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Team # 519

Secure Fit Football Undershirt

Authors: Paul Cunningham, Vivi Huynh, Sawyer O’Bryan,

Nicholas Palestrini, and Morgan Sefcik

FAMU-FSU College of Engineering 2525 Pottsdamer St. Tallahassee, FL. 32310

Abstract

American high school football accounts for nearly 480,000 shoulder injuries per year. Rotator cuff tears, AC (Acromioclavicular) joint injuries and collar bone fractures are some of the more common injuries in football. Mike Holloway has partnered up with our team to develop a product that will help lessen the number of injuries caused by lack of shoulder pad innovation. Hundreds of millions of dollars are invested into helmet technology, while significantly less are spent on advances in shoulder protection. The target consumer of our product will be youth football players. Protecting young players will further their football playing careers and preserve their overall health.

From our market research and interviews with high school athletic trainers, we determined improper fit of football shoulder pads is a major issue. Improper fit is especially an issue for football programs that do not have the budget to purchase pads made to fit the individual player. When there are gaps of space between the shoulder pads and the player's shoulders, the pads will shift in position as the player is moving. This shift out of the proper position exposes vulnerable sections of the shoulder.

Creating an undershirt to improve the fit of the shoulder pads was decided to be the best option for improving the fit while still allowing for maximum comfort. The undershirt will include padding in the shoulder and chest area. It will also have a foam composite collar around the neck to keep the shoulder pads from pinching the neck. This will help spread incoming energy from hits and prevent pinching on the neck. The undershirt will fill the gap between the player and loose shoulder pads. Properly fitted shoulder pads gives the player more confidence and protection during the football game.

Acknowledgement

We would like to start off by thanking Mike Holloway for sponsoring our groups project. Mike came to us with a great idea for how we can reduce injuries in football players through the improvement of football shoulder pads. With his idea he was able to have a senior design project that really challenged us and helped develop our engineering experience.

The next person we would like to thank is our academic advisor Dr. Christian Hubicki. He was willing to meet with us every single week to make sure we were on track and could answer questions if we had them. This was very helpful to the group.

Dr. Camilo Ordóñez is the last person we would like to thank. After reaching out to him about our troubles with our force sensor, he was willing to let us use his mechatronics lab to run tests. His knowledge about oscilloscopes really helped our group.

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Notation

FAMU-FSU	Florida Agricultural and Mechanical University- Florida State University
ISS	Injury Severity Score
NISS	New Injury Severity Score
NASA	National Aeronautics and Space Administration
NFL	National Football League
CAD	Computer-Aid Design

Chapter One: EML 4551C

1.1 Project Scope

1.1.1 Project Description

Secure Fit Football Undershirt's members main objective is to reduce the injuries of football players through the improvement of shoulder pads. As part of the mission, we will work together with our sponsor and advisor to research and analyze data to develop a product that will reduce injuries of football players.

1.1.2 Key goals:

The key goals of this project were determined from the project briefing with the team's sponsor and advisor. The project brief was broken down into a list of achievable objectives to ensure that the project stays on track with the sponsor's project description The first objective is to identify the specific injuries the product will prevent. The following goals pertain to the actual product's function. The first goal of this project is to provide optimal fit of the shoulder pads. The second goal is to protect against impact force from a tackle. The final goal is for the product to be durable enough to withstand one football season's worth of use.

1.1.3 Markets

The markets that this project tailors towards are companies producing sports gear and sportswear, companies that produce protective gear and safety equipment, adult athletes, and parents of athletic children. Incorporating a new structure or material into sports gear and sportswear is the main target of this project, thus partnering with companies that focus on this department is crucial. This infused product caters towards parents and athletic adults with the emphasis on injury prevention and minimizing the longevity of injury consequences. While sports injuries are the main concern for this project, the product application can also be transferrable to other injuries such as automotive or construction; this opens companies producing protective gear as another ideal market.

1.1.4 Assumptions

The assumptions for this project are stated to direct the engineers towards the project description. The first assumption is that the product will be worn by a human, therefore the product will need the proper dimensions to accommodate a human user. It is also assumed that the product will be compatible with the current model of shoulder pads, the product itself will not function as a set of shoulder pads rather it will serve as an add-on to improve the existing model. It is assumed that this product will be used on Earth and thus must be capable of functioning under the Earth's gravity and weather conditions.

1.1.5 Stakeholders

The stakeholders for this project include people with investment, interest, and control in the project.

- Mike Holloway: Sponsor
- Dr. Christian Hubicki: Advisor
- Dr. Shane McConomy: Professor
- Florida State University Athletic Department: Research Aide

1.2 Customer Needs

The customer needs are interpreted answers given by the sponsor and advisor that show the customers wants from the project. The objective of this project is to create new shoulder pads for football players. This project brief gives engineers the basic need of the project, but more detailed information needs to be identified. The first step in identifying the customer's needs is speaking with the sponsor and advisor through a zoom meeting on 9/17/2020 at 7pm Eastern time. Table 1 below shows the questions the team had asked our sponsor, and with the customers statements the interpreted need was determined.

Table 1. Interpreted Customer Needs from Sponsor and Advisor

Questions	**Customer Statements**	**Interpreted Need**
What is your motivation?	The experience from playing football drew him to conceptualizing the idea for shoulder pads.	The product provides better protection than existing shoulder pads.
What is your target audience?	The ideal starting market are parents of athletic children and athletic adults.	The target markets are sports equipment companies and sports organizations ranging from youth to professional.
Do you have any personal ideas?	A type of fabric with air pockets that can easily distribute an outside force is the personal idea.	A constructed fabric or padding of some kind that is very efficient in distributing energy from an outside force.
What is the intended application?	Fabric incorporated into football shoulder pads for better protection on the human body.	The product provides increased force distribution compared to existing products. The product is compatible with existing shoulder pad models

Do you have any alternative application?	Motorcyclists, other sportswear and sports gear, construction gear, etc.	Application of this product is ideally versatile towards any protective need.
What is your final goal?	A full-blown prototype is not expected. I understand that this is theoretical. I want to know how plausible this product could be.	Getting farther in research and calculations with making this fabric incorporation more likely. A prototype is not expected.
Do you have any expectations?	A fabric that can greatly spread out the force of a blow and can be easily incorporated into other available protective gear.	A lightweight, non-bulky, well-made product that can lessen the dangers of point of contact injuries.
What is your ideal project timeline?	A theoretical construction or accessible material is best identified to fit this air pocket fabric.	Create own timeline but stay connected.
Which injuries are of main concern?	Rib fractures and collarbone fractures are of main concern.	This product protects players or people from these injuries better than current options.
Is this product meant to last for a long period of time, or is it only useful once?	That is up to the plausibility of the research. Flexibility within this project is encouraged.	Ideally, this product is able to have multiple uses and resist mid power impacts lasting the span of a few years for sports gear and sportswear. If the research reveals that it is only viable for one-time use, the product infusion will adjust towards high impact protective gear such as helmets instead.

Multiple interpreted needs overlap which helps the team to narrow them down into fundamental needs. These needs are:

1. The product provides improved protection

2. Product is lightweight and non-bulky

3. Compatible with current shoulder pad models

1.3 Functional Decomposition

1.3.1 Introduction

The Functional Decomposition serves as a method to break a project down into its simplest components. These simple components each perform an action that effects the outcome of the project. The purpose of this breakdown is for the team to gain a better understanding of how the product should be developed.

The objective for this project is to create a product that improves the effectiveness of football shoulder pads. To achieve this goal a hierarchy chart and a cross-reference table were created. The hierarchy chart divides the project into two major functions, protect and form which are then broken down into more specific minor functions. These functions were then placed into a cross-reference table to determine the relationship between the major and minor functions.

1.3.2 Data Generation

Data generation started when the team's sponsor Mike Holloway discussed the goals for the project. After discussing in further detail with the advisor, Dr. Christian Hubicki, research was done to clarify the best way to accomplish the goals given by the sponsor. After researching, these goals were interpreted into needs. These needs were further broken down into the "what" the project will accomplish. This "what" are the major functions and minor functions.

1.3.3 Hierarchy Chart

A hierarchy chart was created to present the breakdown of tasks into systems and functions. There are two systems that we have identified: protect and form. These systems are major functions that are necessary to create a successful design. Minor functions branch from each system in the figure below.

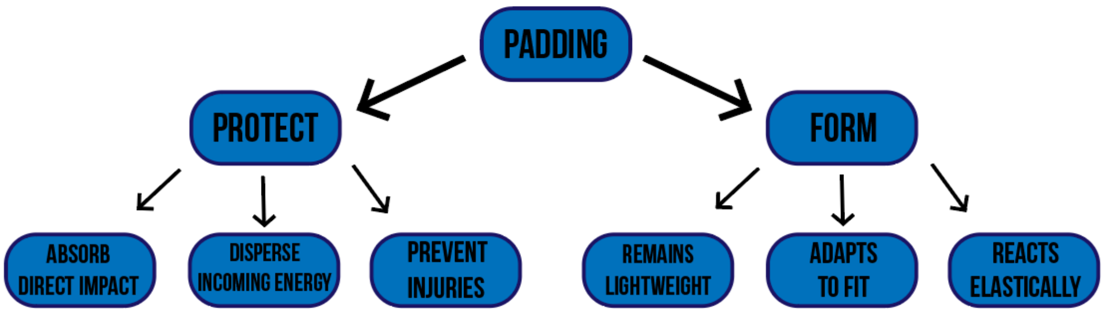


Figure 1. Functional Decomposition Hierarchy Chart

1.3.4 Actions and Outcome

Identifying the minor functions relies on the simplification of the actions that occur to reduce the effects of a single physical impact our outside force. Form is related to the physical nature of the infused product and a reaction from outside forces. The sub systems that stem from this function goes in depth into the forming nature. This product remains lightweight; thus, it does not gain any extra loads overtime such as soaking up sweat. The ability 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. Another sub system is reacting elastically. The elastic nature is necessary for the product to avoid destruction when facing a strong force, allowing the product to be reused. The impact physically alters the shape of the product, described within the form sub-functions, but the product alters the impact for protection through energy transference.

Protect is a function the product does for the user when interacting with its surroundings. The minor function that interacts with the impact is the absorbing of energy. Absorbing the energy within the protective product reduces the amount of energy that the user absorbs, also described as shock-absorption. Another sub system is the dispersion of energy which is concurrent with the absorption of energy. Utilizing the nature of energy dispersion allows the product to guide the spread of energy in a controlled way. The methods of elastic reaction, shock-absorption, and energy dispersion differ from an energy cost barrier method that is used on car windshields. Preventing injuries is a minor function branching from the protect function. The project nature requires the user to clash with a dangerous force rather than avoiding the impact all together, injury prevention for this product focuses on the reduction of injury severity.

1.3.5 Cross Reference Table

The cross-reference table shown in Table 2 shows the main function in the top column, while the minor functions are displayed in each row. The main functions are linked with their minor function with an X in the row. This cross-reference table allows us to compare and/or combine minor functions with the major functions to see if there is overlap.

Table 2. Cross Reference Table

	Protect	Form
Absorb Direct Impact	X	X
Maintain Shape	X	
Remains Lightweight		X
Adapts to Fit	X	X

1.3.6 Connection to Systems

The systems of this project are divided into two categories, Protect and Form, the primary functions the product will serve. The systems are then further divided into minor functions. The function-subsystem relationships were defined in the cross-reference table. As seen above four of the minor functions fall underneath the protect system while five minor functions fall underneath form. This indicates that the form system may take higher priority as it contains more function relationships. However, one of the project's key goals is to reduce the likelihood of injuries and the prevent injuries function only falls underneath the protect system. To achieve the project's objective the product must be able to reduce the likelihood of injury. Therefore, the success of the project is directly proportional to how well the product prevents an injury from occurring.

1.3.7 Smart Integration

Absorb direct impact can be placed into the protect and the form function. This is because direct impact will change the form of the material through some blunt force. Since the force will continue to travel through the material, it must be limited to prevent injury. Maintain Shape was placed in to the protect category. If the material of our product is unable to maintain its structural integrity it will break down after experiencing multiple forces, leaving the material with diminished force reduction capabilities. The primary measure of protecting the player for the sake of this project is reducing the force of impact therefore, “Maintain Shape” belongs in the protect system. Remains Lightweight was designated specifically to the form category. The weight of our product will have more influence on how adept the player will be able to move while using our product. So, this function will be primarily concerned with form rather than protect. The adapts to fit function was designated into both the protect and form systems. The fit of the shoulder pads falls underneath the form category however, keeping the shoulder pads in place can also fall under protect. If the motion of the shoulder pads is reduced the pads will be in a better position to take a potential second hit.

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 blue, are determined to be the critical functions of the project.

Table 3. Targets and Metrics Table

Function	Metric	Target
Absorb Direct Impact	Force (pound-force)	Reduce Force by 75%
Maintain Shape	Volume (in^3)	No reduction in volume
Remains Lightweight	Weight (pounds)	Less than 5 pounds
Adapts to Fit	Motion (percent)	30% reduction of movement during contact

1.4.1 Derivation of Functions Targets and Metrics

Remains Lightweight – Weight (pounds)

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 pounds – 6 pounds. 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.

Reacts Elastically – Volume (in^3)

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 padding's 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.

1.4.2 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 two critical functions determined are "Absorb Direct Impact" and "Adapts to Fit." The critical metrics for each function accordingly are force and percent motion reduction.

Absorb Direct Impact – Force (pound-force)

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 force.

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 for absorb direct impact is a 75% reduction in force.

Adapts to Fit – Motion (percent)

The adapts to fit function is concerned with how effective our product is at improving the fit of the shoulder pads. The team decided that the best way to measure this function was to determine how well our product can reduce the motion of the shoulder pads after taking a hit. Motion in this case is defined as the distance the shoulder pads "slip" after impact. The target is to reduce motion by 30% compared to the shoulder pads without the aid of our product. This target was chosen because of our competition's percent motion reduction that team determined experimentally.

1.4.2 Methods of Validation and Discussion of Measurements

Compression Test

This test was the first materials test to determine which materials would be best suited for the product. The purpose of the compression test is to analyze how well each foam retains its volume after repeated force loads. This coincides with the "Maintains Shape" function, as the metric will be volume and the target is to have no reduction in volume. The apparatus used for this test was a weight-pulley system that can typically be found in a gym. The weight was dropped on to the test sample for 10 seconds and then lifted off for 30 seconds. This process was repeated 5 times for each foam sample. The height of the foam sample was recorded before and after each compression and the data was then interpreted to calculate the mean percentage height reduction.

Pendulum Impact Test

The pendulum impact test was used to test the materials prior to product assembly as well as the final product itself. The purpose of this test was to determine the force reduction capabilities of the test subjects. A pendulum mechanism was built by the team specifically for this test and is pictured below.

Figure 2. Pendulum Swing

A pendulum was chosen as it creates a replicable set of conditions and the team felt it was necessary to perform force reduction calculations on the final product. An oscilloscope was used to take voltage readings from a force sensor.

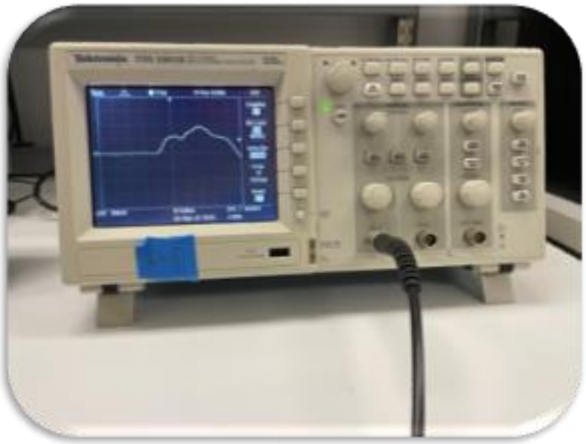


Figure 3. Oscilloscope

The peak voltage recorded for each trial was used in the force reduction calculations for that test subject. The oscilloscope was calibrated, and these voltage values were converted into pound-force.

Fit Optimization – Shoulder Mold

The next set of tests are concerned with identifying where there are gaps between the shoulder pad and the player's shoulder. The purpose of the shoulder mold is to have a mold that shows these gaps by putting molding clay on the player's shoulders and then placing the shoulder pads on top. Ideally, the molding clay would conform to the open spaces between the pad and shoulder and any excess clay would be pushed out.

Fit Optimization – Contact Points

The contact points test was the second test done to identify the gaps between the shoulder and shoulder pad. The purpose of this test was to see exactly where the shoulder pad makes contact with the player's body. This was done by applying a coat of white paint to the underside of the shoulder pads and place them on a team member wearing a black shirt. Thus, there would be a paint outline exactly where the pads and the shoulder make contact.

Figure 4. Paint Test

<u>*Slip Test*</u>

The first to validate with our undershirt was that it reduces the motion of the shoulder pads during and impact. To do this the pendulum from the foam impact test was used; however, for this test the hammer was raised to parallel to the ground a released. A mannequin wearing the shoulder pads was in place a struck by the hammer. The impact was then filmed in slow motion with a checkered reference frame to find the displacement. This was done with no undershirt as a control, a competitor undershirt, and our secure fit undershirt.

Figure 5. Slip Test

Thermal Testing

The next validation that was done was to prove that our shirt did not cause the user to overheat. For this a thermal camera was used to capture the temperature at the center of the chest of a user before and after the user ran 2 laps around the FAMU-FSU College of Engineering. For this test a normal t shirt, a competitor undershirt, and our secure fir undershirt was tested.

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 concept generation tools to each come up with more ideas. Those tools being biomimicry, anti-problem, crapshoot, morphological chart, battle of perspective, and brainstorming. From using these tools 100 concepts were generated (can be seen in Appendix F).

1.5.2 Concept Generation Tools

Biomimicry

Biomimicry is the design and production of materials, structures, and systems that are modeled on biological entities and processes. It was used for some of the concepts. The majority of these concepts were inspired by the skins and shells of animals and plants. Animals and plants use a variety of ways to protect themselves through their skins and shells. Some obvious examples are an armadillo's shell and the skin around oranges and grapefruit. These skins and shell were researched to determine how their natural protection could be useful for shoulder pads.

Anti-Problem

One of the tools used was the anti-problem where the team asks themselves to solve the opposite problem and the solutions to and attributes that are causing what is happening. From this tool some concepts such as removing shoulder pads altogether so that the players will not hit as hard. This was also suggested by Dr. McConomy early in the semester. Another concept that came from anti-problem was adding pressure points on the inside of the shoulder pads in places on the body where injury risk is low so that the energy is distributed away from high-risk areas.

Crapshoot

Crapshoot tool is a used to generate concepts randomly. This had a very unpredictable outcome. The idea is to select words or phrases that can be selected at random and rearranged to come up with concepts. The 6 words selected to be used are undershirt, hard plastic, auxetic foam, rib padding, shoulder shocks, density foam. With a roll of the dice, the concepts were then chosen and added to the concept generation table.

Morphological chart

The measure of how successful the selected design is will depend on successfully achieving the maximum amount of the project's key goals. The morphological chart identifies four solution subsystems: Padding Material, Shell Material, Improve Stability, Improve Mobility. Each of these subsystems identifies a component of the design that will contribute to the achievement of the project's key goals. The rows of the chart were filled with potential choices for each subsystem. A concept is generated by combining one component from each subsystem.

Table 4: Morphological Chart

Morphological Chart			
Padding Material	**Shell Material**	**Increase Stability**	**Increase Mobility**
Memory Foam (Current Material)	Plastic (Current Material)	Compression sleeve underneath shoulder	Reduce Shell Volume
Air Pocket Technology	Kevlar	Compression shirt with rib and sternum padding	Reduce Padding Volume
Negative Poisson Ratio material		Casting structure custom fitted to each player	

Battle of Perspectives

This tool is used to make decisions with the complex global system in a world of uncertainty. This tool was able to help determine a few concepts with the thought in mind that the world of football players and football as a sport will adapt in a way that will remain uncertain to us.

Brainstorming

After multiple meetings and discussions of our customer needs, functional decomposition, and targets and metrics the group started brainstorming ideas of our concepts. These ideas were across the board, which was helpful and unhelpful at the same time. These ideas ranged from Orthocast material to water pockets within padding. This gives us many options when looking into concept selection.

1.5.3 5 Medium Fidelity Concepts

<u>Replace interior padding with non-Newtonian fluid</u>

Non-Newtonian fluids are a type of fluid where their viscosity changes based the amount of stress that the fluid is under. Fit was a constant problem that was brought up in the surveys that was given out to athletic trainers, so in replacing the existing padding with a type of non-Newtonian fluid, the padding would always conform to that specific athlete. It would also provide good protection to the athlete since when it is under stress the fluid becomes more viscous and can prevent the user from feeling the impact.

Figure 6: Non-Newtonian Fluid Taking Impact from Punch

<u>Plate insert centered within padding</u>

Nike’s Vaporfly shoe utilizes a carbon fiber plate centered within an aerospace insulation padding design to aid in stability, stiffness, and propulsions of each enacting force. The plate’s spring is not factored within this design, rather the rigidity aids in proper posture and form. Gathering inspiration from Nike’s shoe design, the additional plate within football shoulder pads has the capability to assist in promoting ideal form for football play along with load reduction.

Further research is required to find the ideal material for the embedded plate best used for football shoulder pads: carbon fiber, metal, etc.

Non-Newtonian fluid padded compression undershirt

This idea would go in tandem with existing shoulder pads. The non-Newtonian fluid discussed previously would be added to a compression under shirt that would be worn underneath the shoulder pads making the fit of the shoulder pads better while still providing more protection to the athlete. This will allow for the protection already given by the shoulder pad while giving the comfort and better fit that can be attained from having a compression shirt with non-Newtonian fluid. Figure 5 below shows an example of a compression under shirt with padding. This design will replace the padding in the shoulder, chest, and rib area with the foam used with a non-Newtonian fluid.

Figure 7: Padded Compression Under Shirt

Replace interior padding with Cellular Urethane

Most padding used within football shoulder pads are constructed with closed cells. A closed cell structure is trapped air cells that aid in rebound when pressure is applied. While closed cell structures are sturdier and more durable, the air pockets can dissipate air over time, negating the beneficial air cell property. Open cell structures have a high expansion rate, high elasticity, and allow air to be dissipated along with an air refilling function. Open cell structures are best exemplified with the squeezable portion of a pipette or dropper. The drawback of open celled structured materials is the increase likeliness of breakage or deformity after the elastic region is passed. Most foams utilized are open celled, and cellular urethane is known best for the shock absorption property.

Figure 8: Example of Open Cell Structure Foam

<u>Inflatable undershirt to compensate for ill-fitting shoulder pads</u>

Rather than having air pockets or air cells within the padding material, an undershirt can consist of inflatable air patches that can aid in securing football shoulder pads for an ideal fit. The inflatable air patches are capable of deflating for storage and inflating for fit use. This design is highly reliant on the strength and elasticity of the material that will encase the air patches because any failure from an extreme impact could pop the air patches and result in injury. Due to this, the undershirt is required to have a failsafe of either air dispersion or an increased inflation when dealing with an impact.

Figure 9: Football Helmet with Inflatable Padding

1.5.4 3 High Fidelity Concepts

<u>*Replace interior padding with negative Poisson ratio material*</u>

Materials with a negative Poisson ratio expands laterally when stretched. So when this material is presented with an impact it will expand, allowing for the energy from the hit to be dispersed over a larger area therefore decreasing the pressure felt by the athlete. Auxetic Foam is example of this type of material that was developed at the High-Performance Materials Institute at FSU by Dr. Chanchung Zeng. If this material is decided to be used Dr. Zeng will be sought after as an advisor to help with research with this specific type of material.

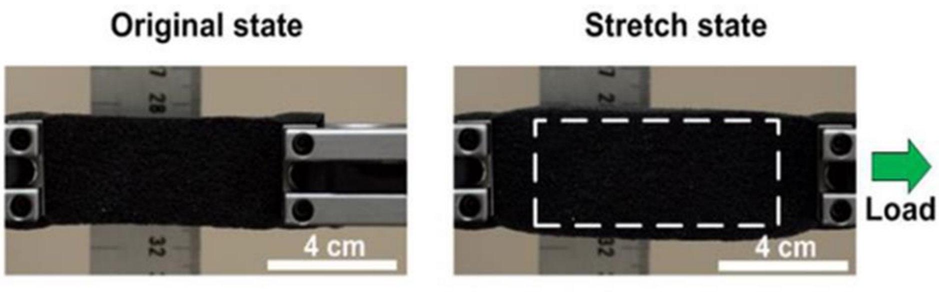


Figure 10: Auxetic Foam Being Stretched

Undershirt to improve fit of shoulder pads

A major problem that the team identified from the interviews with athletic trainers in the Jacksonville area was the improper fit of shoulder pads. The purpose of this undershirt would be to improve the fit of shoulder pads using a sort of loose foam that will conform to the gaps of air between the shoulder pads and the player's shoulders. This would in turn provide a more optimal fit and better protection as more of the shoulder is making contact with padding.

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	Total
1. Aborb Direct Impact	----------	1	1	1	3
2. Remains lightweight	0	----------	1	1	2
3. Maintain Shape	0	0	----------	0	0
4. Adapts To Fit	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
Customer Requirements	Importance Weight Factor	Absorb Direct Impact	Remains Lightweight	Maintains Shape	Adapts To Fit
Absorb Direct Impact	3	9	9	3	0
Remains Lightweight	2	0	0	3	9
Maintains Shape	0	3	1	1	0
Adapts To Fit	1	1	0	3	0
Raw Score	6	28	27	18	18
Relative Weight %		30.77%	29.67%	19.78%	19.78%
Rank Order		1	2	3	3

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 30.77% relative weight with Remains Lightweight being closely behind at 29.67% 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 Direct Impact	Datum	+	+	+	+	+
Maintain Shape		+	+	+	+	+
Remain Light weight		-	-	-	-	S
Adapts to Fit		+	-	S	+	S
# of pluses		3	2	2	3	2
# of minuses		1	2	1	1	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 Design foam padded undershirt that improves fit and protection	Concept 8 Replace interior padding with negative Poisson ratio material
Absorb Direct Impact	Datum	-	+	+
Maintain Shape		-	+	+
Remain Light weight		-	+	+
Adapts to Fit		+	-	+
# of pluses		1	3	4
# 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 Design foam padded undershirt that improves fit and protection
Absorb Direct Impact	Datum	-	+
Maintain Shape		-	S
Remain Light weight		-	+
Adapts to Fit		+	+
# of pluses		2	3
# of minuses		3	0

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				
	Aborb Direct Impact	Remains lightweight	Maintain Shape	Adapts To Fit
Aborb Direct Impact	1.00	7.00	5.00	7.00
Remains lightweight	0.14	1.00	1.00	3.00
Maintain Shape	0.20	1.00	1.00	0.33
Adapts To Fit	0.14	0.33	3.00	1.00
Sum	1.49	9.33	10.00	11.33

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					
	Aborb Direct Impact	Remains lightweight	Maintain Shape	Adapts To Fit	Critical Weight
Aborb Direct Impact	0.673	0.750	0.500	0.618	0.635
Remains lightweight	0.096	0.107	0.100	0.265	0.142
Maintain Shape	0.135	0.107	0.100	0.029	0.093
Adapts To Fit	0.096	0.036	0.300	0.088	0.130
Sum	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 0.635 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
3.00	0.635	4.73
0.72	0.142	5.04
0.41	0.093	4.37
0.00	0.130	0.00

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 7 Design foam padded undershirt that improves fit and protection
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 7 Design foam padded undershirt that improves fit and protection	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 7 Design foam padded undershirt that improves fit and protection
Absorb Direct Impact	0.15	0.07	0.78
Maintain Shape	0.14	0.57	0.29
Remain Light weight	0.33	0.33	0.33
Adapts to Fit	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 7 Design foam padded undershirt that improves fit and protection
Concept 1 Replace interior padding with non-Newtonian fluid	10.681	0.329	
Concept 7 Design foam padded undershirt that improves fit and protection	14.502	0.447	

The final concept was determined to be replace interior padding with negative Poisson's ratio. From the research we have conducted, the negative Poisson's ratio will allow for great energy distribution since the material is subject to expanding when in compression. A type of negative Poisson's ratio material is Auxetic foam. It was discovered here at the FAMU-FSU College of engineering. However, after the team met with its creator, Dr. Xeng we were informed that we would not be able to pursue a project involving auxetic foam. The team then ran through the analytical hierarchy process once more and determined that Concept 7, Design foam padded undershirt that improves fit and protection would be the best option.

1.8 Spring Project Plan

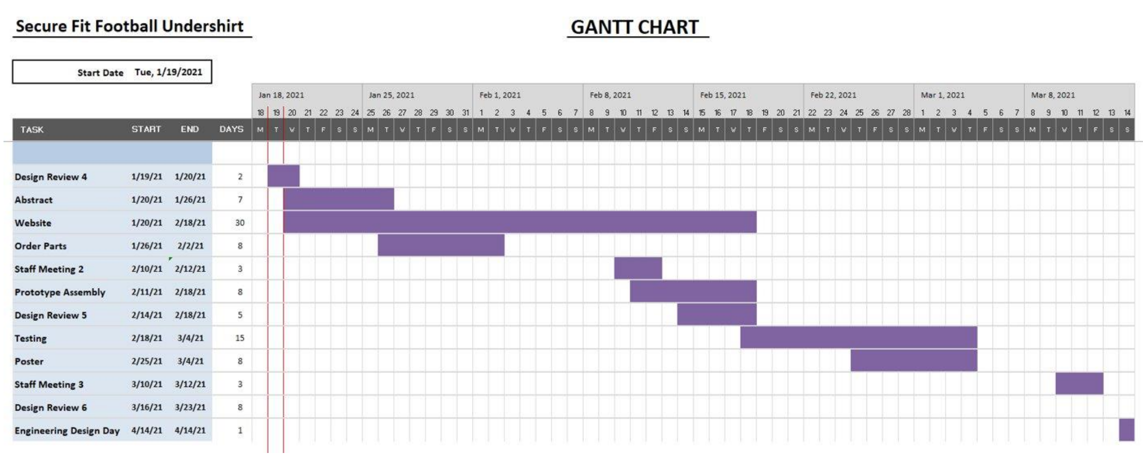


Figure 11. Spring Plan Gantt Chart

Chapter Two: EML 4552

2.1 Restated Project Definition and Scope

Secure Fit Football Undershirt's members main objective is to reduce the injuries of football players through the improvement of shoulder pads. As part of the mission, we will work together with our sponsor and advisor to research and analyze data to develop a product that will reduce injuries of football players.

Project Plan.

The focus of this project is to reduce possible football injuries of the upper torso, specifically on shoulders and neck area, for growing adolescence. The preliminary plans before research were to improve shoulder pads without completely recreating the common shoulder pad design. Due to some complications and lack of standardization of football shoulder pads, the plan shifted to improving quality of life in football. Realistically, it is not ideal to require institutions and companies to restock with new football shoulder pads due to lack of football funding within middle and high schools. By improving football player's quality of life with a cheaper alternative, the product becomes more budget friendly without altering the sport overall.

Build Plan.

The project proceeded with alternate suggestions to amplify the effectiveness of football shoulder pads. After conversing with football player experts, the focus geared more towards improving fit, since adolescent football players are constantly growing. The final concept concluded to creating an undershirt specifically geared for shoulder pads and allow adjustability. The main concerns to improve quality of life are protecting the collar bone, the side of the shoulders, and preventing pinching on the neck without affecting a user's range of motion.

2.2 Results

The results of the plan were to validate our design with self-standardized impact recreations. The properties of foam and the overall design were able to be validated, but force sensors prevented the attempts to create outside impact forces applied to a person. The final product was able to pass the subjective tests of comfort and fit. A temperature test to demonstrate overheating also showed that the final product could be worn without impacting the user's health.

<u>Compression Test</u>

The results of the compression test for each individual foam are listed in the table below.

Table 17: Mean Percent Height Reduction

Mean Percent Height Reduction	
Polyurethane Foam	**0.0288 %**
Polyimide Foam	**0.0400 %**
Open-Cell Polyurethane Foam	**0.0745 %**
Organic Latex Shredded Foam	**0.0867 %**
Gel Shredded Memory Foam	**-0.0207 %**

The gel shredded memory foam had the lowest mean percent height reduction at -0.0207%. Meaning that the gel shredded memory foam increased in height after repeated force application. The team believes that since this type of foam is shredded that some of the foam was displaced upwards inside of the pocket containing the foam when it returned to a relaxed state. This result showed that the gel shredded memory foam would be the best at enabling the "adapts to fit" function. It saw no reduction in volume therefore, it met our target.

Pendulum Impact Test

The results of the pendulum impact test for material samples are listed in the table below.

Table 18: Mean Percent Force Reduction

Mean Percent Force Reduction	
Polyurethane Foam	40.3954 %
Polyimide Foam	28.3345 %
Open-Cell Polyurethane Foam	20.8708%
Organic Latex Shredded Foam	27.7816 %
Gel Shredded Memory Foam	28.8874 %

The polyurethane foam ended up performing the best with a 40.3954 percent force reduction. The gel shredded memory foam barely edged out the polymide foam for second place with a 28.8874 percent force reduction. Since absorbs direct impact was determined to a the function with highest relative weight it is important to consider the foam with the highest force reduction capabilities. Since polyurethane foam greatly exceeded all of the other foams in this category the team felt it must be included in the final foam pocket.

The results of the pendulum impact test for the composite foam pad compared to the competition shirt are listed in the table below. Taking the results of the two previous tests into account the group decided to pursue a composite foam mix for the padding of the undershirt. The following test was done to validate the composite foam pad.

Table 19: Mean Percent Force Reduction 2

Mean Percent Force Reduction	
Composite Foam Pad	**52.3151 %**
Gel Shredded Memory Foam Pad	**21.9074 %**
Nike Competition Padding	**27.4361 %**

The composite foam pad had the highest mean percent force reduction at 52.2891 percent. The Nike competition shirt had a mean percent force reduction of 27.6143 percent. The composite foam pad significantly outperformed the Nike padding as well as the pad with only gel shredded memory foam.

Slip Test

The average displacement of the shoulder pads with no undershirt is 5.24in. Next the competitor undershirt was tested, and the average displacement is 3.84in, which is 26.7% reduction of movement. This number was used to find our target for the reduction of movement that was desired of our undershirt (30%). The secure fit undershirt performed the best with a displacement average of 2.86in for a movement reduction of 45%. This exceeded our goal of 30% as previously stated.

Thermal Test

Before running the temperature of the user's chest was 77.90*F. Next a normal t shirt was used and after running the temperature was 82.76*F. The competition undershirt was next and the temperature after was found to be 86.90*F. Finally, the secure fit undershirt was tested, and the final temperature was 89.24*F. Here our undershirt performed the worst out of all options. This could be something we could look into in the future development of the shirt, this could also be due to our undershirt being tested last and the user not given enough time to return to equilibrium temperature before running the next test as the temperature increase after every trial.

2.3 Discussion

The compression test showed results show us the gel shredded memory foam had a negative height reduction. This can mean a few things, but most likely since it is loose foam it shifted into a higher position after compression. The next best foam was polyurethane foam. For the force reduction test the composite foam (polyurethane foam and gel shredded memory foam) provided significant reduction of force relative to the others. This was able to help conclude the composite foam pad would be the best for the padding in the shirt. The slip test also helped validate the composite padding in the shirt was best for reducing the movement of the shoulder pads after contact. The downside of the composite padding was the heat the user would obtain during activity. It produced 3*F more than the competitive shirt, and 6*F more than a normal t shirt. This will be added to future work. This project was a learning experience. It taught us that we should not assume that any information we receive is accurate and the best thing to do is double check information you receive no matter what the source of the information is. We also learned that when creating a target or metric it is important for that metric to be able to be evaluated. For example, comfort and injuries are values that cannot be put into quantifiable data.

2.4 Conclusions

The padding on the shoulder and neck is made of shredded gel memory foam, polyurethane foam, all wrapped in ultra-weather resistant nylon fabric sheet. The composite foam padding reduced impact by 52.29% however, further testing with more advanced instruments is necessary to obtain more accurate results. Our secure fit football undershirt protects the player's neck from impact. It also decreases the motion of shoulder pads. This is to help protect players against consecutive hits and provide more comfort.

2.5 Future Work

For future work we would like to have our undershirt tested throughout a season with players wearing the shirt during practice and games. This would give us great feedback on the comfort and durability of the shirt as well as if the players can tell a difference on the amount the shoulder pads move and if they fell that they are more protected. We would also like to test the undershirt force readings with the shoulder pads over them to give us a better idea of how much more force they reduce when compared to the shoulder pads alone. Durability tests are also required for future work to ensure the product could withstand at least one football season.

Production of undershirt would replace the super glue adhesive with a cheaper alternative that would still perform the same. Modifications of the design, such as reinforced fabric seams, would allow an adhesive that is less durable than superglue. Production would also emphasize on machine sown products rather than hand sown. While hand sown prototypes allow for rapid assembly and disassembly, an increase in quality and durability, along with a decrease in construction time, allow a more efficient production.

Air pocket technology, inspired by connected bubble wrap channels, was explored as a future concept. Due to the difficulties of air pocket sealing, risk of injury, and overall production, the concept has been assigned for future work. A small scaled air pocket prototype was created to ensure the possibility of the concept, which would replace the foam padding inserts with air pocket bladders and channels.

2.6 References

Crew, B. (n.d.). Physicists Might Have Just Solved The Mystery of Non-Newtonian Fluids. Retrieved November 06, 2020, from https://www.sciencealert.com/physicists-might-have-just-solved-the-mystery-of-non-newtonian-fluids

Elliott, P. W., PhD. (217). We're Working with Padding Manufacturers to Develop Safer [i]Systems and Differentiate Products. Retrieved October 30, 2020, from http://asetservices.com/wp-content/uploads/2018/08/mat-pit-pad-introducton.pdf

Foam Products Company offers a variety of Open Cell and Closed Cell Foams that are made in the U.S.A. (n.d.). Retrieved November 06, 2020, from https://www.allfoam.com/index.html

NASA Technical Reports Server (NTRS). (n.d.). Retrieved October 30, 2020, from https://ntrs.nasa.gov/citations/20160006281

Schutt Air XP Pro Q10 Football Helmet. (n.d.). Retrieved November 06, 2020, from https://www.schuttsports.com/air-xp-pro-q10-football-helmet.html

Vinoski, J. (2019, May 29). Guarding Against Concussions: Startup Auxadyne Makes Ultra-Cushioning Foam For Helmets, Prosthetics. Retrieved November 06, 2020, from https://www.forbes.com/sites/jimvinoski/2019/05/24/auxadynes-foam-padding-might-just-save-your-head-and-other-parts-too/?sh=2f8c15853969

Appendices

Appendix A: Code of Conduct

Senior Design Group 519

FAMU-FSU College of Engineering

EML 4551C: Senior Design I

Dr. Shayne McConomy

September 11, 2020

Mission Statement

Cutting Edge Football Shoulder Pads is committed to reducing the injuries in football players through the improvement of shoulder pads. We will work together with our sponsor and advisor in a professional manner to give athletes the confidence to safely make the tackle.

Team Roles

Each member is delegated a specific role based on experience and skill sets. All duties are assigned by preference, majority rule, and availability via text message or Zoom meeting.The roles are described as follows:

Morgan Sefcik [mas17j@my.fsu.edu] Project Manager

Responsible for overseeing the successful completion of the project. Manage the project scope, schedule, finance, risk, quality and resources. Work in a wide variety of fields, and communicate information effectively between team members, sponsors, and advisers. Ensures the project stays on track and within budget.

Paul Cunningham [pc18d@my.fsu.edu] Design and Materials Engineer

Responsible for design and project research. Will assist with prototyping, testing, and assembly for the product as well as assist in documenting progress.

Vivi Huynh [vh16@my.fsu.edu] Design and Manufacturing Engineer

Responsible for submission assistance, CAD assistance, leading prototype manufacturing, advising modifications for iterations, and assembly. Assistance in documentation.

Sawyer O'Bryan [sao18f@my.fsu.edu] Design and Materials Engineer

Responsible for design and prototyping of the project. Will also assist in testing, research, documentation of assignments.

Nicholas Palestrini [nap16d@my.fsu.edu] Product Development and Data Engineer

Responsible for schedule planning, resource forecasting, managing data and documentation. Will assist with CAD, product assembly and product testing.

Communication

The primary methods of communication will be through Zoom and Basecamp. Virtual meetings will be held on Zoom and a breakdowns of goals and ongoing tasks will be vocally reviewed before the end of each meeting. Zoom meetings will be held on Fridays which will be a mandatory meeting date with advisor. In case of a team member feeling sick or a positive Covid-19 test, that member will not be permitted at any regular meeting and instead must attend the meeting over zoom the day after to review the progress completed from prior meeting. Basecamp will be used for all official team documents and text communication. Text messages will also be an unofficial way for members to communicate and responses are expected within 12 hours of a message. All members must be available for contact via text at least an hour prior to submission of an assignment in case of assignment or submission emergencies. A lack of response from a group member will be considered as, in agreement, with the majority, but submission of any assignment will not be turned in early unless every group member responds. A lack of response will delay any submissions until five minutes before due time and date. If the group is unable to contact a member with any form of communication within 36 hours on a weekday, official emails will be sent to TAs expressing concern of that group member's health and safety: this is under the pretense that the member did not mention plans prior.

Dress Code

Members will require business casual attire (Button down shirt) for any days of presentations and meeting with -professional interactions. Group meetings, sponsor, and advisor meetings allow casual attire, as expressed by sponsor and advisor. Masks are required during face to face. Proper personal protective equipment (PPE) must be worn when in the lab or machine shop.

Health Updates

If any member is questioning their overall physical or mental wellness, that member must immediately notify the rest of the team via text message or base camp message board. There will be a baseline assumption that each member is correctly social distancing for at least the duration of the Fall semester and Spring semester. If this is not the case, all members must be notified. All rules set forth by FAMU and FSU to combat COVID-19 must be followed.

Attendance Policy

Every Friday morning there will be a Zoom mandatory meeting but is subject to change upon circumstance. 15 minutes after every class (Tuesday & Thursday), there must be communication through one of the group text channels (, Text Message) to check in on the status. Tentative meetings after class on Tuesday/Thursday. Mondays after 4pm depending on scheduling. Mondays and Wednesdays are optional/ last resort meetups that allow individual work and do not require every member to attend. Meetings with our advisor, Dr. Hubicki will be Fridays at 10:30am. All zoom meetings will be documented via calandar. A text attendance report will also be kept. If a team member cannot attend a mandatory meeting, they must alert the group prior to the meeting. If a member is absent from any meetings or meetups 4 times within 2 weeks, the group will warn that member via email. Any following absence without an excuse will prompt the group to file an official complaint to Dr. McConomy with gathered evidence of unexcused absences.

Workload Policy

Collaboration in all aspects of the projects is expected between group members. No single group member will be left to do all the work alone and other group members are expected to give input and be involved in all aspects of the project. Subdivisions of the group based off personality traits and individual strengths will be formed to work on different aspects of the project.

Submission Policy

Everyone will review the final document and affirm with the project manager 24 hours in advance from the due date. Project manager will submit documents with an assigned “backup submitter” making sure that the document is submitted.

Revision Policy

Potential revisions to the code of conduct must pass a majority vote from all team members. (3/5)

Conflict Resolution

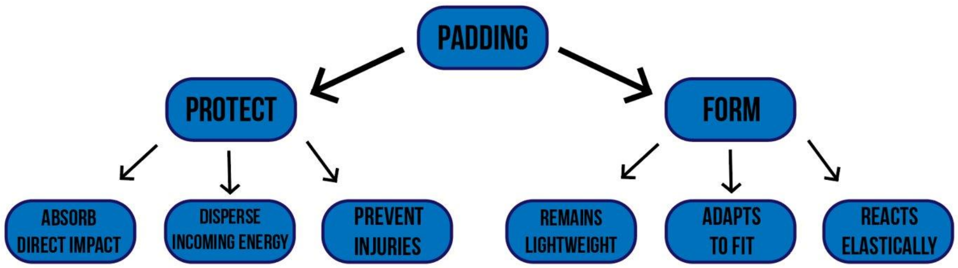
All conflict will be documented and signed by both the project manager and the member(s) involved. Any major decisions will be determined by majority rule. Should majority rule fail to resolve the issue, Dr. McConomy will be notified. Dr. McConomy will have the final say.

Statement of Understanding

By signing this document, members in Senior Design group 519, agree to all of the above and will abide by the code of conduct set for by the group.

Name (Print)	Signature	Date
Paul Cunningham		9/10/20
Vivi Huynh		9/10/20
Sawyer O'Bryan		9/10/20
Nicholas Palestrini		9/10/20
Morgan Sefcik	Morgan Sefcik	9/10/20

Appendix B: Functional Decomposition



Appendix C: Target Catalog

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

(From first semester)

Appendix D: Operation Manual

Operation Manual

Senior Design Team 519
Secure Fit Football Undershirt
Nicholas Palestrini, Paul Cunningham, Sawyer O'Bryan, Morgan Sefcik, Vivi Huynh
FAMU-FSU College of Engineering

Table of Contents

Project Overview

American high school football accounts for nearly 480,000 shoulder injuries per year. Rotator cuff tears, AC (Acromioclavicular) joint injuries and collar bone fractures are some of the more common injuries in football. Mike Holloway has partnered up with our team to develop a product that will help lessen the number of injuries caused by lack of shoulder pad innovation. Hundreds of millions of dollars are invested into helmet technology, while significantly less are spent on advances in shoulder protection. The target consumer of our product will be youth football players. Protecting young players will further their football playing careers and preserve their overall health.

From our market research and interviews with high school athletic trainers, we determined improper fit of football shoulder pads is a major issue. Improper fit is especially an issue for football programs that do not have the budget to purchase pads made to fit the individual player. When there are gaps of space between the shoulder pads and the player's shoulders, the pads will shift in position as the player is moving. This shift out of the proper position exposes vulnerable sections of the shoulder.

Creating an undershirt to improve the fit of the shoulder pads was decided to be the best option for improving the fit while still allowing for maximum comfort. The undershirt will include padding in the shoulder and chest area. It will also have a foam composite collar around the neck to keep the shoulder pads from pinching the neck. This will help spread incoming energy from hits and prevent pinching on the neck. The undershirt will fill the gap between the player and loose-fitting shoulder pads. Properly fitted shoulder pads gives the player more confidence and protection during the football game.

Component/Module Description

This section contains the description for each component of the device. The descriptions consist of relevant information regarding the intended purpose as well as the design and function of each component.

Compression Undershirt:

The compression undershirt serves as the foundation for the product. A compression shirt was chosen because they are optimal for use in athletics as they are known to help reduce muscle fatigue and enhance recovery. The snug fit is ideal as it helps keep the foam pockets from sliding into an undesirable location.

Foam Pockets:

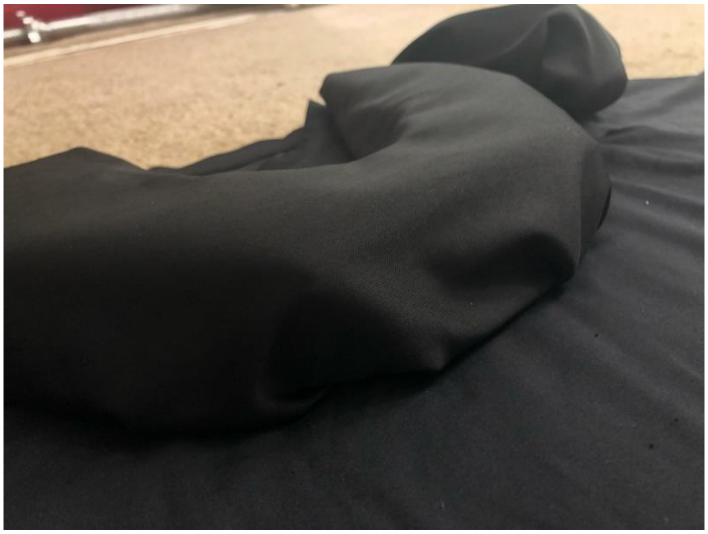
The foam pockets were designed by using a combination of two foams: polyurethane foam and shredded memory foam. The pockets were placed in strategic locations to fill the gaps of air between the shoulder pads and the athlete's shoulders. The purpose of this placement is two-fold. First, to prevent the shoulder pads from moving out of the proper position prior to a tackle. Second, to provide more surface area to dampen the impact force.

Polyurethane Foam - This foam will be used as the bottom layer of the foam pocket.

Shredded Memory Foam - This foam will be used to fill the top layer of the foam pocket.

PVC/Nylon fabric - Material that encases the foam, water-resistant material that protects the foam from fluids such as water or sweat. Adds sturdiness to shape of the foam.

Polyester fabric - Used for outside material of foam pocket, will be sewn on to shirt so that the PVC/Nylon encased foam can be inserted.



Anti-slip fabric - Placed on top of the foam pockets to aid in keeping the shoulder pads in the proper position.

Foam Collar:

The intended purpose of the foam collar is to help protect against "stingers" where the shoulder pads are jammed into the neck region as a result of a tackle. The collar was designed to sit underneath the collar of the shoulder pad and will use a combination of polyurethane and memory foam. The initial idea was to have the collar wrap around the collar of the shoulder pads however, due to time constraints this was not feasible. This design feature could be explored further in future work.

Integration

The compression shirt serves as the base of the product. Pockets are sewn onto the shoulders of the shirt in specific locations where there are gaps of air between the shoulder pads and they athlete's shoulders. These locations were identified from a contact point paint test pictured below.

The pockets are made to house a foam insert that can be removed to wash the shirt. The foam insert contains a composite foam mix of polyurethane foam and shredded memory foam. The polyurethane foam is placed on the bottom of the insert to provide a stable shape to the pocket and provide better protection. This is because the polyurethane has a higher structural integrity and better damping qualities. The shredded memory foam is then placed on top of the polyurethane to fill in the gaps between the shoulder pads and the player's shoulder. A slip resistant fabric was then glued on top of the foam pockets to prevent the shoulder pads from moving out of the proper position prior to or after a tackle.

<u>Operation</u>

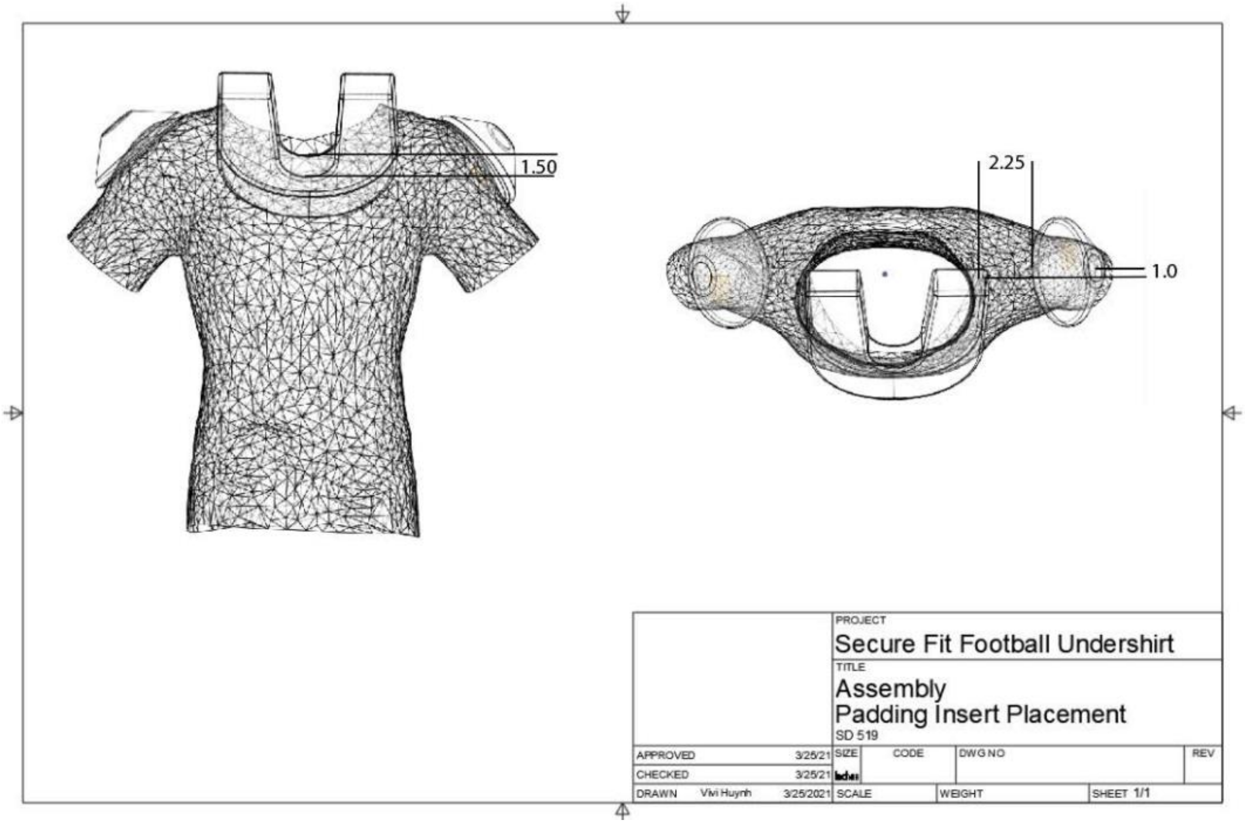
The Pockets with have removable foam inserts located on each shoulder and around the neck.

These inserts are contained in the zipper pockets on the shirt and should be removed when the shirt is washed. These inserts can be easily removed by unzipping the pockets and pulling out the inserts. After washing the shirt place the inserts back into the pockets and close them back with the zipper.

<u>Troubleshooting</u>

In use the sewing may start to come undone. If this becomes a problem, resew the problematic areas.

Appendix E: Engineering Drawings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SD 519
APPROVED 3/26/21
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DRAWN Vivi Huynh 3/25/2021
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SCALE
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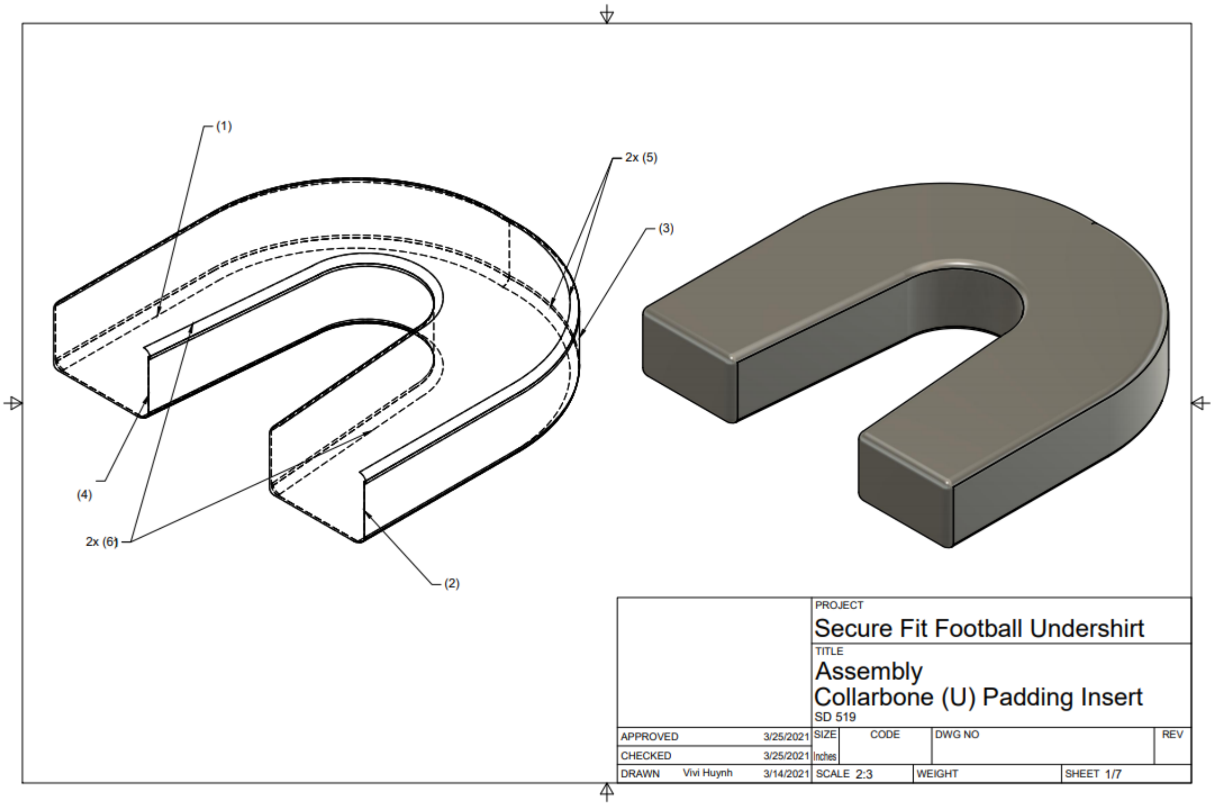
SHEET 1/1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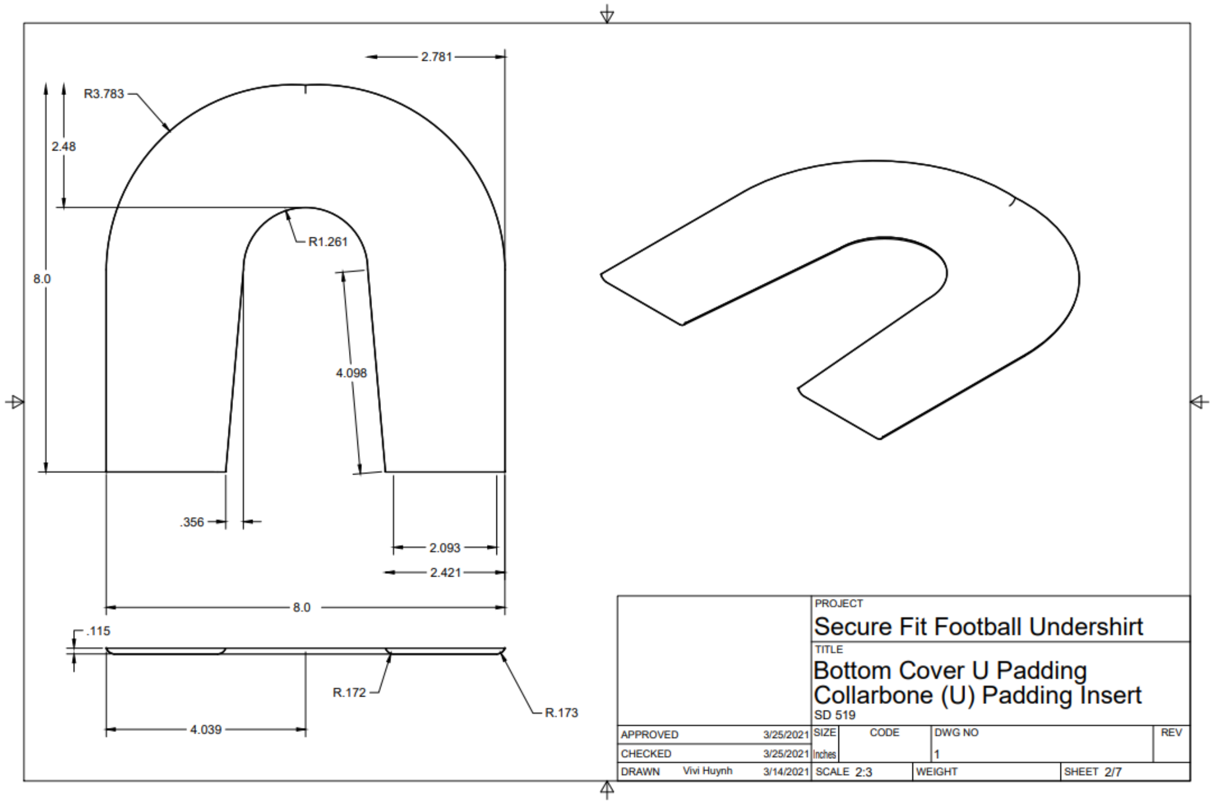
TITLE
Assembly
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO
REV
SCALE 2:3
WEIGHT
SHEET 1/7



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R3.783
2.48
R1.261
8.0
4.098
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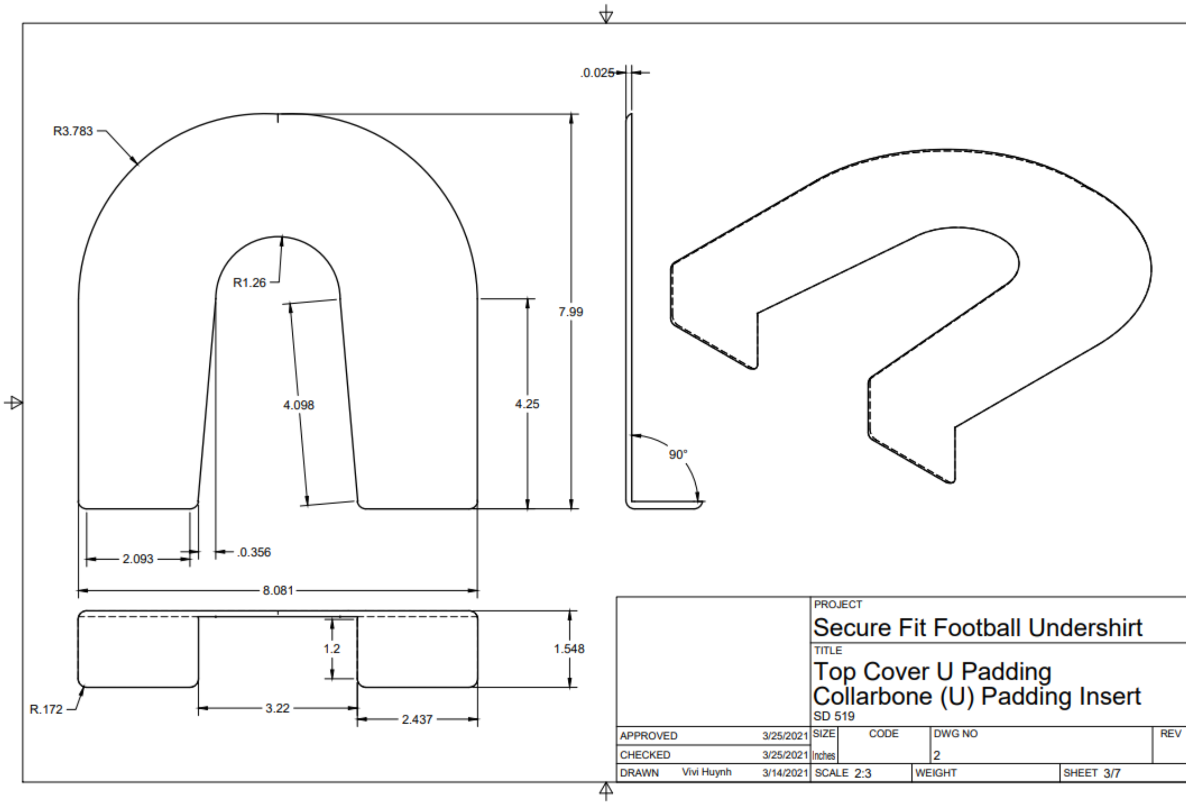
2.093
2.421
8.0
.115
R.172
R.173
4.039
PROJECT
Secure Fit Football Undershirt
TITLE
Bottom Cover U Padding
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO 1
REV
SCALE 2:3
WEIGHT
SHEET 2/7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R1.26
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4.25
7.99
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.0.356
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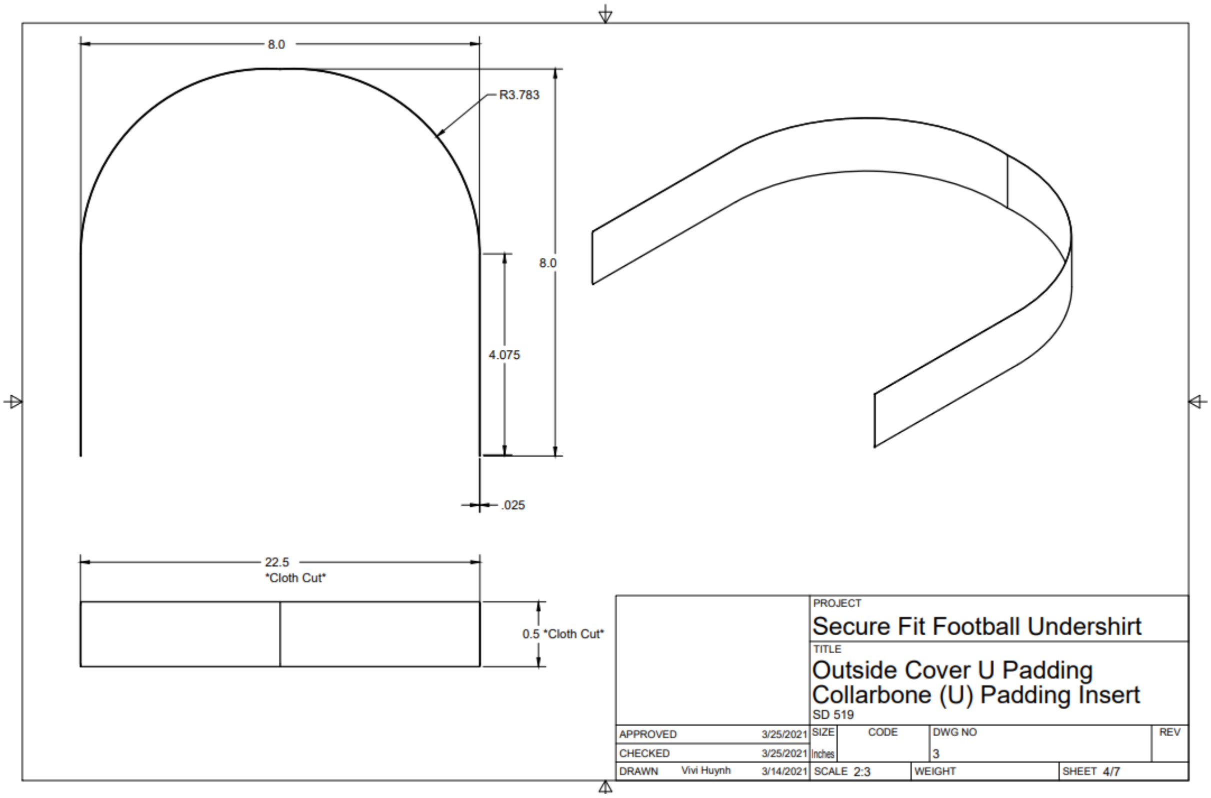
1.548
R.172
3.22
2.437
PROJECT
Secure Fit Football Undershirt
TITLE
Top Cover U Padding
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO 2
REV
SCALE 2:3
WEIGHT
SHEET 3/7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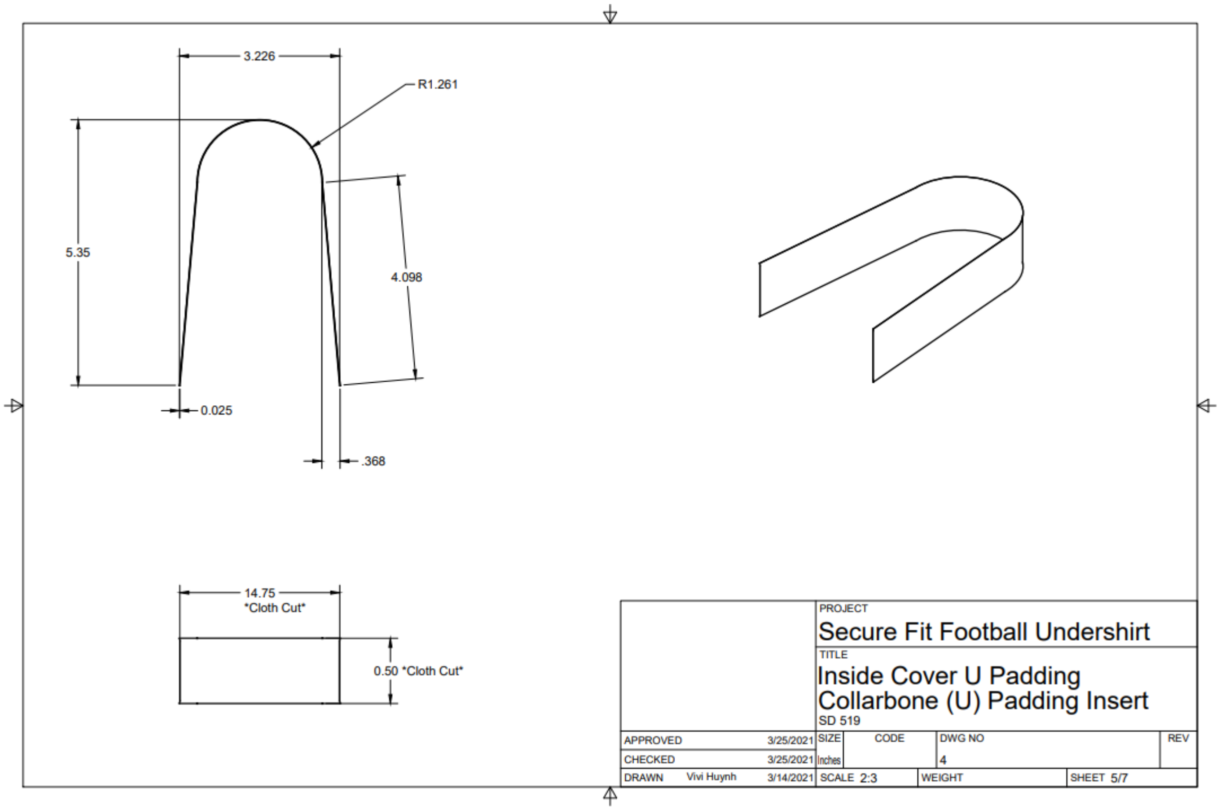
R3.783
8.0
4.075
.025
22.5
Cloth Cut
0.5 *Cloth Cut*
PROJECT
Secure Fit Football Undershirt
TITLE
Outside Cover U Padding
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO 3
REV
SCALE 2:3
WEIGHT
SHEET 4/7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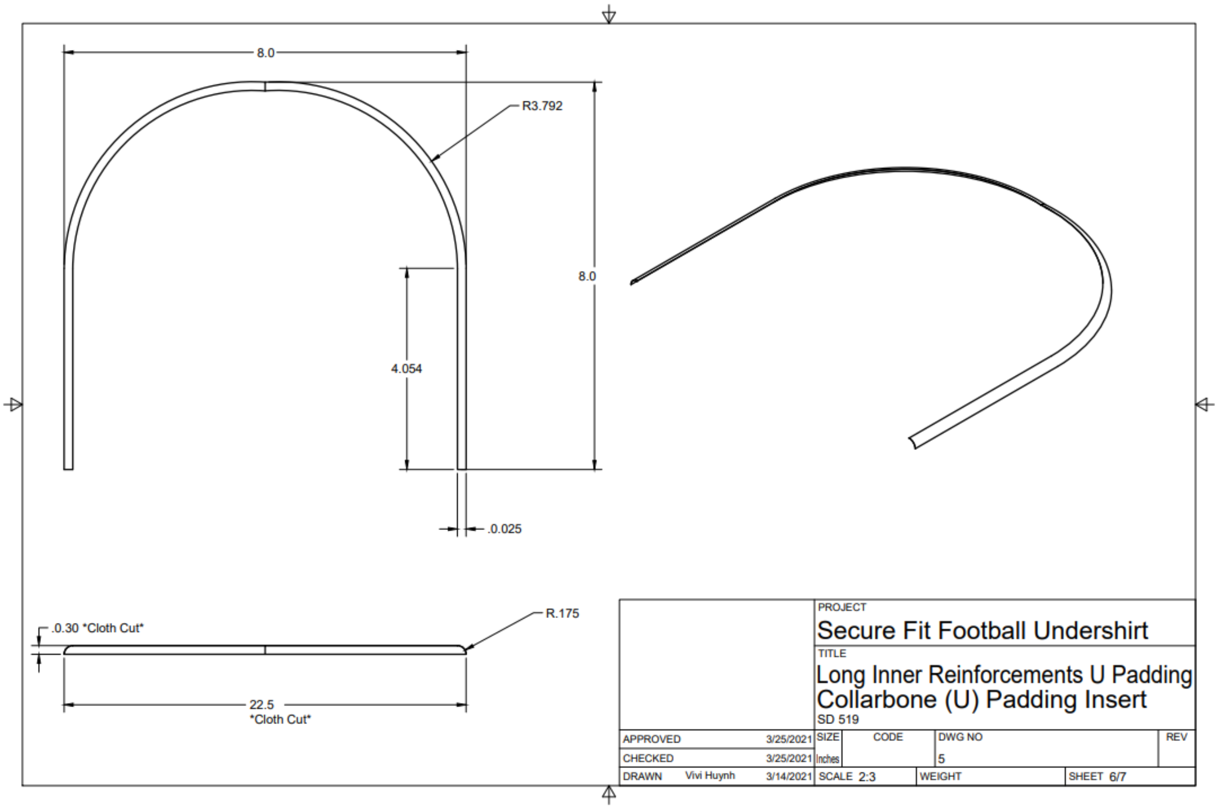
PROJECT
Secure Fit Football Undershirt
TITLE
Inside Cover U Padding
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO 4
REV
SCALE 2:3
WEIGHT
SHEET 5/7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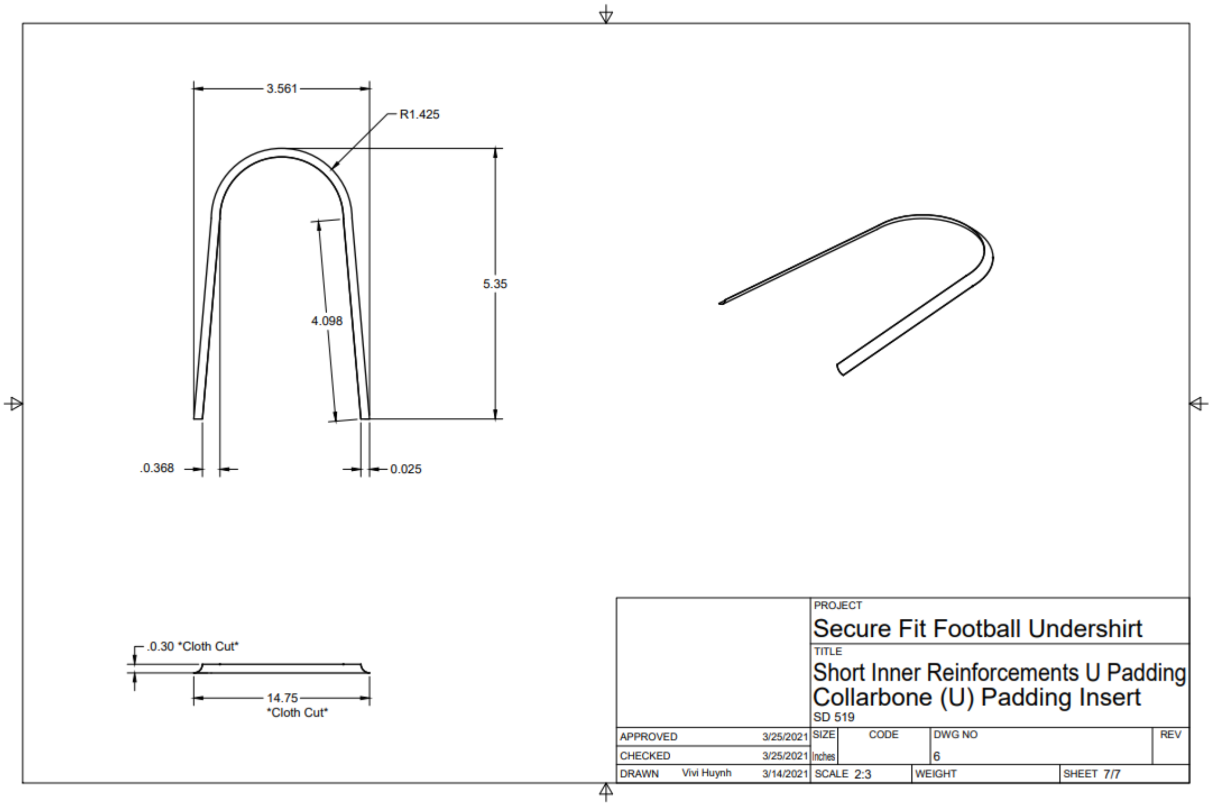
8.0
4.054
.0.025
.0.30 *Cloth Cut*
R.175
22.5
Cloth Cut
PROJECT
Secure Fit Football Undershirt
TITLE
Long Inner Reinforcements U Padding
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO 5
REV
SCALE 2:3
WEIGHT
SHEET 6/7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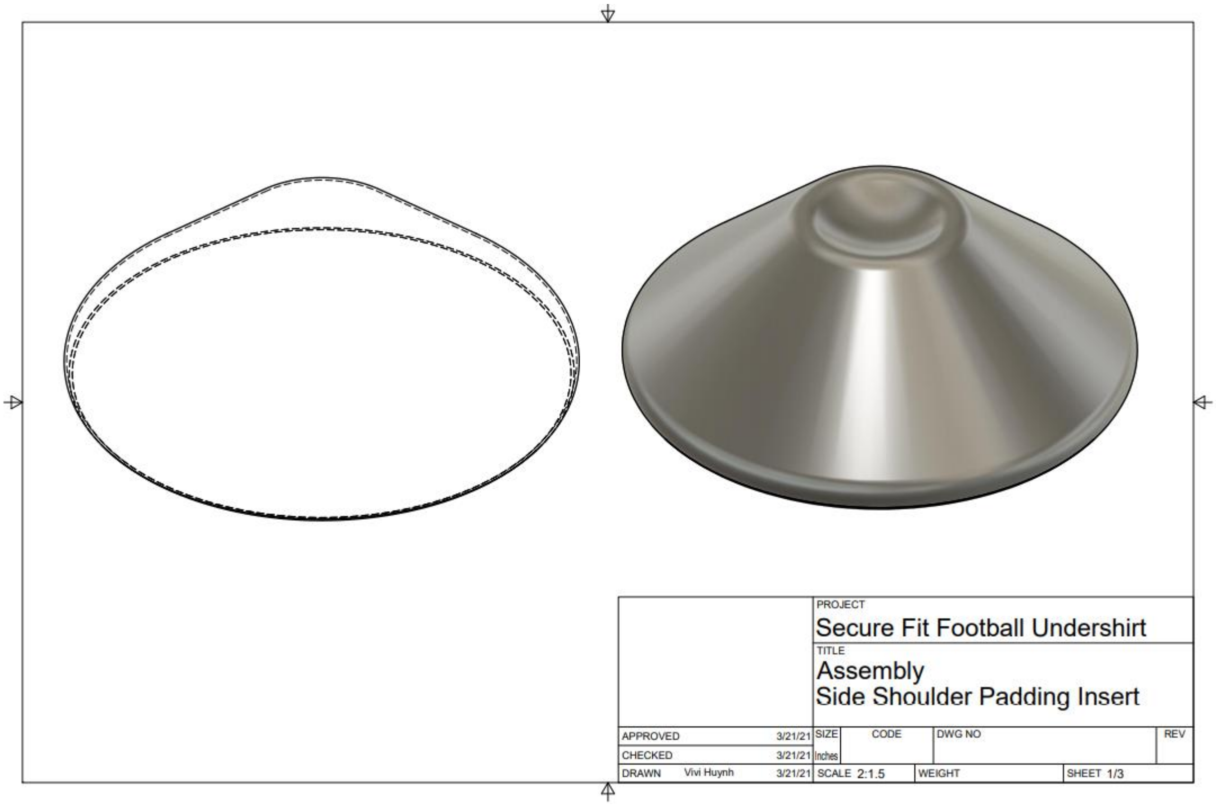
14.75
Cloth Cut
PROJECT
Secure Fit Football Undershirt
TITLE
Short Inner Reinforcements U Padding
Collarbone (U) Padding Insert
SD 519
APPROVED 3/25/2021
CHECKED 3/25/2021
DRAWN Vivi Huynh 3/14/2021
SIZE Inches
CODE
DWG NO 6
REV
SCALE 2:3
WEIGHT
SHEET 7/7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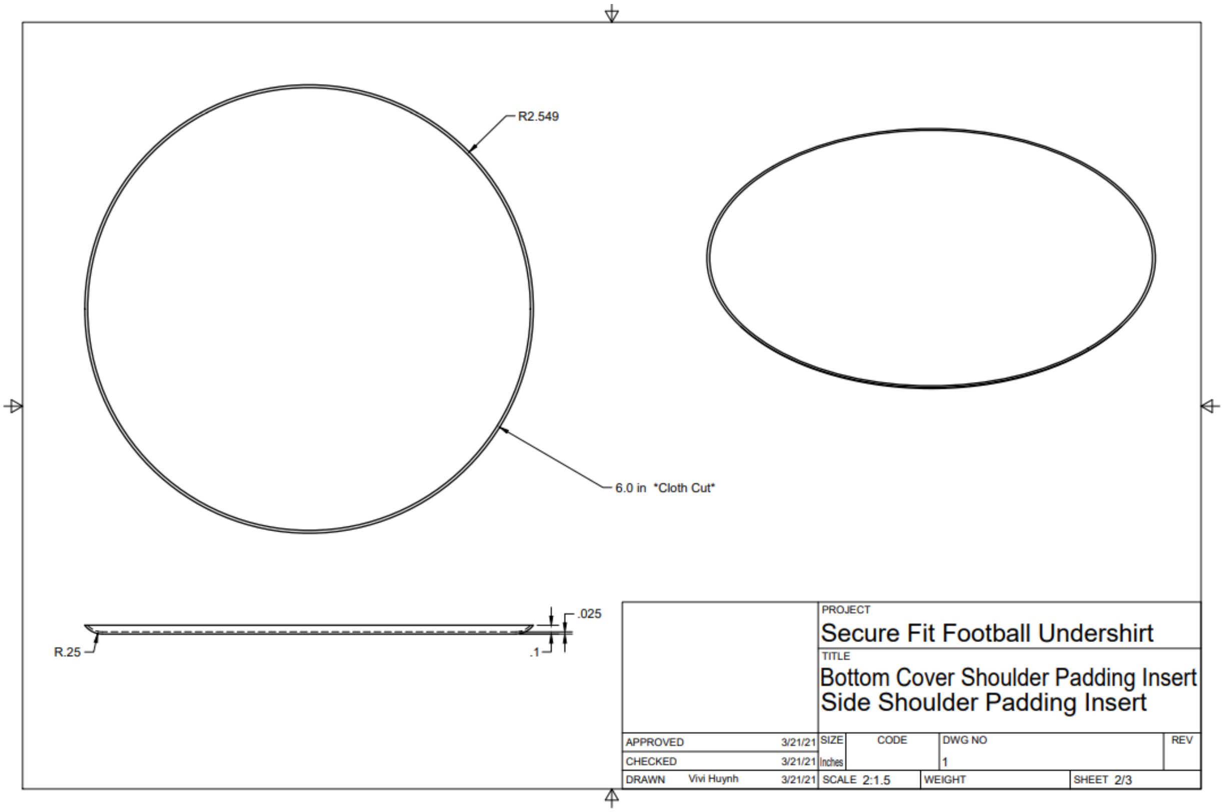
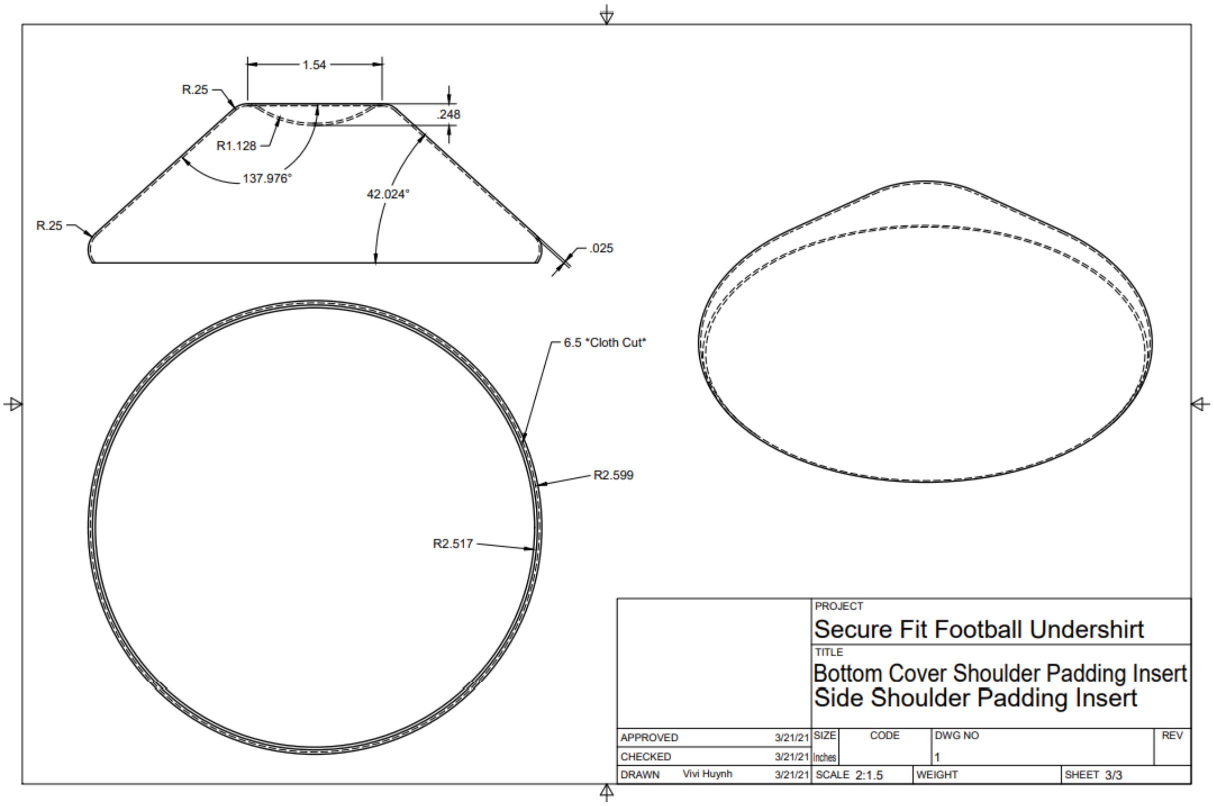
Secure Fit Football Undershirt
TITLE
Assembly
Side Shoulder Padding Insert
APPROVED 3/21/21
CHECKED 3/21/21
DRAWN Vivi Huynh 3/21/21
SIZE Inches
CODE
DWG NO
REV
SCALE 2:1.5
WEIGHT
SHEET 1/3


R2.549
6.0 in *Cloth Cut*
R.25
.025
.1
PROJECT
Secure Fit Football Undershirt
TITLE
Bottom Cover Shoulder Padding Insert
Side Shoulder Padding Insert
APPROVED 3/21/21
CHECKED 3/21/21
DRAWN Vivi Huynh 3/21/21
SIZE Inches
CODE
DWG NO 1
REV
SCALE 2:1.5
WEIGHT
SHEET 2/3


1.54
R.25
.248
R1.128
137.976°
42.024°
R.25
.025
6.5 "Cloth Cut"
R2.599
R2.517
PROJECT
Secure Fit Football Undershirt
TITLE
Bottom Cover Shoulder Padding Insert
Side Shoulder Padding Insert
APPROVED 3/21/21
CHECKED 3/21/21
DRAWN Vivi Huynh 3/21/21
SIZE Inches
CODE
DWG NO 1
REV
SCALE 2:1.5
WEIGHT
SHEET 3/3

Appendix F: Work Break Down Structure

Milestone Number	Milestones & Breakdown			Designated Member
1	Project Charter			
		1.1 Code of Conduct		Morgan Sefcik
			1.1.1 Mission Statement	Morgan Sefcik
			1.12 Team Roles	Morgan Sefcik
			1.1.3 Methods of Communication	Nicholas Palestrini
			1.1.4 Dress Code	Vivi Huynh
			1.1.5 Attendance Policy	Nicholas Palestrini
			1.1.6 Statement of Understanding	Vivi Huynh
			1.1.7 Tailored Code of Conduct	Sawyer O'Bryan
			1.1.8 Grammar Check	Sawyer O'Bryan
			1.1.9 Rubric/ Quality Check	Paul Cunningham
			1.1.10 File Submission	Morgan Sefcik
		1.2 Project Scope		Paul Cunningham
			1.2.1 Project Description	Paul Cunningham
			1.2.2 Key Goals	Morgan Sefcik
			1.2.3 Market	Nicholas Palestrini
			1.2.4 Assumptions	Paul Cunningham
			1.2.5 Stakeholders	Paul Cunningham
			1.2.6 Grammar Check	Vivi Huynh
			1.2.7 Rubric/ Quality Check	Sawyer O'Bryan
			1.2.8 File Submission	Morgan Sefcik
2	Sponsor Meet and Greet			
		2.1 Initial Contact		Morgan Sefcik
			2.1.1 Instructor in Correspondence	Morgan Sefcik
			2.1.2 Meeting Scheduled	Morgan Sefcik
		2.2 Notes Taken		Nicholas Palestrini
			2.2.1 Meeting Minutes Submitted	Nicholas Palestrini
			2.2.2 Attendance Taken	Nicholas Palestrini
			2.2.3 Action Iteams Noted	Nicholas Palestrini
		2.3 Write Up Report		Vivi Huynh
			2.3.1 Grammar Check	Paul Cunningham
			2.3.2 Rubric/Quality Check	Sawyer O'Bryan
			2.3.3 File Submission	Morgan Sefcik
3	Work Break Down Structure			
		3.1 Tabe Formulation		Vivi Huynh
			3.1.1 Determine Milestones	Vivi Huynh
			3.1.2 Breakdown Milestones	Nicholas Palestrini
			3.1.3 Designate Members	Sawyer O'Bryan
			3.1.4 Format Spreadsheet	Nicholas Palestrini
		3.2 Write Up Report		Vivi Huynh
			3.2.1 Grammar Check	Paul Cunningham
			3.2.2 Rubric/Quality Check	Sawyer O'Bryan
			3.2.3 File Submission	Morgan Sefcik
4	Customer Needs			
		4.1 Customer Statements		Nicholas Palestrini
		4.2 Interpreted Need		Paul Cunningham
			4.2.1 State "What" not "How"	Paul Cunningham
			4.2.2 Be Positive not Negative	Paul Cunningham
			4.2.3 Avoid "Must" and "Should"	Paul Cunningham
		4.3 Explanation of Results		Vivi Huynh
			4.3.1 Discuss how statements were gathered	Vivi Huynh
			4.3.2 Synthesize Information	Vivi Huynh
		4.4 Write Up Report		Nicholas Palestrini
			4.4.1 Grammar Check	Nicholas Palestrini
			4.4.2 Rubric/Quality Check	Sawyer O'Bryan
			4.4.3 File Submission	Morgan Sefcik
5	Functional Decomposition			
		5.1 Indication Action		Morgan Sefcik
			5.1.1 Starts with a verb	Morgan Sefcik
		5.2 Graphics		Sawyer O'Bryan
			5.2.1 FD Cross Reference Table	Sawyer O'Bryan
			5.2.2 FD Hierarchy Chart or Flow Chart	Vivi Huynh
		5.3 Explaination of Results		Morgan Sefcik
			5.3.1 Introduction of FD	Paul Cunningham
			5.3.2 Discussion of Data Generation	Paul Cunningham
			5.3.3 Introduction of Graphics	Sawyer O'Bryan
			5.3.4 Discussion on Gathered Process	Vivi Huynh
			5.3.5 Function Relationships	Vivi Huynh
		5.4 Connection to Systems		Morgan Sefcik
			5.4.1 Documents Series of Function Relations of Sub Systems	Morgan Sefcik
		5.5 Smart Integration		Nicholas Palestrini
			5.5.1 Highlight Cross Sub-System Relationoships of Functions	Nicholas Palestrini
		5.6 Action and Outcome		Paul Cunningham
			5.6.1 Describe Physical Action and Expected Outcome	Paul Cunningham
		5.7 Function Resolution		Morgan Sefcik
			5.7.1 "What the Project has to Do"	Morgan Sefcik
		5.8 Clear Communication		Nicholas Palestrini
		5.9 Write Up Report		Vivi Huynh
			5.9.1 Grammar Check	Paul Cunningham
			5.9.2 Rubric/Quality Check	Sawyer O'Bryan
			5.9.3 File Submission	Morgan Sefcik

6	Target Summary			
		6.1 Targets/ Metrics Match Functions		Sawyer O'Bryan
			6.1.1 Each Function Has at Least 1 Target/ Metric	Morgan Sefcik
			6.1.2 Targets Address More than Functions	Morgan Sefcik
			6.1.3 Method of Validation	Nicholas Palestrini
			6.1.4 Discuss How are Targets Determined	Sawyer O'Bryan
			6.1.5 Discussion of Measurement	Vivi Huynh
			6.1.6 Critical Targets and Metrics	Paul Cunningham
		6.2 Summary and Catolog		Nicholas Palestrini
			6.2.1 Summary of Targets Given in Chapter	Paul Cunningham
			6.2.2 Catalog of Targets in Appendix	Vivi Huynh
		6.3 Communication		Nicholas Palestrini
		6.4 Write Up Report		Vivi Huynh
			6.4.1 Grammar Check	Paul Cunningham
			6.4.2 Rubric/Quality Check	Sawyer O'Bryan
			6.4.3 File Submission	Morgan Sefcik
7	Concept Generation			
		7.1 Documenting "100" Concepts		Nicholas Palestrini
		7.2 Concept Generation Tools		Morgan Sefcik
			7.2.1 Morphological Chart (Optional)	Vivi Huynh
			7.2.2 Biomimicry (Optional)	Sawyer O'Bryan
			7.2.3 Crap Shoot (Optional)	Paul Cunningham
			7.2.4 Forced Analogy (Optional)	Morgan Sefcik
			7.2.5 Anti-Problem (Optional)	Morgan Sefcik
			7.2.6 Battle of Perspectives (Optional)	Vivi Huynh
		7.3 Communication		Nicholas Palestrini
		7.4 Write Report		Vivi Huynh
			7.4.1 Grammar Check	Paul Cunningham
			7.4.2 Rubric/Quality Check	Sawyer O'Bryan
			7.4.3 File Submission	Morgan Sefcik
8	Concept Selection			
		8.1 Pairwise Comparison		Nicholas Palestrini
			8.1.1 "5" Medium Fidelity Concepts	Nicholas Palestrini
			8.1.2 "3" High Fidelity Concepts	Nicholas Palestrini
		8.2 Concept Selection Breakdown		Morgan Sefcik
			8.2.1 House of Quality	Paul Cunningham
			8.2.2 Pugh Chart	Vivi Huynh
			8.2.3 AHP	Nicholas Palestrini
			8.2.4 Communication	Morgan Sefcik
			8.2.5 Final Selection	Sawyer O'Bryan
		8.3 Write Up Report		Vivi Huynh
			8.3.1 Discuss Outcomes of Chart	Sawyer O'Bryan
			8.3.2 Grammar Check	Paul Cunningham
			8.3.3 Rubric/Quality Check	Sawyer O'Bryan
			8.3.4 File Submission	Morgan Sefcik
9	Spring Project Plan			
		9.1 Mathmatical Calculations		Sawyer O'Bryan
		9.2 CAD Design First Draft		Vivi Huynh
		9.3 Virtual Simulation		Paul Cunningham
		9.4 Decide on Ideal Materials		Nicholas Palestrini
		9.5 Prototype and Iterations		Vivi Huynh
		9.6 Testing		Paul Cunningham
			9.6.1 Repeat 9.1-9.6 Until Final Design	Sawyer O'Bryan
		9.7 CAD Final Design		Vivi Huynh
		9.8 Final Prototype		Vivi Huynh
		9.9 Final Testing with Prototype		Paul Cunningham
		9.10 Assembly with Materials		Nicholas Palestrini
		9.11 Testing with Final Product		Paul Cunningham
10	Virtual Design Review			
		10.1 Bi-Weekly Meetings With Advisor		Nicholas Palestrini
			10.1.1 Meeting 1	Morgan Sefcik
			10.1.2 Meeting 2	Morgan Sefcik
			10.1.3 Meeting 3	Morgan Sefcik
			10.1.4 Meeting 4	Morgan Sefcik
			10.1.5 Meeting 5	Morgan Sefcik
			10.1.6 Meeting 6	Morgan Sefcik
			10.1.7 Meeting 7	Morgan Sefcik
			10.1.8 Meeting 8	Morgan Sefcik
		10.2 Final Fall Presentation		
			10.2.1 Checking Format and Structure	Morgan Sefcik

Appendix G: 100 Concept Generation

Concept Generation		
Method	**Number**	**Concepts**
Crap Shoot	1	Undershirt combined with Hard Plastic
	2	Undershirt combined with Auxetic Foam
	3	Undershirt combined with Rib Padding
	4	Undershirt combined with Shoulder Shocks
	5	Undershirt combined with Density Foam
	6	Hard Plastic combined with Auxetic Foam
	7	Hard Plastic combined with Rib Padding
	8	Hard Plastic combined with Shoulder Shocks
	9	Hard Plastic combined with Density Foam
	10	Auxetic Foam combined with Rib Padding
	11	Auxetic Foam combined with Shoulder Shocks
	12	Auxetic Foam combined with Density Foam
	13	Rib Padding combined with Shoulder Shocks
	14	Rib Padding combined with Density Foam
	15	Shoulder Shocks combined with Density Foam
Battle of Perspectives	16	Decrease size of shoulder pads because players are getting smaller
	17	Increase size of shoulder pads because players are getting bigger
	18	Remove padding from shoulder pads because players are running slower
	19	Add padding to shoulder pads because players are running faster
	20	Remove shoulder pads because football will no longer be tackle football
Biomimicry	21	Bone structure padding
	22	Grapefruit structure padding
	23	"Fatty" structured padding
	24	Bark structured padding
	25	Armadillo structured shoulder pads
	26	Conch shell structured shoulder pads
	27	Rino structured shoulder pads
	28	Turtle Shell structured shoulder pads
	29	Pangolin layered shoulder pads
	30	Beetle structured shoulder pads
	31	Alligator structured shoulder pads
	32	Lobster structured shoulder pads
	33	Komoto dragon structured shoulder pads
	34	Dinosaurs inspired should pads
	35	Elephant skin structured padding
	36	Ironclad beetle structured shoulder pads
	37	Deep sea fish inspired padding
	38	Skull structured shoulder pads
	39	Giraffe skin inspired cooling padding

Morphological	80	Memory Foam (Current Material)
	81	Air Pocket Technology
	82	Auxetic Foam
	83	Plastic (Current Material)
	84	Kevlar
	85	Aluminum
	86	Compression sleeve underneath shoulder
	87	Compression shirt with rib and sternum padding
	88	Casting structure custom fitted to each player
	89	Reduce Padding Volume
	90	Reduce Shell Volume
	91	Memory foam compression sleeve
	92	Kevlar compression sleeve
	93	Aluminum casting structure
	94	Air pocket casting structure
	95	Aluminum compression shirt
	96	Memory foam casting structure
	97	Air pocket compression sleeve
	98	Air pocket compression shirt
	99	Kevlar reduce shell volume
	100	Aluminum reduce padding volume

Appendix H: Concept Selection Tools (First Semester)

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**

Criteria Comparison Matrix							
	Absorbs Impact	Disperses Energy	Prevent Injury	Remains Lightweight	Adapts to Fit	Reacts Elastically	{Ws}
Absorbs Impact	0.502	1.175	0.520	1.001	0.286	0.299	3.782
Disperses Energy	0.072	0.168	0.104	0.429	0.204	0.213	1.190
Prevent Injury	0.100	0.168	0.104	0.048	0.122	0.128	0.670
Remains Lightweight	0.072	0.056	0.312	0.143	0.204	0.128	0.914
Adapts to Fit	0.072	0.034	0.035	0.029	0.041	0.043	0.252
Reacts Elastically	0.072	0.034	0.035	0.048	0.041	0.043	0.271

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**

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

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**

Absorbs Impact Comparision			
	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	3.00	0.14
Concept 1 Replace interior padding with non-Newtonian fluid	0.33	1.00	0.11
Concept 8 Replace interior padding with negative Poisson ratio material	7.00	9.00	1.00
Sum	**8.33**	**13.00**	**1.25**

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**

Prevent Injury 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	1.00	1.00
Concept 1 Replace interior padding with non-Newtonian fluid	1.00	1.00	1.00
Concept 8 Replace interior padding with negative Poisson ratio material	1.00	1.00	1.00
Sum	**3.00**	**3.00**	**3.00**

Lightweight Comparision			
	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	5.00	0.33
Concept 1 Replace interior padding with non-Newtonian fluid	0.20	1.00	0.20
Concept 8 Replace interior padding with negative Poisson ratio material	3.00	5.00	1.00
Sum	**4.20**	**11.00**	**1.53**

Absorbs Impact Normalization				
	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	DAP
Concept 5 Replace interior padding with Cellular Urethane	0.12	0.23	0.11	0.15
Concept 1 Replace interior padding with non-Newtonian fluid	0.04	0.08	0.09	0.07
Concept 8 Replace interior padding with negative Poisson ratio material	0.84	0.69	0.80	0.78
Sum	**1.00**	**1.00**	**1.00**	**1.00**

Disperses Energy Normalization				
	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	DAP
Concept 5 Replace interior padding with Cellular Urethane	0.14	0.20	0.08	0.14
Concept 1 Replace interior padding with non-Newtonian fluid	0.43	0.60	0.69	0.57
Concept 8 Replace interior padding with negative Poisson ratio material	0.43	0.20	0.23	0.29
Sum	**1.00**	**1.00**	**1.00**	**1.00**

Prevents Injury Normalization				
	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	DAP
Concept 5 Replace interior padding with Cellular Urethane	0.33	0.33	0.33	0.33
Concept 1 Replace interior padding with non-Newtonian fluid	0.33	0.33	0.33	0.33
Concept 8 Replace interior padding with negative Poisson ratio material	0.33	0.33	0.33	0.33
Sum	**1.00**	**1.00**	**1.00**	**1.00**

Lightweight Normalization				
	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	DAP
Concept 5 Replace interior padding with Cellular Urethane	0.24	0.45	0.22	0.30
Concept 1 Replace interior padding with non-Newtonian fluid	0.05	0.09	0.13	0.09
Concept 8 Replace interior padding with negative Poisson ratio material	0.71	0.45	0.65	0.61
Sum	**1.00**	**1.00**	**1.00**	**1.00**

Adapts to Fit Comparision			
	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	1.00
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	1.00	0.33	1.00
Sum	**5.00**	**1.67**	**5.00**

Reacts Elastically Comparision			
	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	5.00	0.33
Concept 1 Replace interior padding with non-Newtonian fluid	0.20	1.00	0.20
Concept 8 Replace interior padding with negative Poisson ratio material	3.00	5.00	1.00
Sum	**4.20**	**11.00**	**1.53**

Adapts to Fit Normalization				
	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	DAP
Concept 5 Replace interior padding with Cellular Urethane	0.20	0.20	0.20	0.20
Concept 1 Replace interior padding with non-Newtonian fluid	0.60	0.60	0.60	0.60
Concept 8 Replace interior padding with negative Poisson ratio material	0.20	0.20	0.20	0.20

Reacts Elastically Normalization				
	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	DAP
Concept 5 Replace interior padding with Cellular Urethane	0.24	0.45	0.22	0.30
Concept 1 Replace interior padding with non-Newtonian fluid	0.05	0.09	0.13	0.09
Concept 8 Replace interior padding with negative Poisson ratio material	0.71	0.45	0.65	0.61

Appendix I: Calculations

SD Team 519 Compression Test

3/15/2021

```
clc
clear all
format compact


x= linspace(0,1,5);



%Polyurethane
white_original_height = 12.5;
white_compressed = [ 4.5 4.2 4.4 3.9 4.4]; %[mm]
white_expanded = [12.2 12.1 12.5 12 11.9]; %[mm]
Dif_fin_height1 = white_original_height - white_expanded;
white_pcent_height_red = Dif_fin_height1./white_original_height;
mean_white_pcent_height_red = mean(white_pcent_height_red)



%Polyimide
yellow_original_height = 5;
yellow_compressed = [1.8 1.6 1.7 1.6 2]; %[mm]
yellow_expanded = [5.1 4.8 4.8 5.4 5]; %[mm]
Dif_fin_height2 = yellow_original_height - yellow_expanded;
yellow_pcent_height_red = Dif_fin_height2./yellow_original_height;
mean_yellow_pcent_height_red = mean(yellow_pcent_height_red)


%Open-Celled Polyurethane
squared_original_height = 23.1;
squared_compressed = [7.2 7.2 7 7.5 7.5]; %[mm]
squared_expanded = [21.7 21.7 21 21 21.5]; %[mm]
Dif_fin_height3 = squared_original_height - squared_expanded;
squared_pcent_height_red = Dif_fin_height3./squared_original_height;
mean_squared_pcent_height_red = mean(squared_pcent_height_red)


%Polyethylene
flat_black_original_height = 6.5;
flat_black_compressed = [6.3 6.2 6.3 6.2 6.1]; %[mm]
flat_black_expanded = [6.4 6.2 6.6 6.3 6.1]; %[mm]
Dif_fin_height4 = flat_black_original_height - flat_black_expanded;
```

```
flat_black_pcent_height_red = Dif_fin_height4./flat_black_original_height;
mean_flat_balck_pcent_height_red = mean(flat_black_pcent_height_red)


%Organic Latex Foam
five_original_height = 30;
five_compressed = [8 8.6 8.2 8.3 9]; %[mm]
five_expanded = [28.1 26.8 27.1 27.2 27.8]; %[mm]
Dif_fin_height5 =five_original_height - five_expanded;
five_pcent_height_red = Dif_fin_height5./five_original_height;
mean_five_pcent_height_red = mean(five_pcent_height_red)


%Gel memory Foam
six_original_height = 30;
six_compressed = [8.5 8 8.3 7.8 8]; %[mm]
six_expanded = [31.5 30 31.5 30.1 30]; %[mm]
Dif_fin_height6 =six_original_height - six_expanded;
six_pcent_height_red = Dif_fin_height6./six_original_height;
mean_six_pcent_height_red = mean(six_pcent_height_red)
```

```
mean_white_pcent_height_red =
    0.0288
mean_yellow_pcent_height_red =
   -0.0040
mean_squared_pcent_height_red =
    0.0745
mean_flat_balck_pcent_height_red =
    0.0277
mean_five_pcent_height_red =
    0.0867
mean_six_pcent_height_red =
   -0.0207
```

Published with MATLAB® R2018b

```
%% Control Readings
const = (15/142);
Freadings_control = [279, 287, 304, 294, 283 ];
Freadings_control_lb = Freadings_control*const;
avg_F_control = mean(Freadings_control_lb);

Return_time = 0;

%% Foam 1 White

Freadings_Foam1_mV = [139, 174, 182,195,173];                % Foam 1 Force Readings↙
in mV
Freadings_Foam1_lb = Freadings_Foam1_mV*const;             % Convert Force to lbf

Dif_F_1 = avg_F_control - Freadings_Foam1_lb       % Difference from control

Pcent_Fred1 = ((Dif_F_1)./ avg_F_control)*100;          % Percent Force Reduction

Avg_Pcent_Fred1 = mean(Pcent_Fred1)              % Average Percent Force Reduction


%% Foam 2 Cubed

Freadings_Foam2_mV = [210, 214,228,236,257];                % Foam 2 Force Readings in↙
mV
Freadings_Foam2_lb = Freadings_Foam2_mV*const;       % Convert Force to lbf

Dif_F_2 = avg_F_control - Freadings_Foam2_lb;       % Difference from control

Pcent_Fred2 = ((Dif_F_2)./ avg_F_control)*100;          % Percent Force Reduction

Avg_Pcent_Fred2 = mean(Pcent_Fred2)              % Average Percent Force Reduction

%% Foam 3 Gel Memory foam

Freadings_Foam3_mV = [195, 204, 213, 215, 202];                   % Foam 3 Force↙
Readings in mV
Freadings_Foam3_lb = Freadings_Foam3_mV*const;             % Convert to lbf

Dif_F_3 = avg_F_control - Freadings_Foam3_lb;       % Difference from control

Pcent_Fred3 = ((Dif_F_3)./ avg_F_control)*100;          % Percent Force Reduction

Avg_Pcent_Fred3 = mean(Pcent_Fred3)              % Average Percent Force Reduction

%% Foam 4 Yellow

Freadings_Foam4_mV = [206,217,201,192,221];                % Foam 4 Force Readings in↙
```

```
kg
Freadings_Foam4_lb = Freadings_Foam4_mV*const;          % Convert Force to Newtons

Dif_F_4 = avg_F_control - Freadings_Foam4_lb;       % Difference from control

Pcent_Fred4 = ((Dif_F_4)./ avg_F_control)*100;          % Percent Force Reduction

Avg_Pcent_Fred4 = mean(Pcent_Fred4)             % Average Percent Force Reduction


%% Foam 5 Memory Foam

Freadings_Foam5_mV = [192,208,202,219,224];                 % Foam 5 Force Readings in↙
kg
Freadings_Foam5_lb = Freadings_Foam5_mV*const;      % Convert Force to Newtons

Dif_F_5 = avg_F_control - Freadings_Foam5_lb;       % Difference from control

Pcent_Fred5 = ((Dif_F_5)./ avg_F_control)*100;          % Percent Force Reduction

Avg_Pcent_Fred5 = mean(Pcent_Fred5)             % Average Percent Force Reduction


%% Foam 6 Composite Pad

Freadings_Foam6_mV = [124, 131 , 147, 139, 149];                    % Foam 6 Force↙
Readings in kg
Freadings_Foam6_lb = Freadings_Foam6_mV.*(const);                   % Convert Force to↙
Newtons

Dif_F_6 = avg_F_control - Freadings_Foam6_lb;                       % Difference from↙
control

Pcent_Fred6 = ((Dif_F_6)./ avg_F_control)*100;                      % Percent Force↙
Reduction

Avg_Pcent_Fred6 = mean(Pcent_Fred6)                                 % Average Percent↙
Force Reduction


%% Foam 7 Gel Shredded memory foam pad

Freadings_Foam7_mV = [227 , 218 , 242, 210, 233];                    % Foam 7 Force↙
Readings in kg
Freadings_Foam7_lb = Freadings_Foam7_mV.*(const);                    % Convert Force to↙
Newtons

Dif_F_7 = avg_F_control - Freadings_Foam7_lb;                        % Difference from↙
control

Pcent_Fred7 = ((Dif_F_7)./ avg_F_control)*100;                       % Percent Force↙
```

```
Reduction

Avg_Pcent_Fred7 = mean(Pcent_Fred7)                 % Average Percent↙
Force Reduction


%% Foam 8 Nike Competition Pad

Freadings_Foam8_mV = [201, 216 , 208, 223, 202];    % Foam 8 Force↙
Readings in kg
Freadings_Foam8_lb = Freadings_Foam8_mV.*(const);   % Convert Force to↙
Newtons

Dif_F_8 = avg_F_control - Freadings_Foam8_lb;       % Difference from↙
control

Pcent_Fred8 = ((Dif_F_8)./ avg_F_control)*100;      % Percent Force↙
Reduction

Avg_Pcent_Fred8 = mean(Pcent_Fred8)                 % Average Percent↙
Force Reduction
```

```
Avg_Pcent_Fred1 =

   40.3594

Avg_Pcent_Fred2 =

   20.8708

Avg_Pcent_Fred3 =

   28.8874

Avg_Pcent_Fred4 =

   28.3345

Avg_Pcent_Fred5 =

   27.7816

Avg_Pcent_Fred6 =

   52.3151

Avg_Pcent_Fred7 =

   21.9074

Avg_Pcent_Fred8 =

   27.4361

avg_F_control =

   30.5704

>>
```

Appendix J: Risk Management

Project Hazard Control- For Projects with Medium and Higher Risks

Name of Project: Football Shoulder Pads		**Date of submission: 12 / 4 / 2020**
Team member	**Phone number**	**e-mail**
Sawyer O'Bryan	(850) 557-3995	sawyerobryan333@gmail.com
Paul Cunningham	(850) 556-0917	pmcham22@gmail.com
Vivi Huynh	(850) 341-6531	vivi.huynh@outlook.com
Nicholas Palestrini	(813) 716-6292	nick.palestrini@gmail.com
Morgan Sefcik	(904) 718-4838	morgansefcik@gmail.com
Faculty mentor	**Phone number**	**e-mail**
Dr. Christian Hubicki	(850) 645-0144	hubicki@eng.famu.fsu.edu
Dr. Shayne McConomy	(850) 410-6624	smcconomy@eng.famu.fsu.edu
Dr. Dorr Campbell	(850) 410-6610	dcampbell@eng.famu.fsu.edu

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

Face masks are worn at all times. Social distancing of at least 6 feet apart with face masks is enforced.

97%-99% alcohol spray and paper towels are utilized to disinfect all rooms, chairs, desks, and machines before and after use.

Long pants and close toed shoes are required, loose hair is pulled back, and loose jewelry is removed or protected: rings, necklaces, bracelets. Any long sleeves are rolled up the arms.

Food and drinks are prohibited in laboratory or near any machinery.

Test materials using impact tests -

Wear protective glasses and safety gloves, assign each person to a specific task prior to carrying out the procedure, follow proper testing instructions. Users refrain from standing close to machine during testing to avoid any possible projectiles.

Test materials using compression tests -

Wear protective glasses and safety gloves, assign each person to a specific task prior to carrying out the procedure, follow proper testing instructions. Users refrain from standing close to machine during testing to avoid any possible projectiles.

Remove previous material from shoulder pad shell -

Wear protective glasses and safety gloves, assign each person to a specific task prior to carrying out the procedure, solidify or harden glue before disposal.

Installing new material into shoulder pad shell -

Wear protective glasses and safety gloves, assign each person to a specific task prior to carrying out the procedure, solidify or harden glue before disposal.

Test Shoulder Pads -

Wear protective glasses and safety gloves, assign each person to a specific task prior to carrying out the procedure, follow proper testing instructions.

After completion of tests, waste is disposed properly. Machinery and tools are turned off, cleaned, reset, and put away. Any used chairs are returned to original position.

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

In case of high-strength glue coming in contact with skin immediately rinse with cold soapy water, if there is still residual glue use nail polish remover to dissolve it.

In case of being struck by an impact or injury with heavy machinery immediately call 911 followed by calling emergency contacts.

List emergency response contact information:

- Call 911 for injuries, fires or other emergency situations
- Call your department representative to report a facility concern

Name	Phone number	Faculty or other COE emergency contact	Phone number
Universal Emergency Number	**911**	**Dr. Christian Hubicki**	**(850) 645-0144**

Tallahassee Police Department	**(850) 891-4200**	**Dr. Shayne McConomy**	**(850) 410-6624**
FSU Emergency Management	**(850) 644-1234**	**Keith Larson**	**(850) 410-6108**
FSUPD Headquarters	**(850) 644-1234**	**Jeremy Philips**	**(850) 410-6113**
		Mechanical Engineering Department	**(850) 410-6335**
Safety review signatures			
Team member	Date	Faculty mentor	Date
Sawyer O'Bryan	12/01/20	Dr. Christian Hubicki	12/02/20
Paul Cunningham	12/01/20	Dr. Shayne McConomy	12/03/20
Vivi Huynh	12/01/20	Dr. Dorr Campbell	
Nicholas Palestrini	12/01/20		
Morgan Sefcik	12/01/20		

Report all accidents and near misses to the faculty mentor.

FAMU-FSU College of Engineering
Project Hazard Assessment Policy and Procedures

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.
5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.
6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).
7. PI/instructor must ensure that approved methods and precautions are being followed by :
   a. Performing periodic laboratory visits to prevent the development of unsafe practice.
   b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.

c. Assigning a safety representative to assist in implementing the expectations.
d. Etc.

8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Dr. Shayne McConomy Dr. Dorr Campbell	Phone #: (850) 410-6624 (850) 410-6610	Dept.:	Start Date:	Revision number:
Project: Football Shoulder Pads			Location(s): FAMU-FSU College of Engineering	
Team member(s): Sawyer O'Bryan Paul Cunningham Vivi Huynh Nicholas Palestrini Morgan Sefcik			Phone #: (850) 557-3995 (850) 556-0917 (850) 341-6531 (813) 716-6292 (904) 718-4838	Email: sawyerobryan333@gmail.com pmcham22@gmail.com vivi.huynh@outlook.com nick.palestrini@gmail.com morgansefcik@gmail.com

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Test materials using impact tests	HPMI	Morgan Sefcik Paul Cunningham	Debris from high-speed impacts Body parts or clothing getting caught in the machine Being struck by impact	1 person does the testing. 1 person records data. Both testers are a safe distance away from testing machines. After numerous	Protective glasses	Follow testing instructions	HAZARD: 1 CONSEQ: 3 Residual: Medium	. 1. After approval by the PI, a copy must be sent to the Safety Committee. 2. A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the

				tests, the testers will switch roles to help prevent accidental hazards.				Safety Committee. 3. A second worker must be in place before work can proceed (buddy system). 4. Limit the number of authorized workers in the hazard area.
Test materials using compression tests	FAMU-FSU College of Engineering	Vivi Huynh Nicholas Palestrini	Body parts or clothing getting caught in the machine	1 person does the testing. 1 person records data. Both testers are a safe distance away from testing machines. After numerous tests, the testers will switch roles to help prevent accidental hazards.	Protective glasses	Follow testing instructions	HAZARD: 1 CONSEQ:3 Residual: Medium	1. After approval by the PI, a copy must be sent to the Safety Committee. 2. A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee. 3. A second worker must be in place before work can proceed (buddy system). 4. Limit the number of authorized workers in the hazard area.
Remove previous material from	FAMU-FSU College of	Vivi Huynh Morgan Sefcik	Cutting fingers with tools used to	1 person will hold the shoulder	Protective glasses Gloves	Solidify or harden glue before disposal	HAZARD: 2	1. Safety controls are planned by both the worker and supervisor.

shoulder pad shell	Engineering		remove material High-strength glue touching skin	pads while 1 person will remove material			CONSEQ :2 Residual: Low	2. Proceed with supervisor authorization
Installing new material into shoulder pad shell	FAMU-FSU College of Engineering	Nicholas Palestrini Sawyer O'Bryan	High-strength glue touching skin Cutting fingers on the sewing needle	1 person will hold the shoulder pads while 1 person installs material	Protective glasses Gloves	Solidify or harden any extra glue before disposal	HAZARD : 2 CONSEQ :2 Residual: Low	1. Safety controls are planned by both the worker and supervisor. 2. Proceed with supervisor authorization.
Test shoulder pads	FAMU-FSU College of Engineering	Paul Cunningham Sawyer O'Bryan	Debris from high-speed impacts Body parts or clothing getting caught in the machinery Being struck by impact	1 person does the testing. 1 person records data. Both testers are a safe distance away from testing machines. After numerous tests, the testers will switch roles to help prevent accidental hazards.	Protective glasses	Follow testing instructions	HAZARD : 1 CONSEQ :3 Residual : Medium	1. After approval by the PI, a copy must be sent to the Safety Committee. 2. A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee. 3. A second worker must be in place before work can proceed (buddy system). 4. Limit the number of authorized workers in the hazard area.

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	Signature	Date	Name
Dr. Shayne McConomy		12/03/20	Dr. Dorr Campbell

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	Signature	Date	Name	Signature	Date
Sawyer O'Bryan		12/01/20	Paul Cunningham		12/01/20
Vivi Huynh		12/01/20	Nicholas Palestrini		12/01/20
Morgan Sefcik		12/01/20			

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DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.
2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
Familiarity Level	Very Familiar	1	2	3

	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.
    a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
    b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
    c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
    d. Significant: severe injuries requiring hospitalization.
    e. Severe: death or permanent disability.
3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 2. Residual risk assessment matrix.

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.
  Med High:
- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.
  High:
- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Appendix A: Hazard types and examples

Types of Hazard	Example
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn
Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.
Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.

Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.
Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or down stairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects
Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic response.