Replace interior padding with air pocket technology

Initially when the sponsor of this project, Mike Holloway brought the idea of implementing helmet air technology into shoulder pads. In recent years a lot of research has gone into reducing concussions for football players. From this research helmets companies such as Schutt have implemented air pockets into helmets. To do this the athlete puts on the helmets and then the helmet lining is filled with air, which conforms to the athletes own head. This is the same type of technology would be implemented into shoulder pads. The inner layer of the shoulder pad would be lined with air pockets that will be filled when the athlete is wearing them to conform to that specific person. Figure 7 shows the type of technology that would be implemented for this design.

1.6 Concept Selection

1.6.1 House of Quality

The pairwise comparison is used to determine the importance weight factor of each customer requirement. This is done by comparing each customer requirement head-to-head to determine which is valued above the other receiving a 1 if it is deemed more valuable and a 0 is deemed less valuable.

Table 5: Pairwise Comparison

Pairwise Comparison						
	1	2	3	4	5	Total
1. Impact absorbent	----------	1	1	1	1	4
2. Lightweight	0	----------	1	1	1	3
3. Flexible	0	0	----------	0	1	1
4. Durable	0	0	1	----------	0	1
5. Easily incorporated into existing products	0	0	0	1	----------	1

From the pairwise comparison it was determined that impact absorbent was the highest weighted customer requirement, followed by lightweight with flexible, durable, and easily incorporated into existing products all tied for lowest importance weight factor.

The importance weight factors were incorporated into the House of Quality table. This table compares the customer requirements with the engineering characteristics. The table does this using a scale of 0, 1, 3, 9 to describe the importance of an engineering characteristic for a certain customer requirement. A 9 means that the customer requirement very much relies on that engineering characteristic for the customer requirement to be met.

Table 6: House of Quality

House of Quality							
		Engineering Characteristics					
IMPROVEMENT DIRECTION		⇧	⇧	⇧	⇧	⇧	⇧
UNITS		Gs	lbf	n/a	lb	in	in^3
Customer Requirements	Importance Weight Factor	Absorbs impact	Disperse energy	Prevent Injury	Lightweight	Adapts to fit	Reacts Elastically
Impact absorbent	4	9	9	3	0	0	1
Lightweight	3	0	0	3	9	0	0
Flexible	1	3	1	1	0	3	3
Durable	1	1	0	3	0	0	3
Easily incorporated into existing products	1	0	0	3	3	3	1
Raw Score	10	40	37	28	30	6	11
	Relative Weight %	26.32%	24.34%	18.42%	19.74%	3.95%	7.24%
	Rank Order	1	2	4	3	6	5

Key
0 - not at all
1 - slightly
3 - moderately
9 - very much

The House of Quality shows, based on the customer requirements, the order of importance for each of the engineering characteristics. These ratings also have a relative weight showing how much importance they hold out of the whole 100% of the project. Absorb impact was determined to be the most important engineering characteristic at 26.32% relative weight with disperse energy being closely behind at 24.34% relative weight. These two engineering characteristics were the most important. This is because those two engineering characteristics have the greatest impact to fulfill the customer needs with the highest importance weight factor which is impact absorbent.

1.6.2 Pugh Charts

Pugh Chart 1 was used to determine if our concept was better (+), worse (-), or the same (S) as the datum which is existing shoulder pads. Each concept was put through this test and was compared to the Datum on the selected criteria. From the Pugh Chart 1 we were able to add up all the pluses and minuses to determine which concept will move on to Pugh Chart 2 which will then be the new datum. This winner was replace interior padding with Cellular Urethane.

Table 7: Pugh Chart 1

Pugh Chart 1						
SELECTION CRITERIA	Existing Shoulder Pads	Concept 1 Replace interior padding with non-Newtonian fluid	Concept 2 Metal plate insert centered within padding	Concept 3 Non-Newtonian fluid padded compression undershirt	Concept 4 Inflatable undershirt to compensate for ill-fitting shoulder pads	Concept 4 Replace interior padding with Celluelar Urethane
Absorb Impact	Datum	+	+	+	+	+
Disperse Energy		+	+	+	+	+
Prevent Injury		+	+	+	+	+
Lightweight		-	-	-	-	S
Adapts to Fit		+	-	S	+	S
Reacts Elastically		-	S	-	S	S
# of pluses		4	3	3	4	3
# of minuses		2	2	2	2	0

Pugh Chart 2 is an extension of Pugh Chart 1 and is used to compare concepts 6, 7, and 8 with the winner of Pugh Chart 1. Once each concept has gone through the selected criteria the winner is determined to be replace interior padding with negative Poisson ration material.

Table 8: Pugh Chart 2

Pugh Chart 2				
SELECTION CRITERIA	Replace interior padding with Cellular Urethane	Concept 6 Replace interior padding with air pocket technology	Concept 7 Negative Poisson ratio material padded compression undershirt	Concept 8 Replace interior padding with negative Poisson ratio material
Absorb Impact	Datum	-	+	+
Disperse Energy		-	+	+
Prevent Injury		-	+	+
Lightweight		+	-	+
Adapts to Fit		+	+	+
Reacts Elastically		S	+	+
# of pluses		2	5	6
# of minuses		3	1	0

Pugh Chart 3 is the last Pugh Chart used for comparing concepts. This chart uses Replace interior padding with negative Poisson ratio material as the datum. After comparing concepts 6 and 7 with the datum, it was clear replace interior padding with negative Poisson ratio material was the overall winner.

Table 9: Pugh Chart 3

Pugh Chart 3			
SELECTION CRITERIA	Replace interior padding with negative Poisson ratio material	Concept 6 Replace interior padding with air pocket technology	Concept 7 Negative Poisson ratio material padded compression undershirt
Absorb Impact	Datum	-	-
Disperse Energy		-	-
Prevent Injury		-	S
Lightweight		+	+
Adapts to Fit		S	S
Reacts Elastically		+	-
# of pluses		2	1
# of minuses		3	3

1.6.3 Analytical Hierarchy Process

The analytical hierarchy process (AHP) uses a series of matrices to select the best concept. The first step of the AHP is the criteria comparison matrix, this is used to rank the evaluation criteria. Each evaluation criterion is listed along the rows and columns and is given an odd number rating that represents its importance in relation to the criterion it is being compared to, seen below in Table 10.

Table 10: Criteria Comparison Matrix

Criteria Comparison Matrix						
	Absorbs Impact	Disperses Energy	Prevent Injury	Remains Lightweight	Adapts to Fit	Reacts Elastically
Absorbs Impact	**1.00**	7.00	5.00	7.00	7.00	7.00
Disperses Energy	0.14	**1.00**	1.00	3.00	5.00	5.00
Prevent Injury	0.20	1.00	**1.00**	0.33	3.00	3.00
Remains Lightweight	0.14	0.33	3.00	**1.00**	5.00	3.00
Adapts to Fit	0.14	0.20	0.33	0.20	**1.00**	1.00
Reacts Elastically	0.14	0.20	0.33	0.33	1.00	**1.00**
Sum	**1.77**	**9.73**	**10.67**	**11.87**	**22.00**	**20.00**

If a criterion was deemed more important than the opposing criterion it was given an odd whole number to represent this relationship. The inverse of this value was then reflected over the diagonal line. The results were then normalized to exemplify the consistency of the matrix and can be seen below in table 11.

Table 11: Normalized Criteria Comparison Matrix

Normalized Criteria Comparison Matrix							
	Absorbs Impact	Disperses Energy	Prevent Injury	Remains Lightweight	Adapts to Fit	Reacts Elastically	Critical Weight
Absorbs Impact	0.565	0.719	0.469	0.590	0.318	0.350	**0.502**
Disperses Energy	0.081	0.103	0.094	0.253	0.227	0.250	**0.168**
Prevent Injury	0.113	0.103	0.094	0.028	0.136	0.150	**0.104**
Remains Lightweight	0.081	0.034	0.281	0.084	0.227	0.150	**0.143**
Adapts to Fit	0.081	0.021	0.031	0.017	0.045	0.050	**0.041**
Reacts Elastically	0.081	0.021	0.031	0.028	0.045	0.050	**0.043**
Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

The critical weights are found by averaging the normalized comparison value for each evaluation criterion. These critical weights identify the importance each criterion will have in deciding the best concept. The sum of all the average critical weights should be equal to one as they represent portions of a whole. Absorbs impact was by far the highest weighted criterion with about half of the critical weight. The next step in the AHP was to check the consistency, the results can be seen below in table 12.

Table 12: Consistency Check

Consistency Check		
{Ws}	{W}	Cons
3.78	0.502	7.54
1.19	0.168	7.09
0.67	0.104	6.45
0.91	0.143	6.40
0.25	0.041	6.18
0.27	0.043	6.35
Average (λ)		**6.67**

The average consistency vector was found to be 6.67 and is denoted as lambda. This lambda value is used to calculate the consistency ratio and the calculations are shown below in Table 13.

Table 13: Consistency Comparison

Consistency Comparison	
λ - n	0.67
n - 1	5
Consistency index	0.133
RI Value	1.35
Consistency Ratio	0.099

The consistency ratio must be lower than 0.10 to prove that the criteria comparison matrix is valid. From the calculations above, the consistency ratio was found to be 0.099 which proves that the criteria comparison matrix is valid. The next step was to take the three highest scoring concepts from the house of quality of compare them to each other based on each individual criterion. The example below in Table 14 shows the concepts compared to one other based on the Disperses Energy evaluation criterion.

Table 14: Disperses Energy Comparison

Disperses Energy Comparison			
	Concept 5 Replace interior padding with Cellular Urethane	Concept 1 Replace interior padding with non-Newtonian fluid	Concept 8 Replace interior padding with negative Poisson ratio material
Concept 5 Replace interior padding with Cellular Urethane	1.00	0.33	0.33
Concept 1 Replace interior padding with non-Newtonian fluid	3.00	1.00	3.00
Concept 8 Replace interior padding with negative Poisson ratio material	3.00	0.33	1.00
Sum	**7.00**	**1.67**	**4.33**

The concepts were compared in a similar fashion to the evaluation characteristics in the criteria comparison chart used earlier in the AHP. Once the concepts were compared on each evaluation criteria the charts were normalized to find the Design Alternative Priorities (DAP) values, the DAP values were then used in the Final Rating Matrix to select the final concept.

1.6.4 Final Selection

The Final Rating Matrix is the results from the concept AHP normalized tables. Each of these results are compiled into this table so that the different concepts can be more easily seen and used to calculate.

Table 15: Final Rating Matrix

Final Rating Matrix			
	Concept 5 Replace interior padding with Cellular Urethane	Concept 1 Replace interior padding with non-Newtonian fluid	Concept 8 Replace interior padding with negative Poisson ratio material
Absorbs Impact	0.15	0.07	0.78
Disperses Energy	0.14	0.57	0.29
Prevent Injury	0.33	0.33	0.33
Remains Lightweight	0.30	0.09	0.61
Adapts to Fit	0.20	0.60	0.20
Reacts Elastically	0.30	0.09	0.61

The Final Rating Matrix shows the DAP values for each concept that correspond to each evaluation criterion. These DAP values were then multiplied by the corresponding criteria weight vector and then normalized to find the alternative ratings which were the determining factor for choosing a final concept.

Table 16: Concept Final Winner Table

Alternative Ratings			Concept Final Winner
Concept 5 Replace interior padding with Cellular Urethane	7.241	0.223	Concept 8 Replace interior padding with negative Poisson ratio material
Concept 1 Replace interior padding with non-Newtonian fluid	10.681	0.329	
Concept 8 Replace interior padding with negative Poisson ratio material	14.502	0.447	

The final concept was determined to be replace interior padding with negative Possion ratio. From the research we have conducted, the negative Possion's ratio will allow for great energy distribution since the material is subject to expanding when in compression. A type of negative Possion's ratio material is Auxetic foam. A picture of Auxetic foam is in Figure 9. This will be a great material to put under tests to see if our hypothesis and selection tools matches resulting data discoveries. This concept has gone through multiple comparisons and has fulfilled all the customer needs.

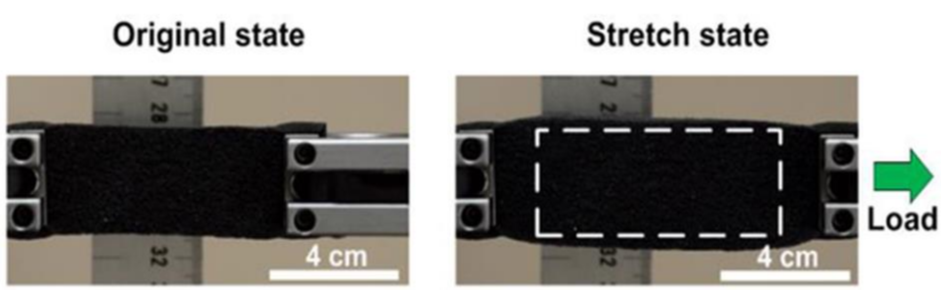

Figure 9: Auxetic Foam with negative Poisson's Ratio