding functions correctly. A numerical rating scale of 1 to 10 symbolizing least comfortable to most comfortable is applied to convert human experience to numerical values. The target for comfortability is to average a comfortability level of at least 7 out of 10.

1.4.2 Derivation of Critical Targets and Metrics

The critical targets and metrics were derived directly from the critical functions generated in the functional decomposition. The critical functions were determined by using a cross-reference table, a function was then deemed a critical function if it corresponded to both systems (primary functions). The three critical functions determined are "Absorb Direct Impact", "Disperse Incoming Energy", and "Reacts Elastically". The critical metrics for each function accordingly are acceleration, force, and pressure.

Absorb Direct Impact – Acceleration

The key goal of a shoulder pad is to reduce the likelihood of an impact injury. Thus, the product experiences impact during every use. The metric used to measure the impact absorption of our product is acceleration. Since the product has no control over the force being generated by the football players, it's focus is reducing the amount of force felt by the athlete upon impact.

Since force is a function of acceleration, the most effective way to reduce the force in such a short amount of time would be to rapidly decelerate the bodies in motion. Therefore, when a player is impacted, the product will need to reduce the acceleration of the body that is causing the impact. The critical target for this function will be to reduce at least 75% of impacts. From NASA research, a safe impact on a human body is less than 40 G's. With extreme football tackles estimated to be around 150 G's, the target deacceleration of an impact

Disperse Incoming Energy - Force

While absorbing impact is beneficial to reducing the probability of injury, injuries can still occur at lower g-force levels. An impact at a lower g-force can have a more devastating effect than one of a higher g-force depending on how direct the force is. A direct impact will transfer a higher percentage of the force to a more concentrated area. Therefore, it will be imperative that our product can disperse force to reduce the severity of point-force direct impacts. The measured force to crack a person's ribs is about 740 lbf, the target for "disperse incoming energy" is to limit the point force impact at any given point to less than 740 lbf.

Reacts Elastically – Volume

Since the shoulder pad will be under compression, padding is tasked to receive multiple compressions and continue to return to its original shape. This is important to allow the padding to last for at least an entire season before it wears out. If the padding fails to return to its original volume, it would be unable to continue to provide protection. If there was a decrease in volume the paddings ability to absorb impact and disperse energy will be affected. Furthermore, any decrease in volume affects the form of the shoulder pads and will cause them to fit incorrectly leading to more injury risks.

1.4.3 Methods of Validation and Discussion of Measurements

There will be several different methods to validate that out design of shoulder pads meet the described targets. First to validate absorbing direct impact a drop test will be conducted using different materials to evaluate how they deaccelerate a weight dropped from various heights. ASET Services conducted a similar drop test to test helmet material padding to help reduce concussions. Figure 2 below shows an example of one of the drop tests using a 20lbs weight that is dropped on the blue foam below. The material will need to be able to deaccelerate as efficiently as possible while using a relatively small amount of material so that the design can remain lightweight and as cost effective. For this an accelerometer will be needed to examine the deceleration of the dropped weight. This same method will be used to validate the dispersing of incoming energy. In this case however the force from the falling weight will be calculated and be compared to how much pressure is found on the opposite side of the padding. For this a pressure gauge will be needed on the opposite side of the tested material to calculate how the material distributes the force from the dropped weight. Finite Element Analysis (FEA) will also be used to simulate the reactions of materials have to an impact. FEA will help narrow down the materials that will be physically tested so that cost of materials can be reduced.

Figure 2. Example Drop Test from ASET Service

The elasticity of the materials can also be examined under the same impact test as previously mentioned. If the material can withstand repeated impacts simulating a hit from a football player then return to shape, then the material will react elastically enough for our design. After each test the material length width and height will be measured with a caliper to determine any changes have been made. While durability over time is an important function, the timeline for this project cannot account for long term experiments. Due to this, associations of long-term durability are connected to multiple and repetitive compression tests of materials for elasticity.

1.5 Concept Generation

1.5.1 Introduction

Now knowing what targets are needed for our project to be successful the next step is to generate concepts that can possibly meet those targets. First group members gathered and brainstormed to come up with possible designs, then each group member was assigned different