Final Report

Traumatic Brain Injury Reducing Army Combat Helmet

By:
Damian Frankiewicz
Kristin Ohanian
Jim Veronick
Team 6

Client Contact: Denise Panosky
University of Connecticut School of Nursing
Storrs Hall, Room 208
231 Glenbrook Road, Unit 2026
Storrs, CT 06269
(860) 486-0549
Table of Contents

Abstract...........................................................................................................................................2

1  Introduction......................................................................................................................................3
  1.1 Background............................................................................................................................3
  1.2 Purpose of the Project..............................................................................................................3
  1.3 Previous Work Done by Others.............................................................................................3
    1.3.1 Products..........................................................................................................................3
    1.3.2 Patent Search Results......................................................................................................4
  1.4 Map for the Rest of the Report...............................................................................................6

2  Project Design..................................................................................................................................6
  2.1 Final Design.............................................................................................................................10
    2.1.1 Objective........................................................................................................................10
    2.1.2 Subunits..........................................................................................................................13
      2.1.2.1 Outer Shell................................................................................................................13
      2.1.2.2 Expanded Polystyrene Layer.....................................................................................16
      2.1.2.3 Retention Padding......................................................................................................18
      2.1.2.4 Suspension System....................................................................................................20
      2.1.2.5 Chin Guard................................................................................................................23
    2.1.2.6 Testing........................................................................................................................25
  2.2 Prototype....................................................................................................................................27

3  Realistic Constraints......................................................................................................................37

4  Safety Issues....................................................................................................................................39

5  Impact of Engineering Solutions..................................................................................................40

6  Life-Long Learning.......................................................................................................................42

7  Budget ..........................................................................................................................................43

8  Team Member Contribution..........................................................................................................45
  8.1 Kristin .......................................................................................................................................45
  8.2 Jim...........................................................................................................................................46
  8.3 Damian....................................................................................................................................46

9  Conclusion.....................................................................................................................................47

10 References......................................................................................................................................48

11 Acknowledgements....................................................................................................................50

12 Appendix.....................................................................................................................................50
  12.1 Updated Specifications..........................................................................................................50
### 12.2 Abstract

Current military helmets used are designed around the premise of optimal ballistic protection. However, there have been documented reports of a substantial number of soldiers experiencing brain injuries ranging from mild to very severe. The original thinker of this project, Gregory Lutkus, has had first-hand experience with the Advanced Combat Helmet currently used in the Army and National Guard. His observations include an alarming reduction in the protection of the helmet around the side of the head and on the back protecting the cerebellum and a genuine discomfort. Many of his contacts there report that the helmet simply isn’t comfortable enough to wear with the chin strap secured on correctly to provide maximum protection. The second contact, Denise Panosky, has a nursing background and has looked at the problems of the current helmet through the scope of preventing brain injuries. Therefore, the design specifications include improved brain safety, increased comfort, and increased covering of the head. Although the second two parameters are fairly common in the field of military helmet design, no real helmet has been created to decrease the amount of brain injuries based on the current and previous helmet designs of the United States military and other democracies.

The hard Kevlar composite outer shell of the current Advanced Combat Helmet made by the Gentex Corporation does not meet the specifications of the contact. Therefore, a large amount of this project’s time will be spent designing and creating a unique shell out of the same Kevlar 29 composite used as an industry standard for ballistics protection. This includes the creation of a mold for the shell and also the controlled reaction of an aramid composite. The goal of this is to provide ballistics protection in areas that the current helmet does not, specifically in the back and sides of the head.

The designs of motocross helmets were looked at for insight on how to prevent brain injuries. The first contact Gregory Lutkus has been a motocross rider for several years and has insight into areas of that particular helmet design that may be beneficial when adapted to a helmet used in the military. For instance, the padding of a motocross helmet is superior and will both provide more protection and absorb sweat. In addition, many non-ballistic helmets have a layer of high energy absorption foam called expanded polystyrene, or EPS. The inclusion of a layer of this material will help increase the energy absorption of the helmet with the desired conclusion of reducing the risk of traumatic brain injuries to the user.
1. Introduction

1.1 Background

A redesign for an army helmet project was brought to the Biomedical Engineering program by the School of Nursing. During a lecture on traumatic brain injuries, a nursing student who was a former soldier in the US Army inquired upon the helmets he used in Iraq. An avid motocross rider, the nursing student was curious as to why the helmets used in motocross provided better protection from traumatic brain injury (TBI) than those used in combat in Iraq. It is estimated that almost 90% of military personnel treated for injuries in Iraq were injured by IED (Improvised Explosive Device) explosions. Almost half of those injuries were incurred on the head.

Research and experience shows that the greatest cause for traumatic brain injuries are due to blasts or explosions from IEDs, vehicle accidents, and falls. Fewer TBIs were caused by bullets, fragments, or shrapnel. The effect of IED blasts is of growing concern for the military as current warfare practices have progressed from ballistic to explosive measures.

1.2 Purpose of the project

The current military design for helmets is most effective at protecting a soldier’s head from bullets, fragments, or shrapnel penetration; however, the risk of TBI is still present. The purpose of the project will be to research TBIs, forces from explosions, shock resistant materials, and other areas in order to ultimately design a more protective military helmet to prevent TBIs. To account for TBIs, the new helmet design will incorporate the protective features of the current Advanced Combat Helmet, but also will include ideas from the common protective motocross helmet which is more successful at preventing head injuries from impact forces. The new helmet will provide better protection against TBIs from explosions, vehicle accidents, and falls.

1.3 Previous Work Done by Others

1.3.1 Products

While most helmets used by the United States Army were created internally by Army engineers, in recent years helmet design and manufacturing have been awarded to the Gentex Corporation, who has recently created three helmets used by different branches of the military. The Lightweight Helmet, or LWH, was initially used by the Marines. The Modular Integrated Communications Helmet, or MICH, and the Advanced Combat Helmet, or ACH, have been used by the Army. All three of these designs by inspection are seen to have much less protection than older helmets, partly due to the fact that they cover much less of the back and sides of the head as opposed to the older Personal Armor System Ground Troops, or PASGT helmet, which was used in the eighties and nineties and was developed by the United States Army Aeromedical
Research Laboratory. Before this design, the Army used a generic M1 helmet in Vietnam.

1.3.2 Patent Search Results

Although the Army developed older models of helmets, no patents pertaining to protective helmets can be found under the holder the United States of America as Represented by the Secretary of the Army, or other such military branches. The following two tables show a search of all patents pertaining to the project at hand. Table A is a compiled list of protective combat helmets held by private companies. Most of these patents are held by Gentex, who owns the patents pertaining to the helmet being studied and improved upon. Table B is a list of patents pertaining to motocross helmets, which are held by several leading companies in this industry. These patents are important in order to ensure that no infringements occur in the areas of the chin straps, padding, or chin guard.
<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
<th>Patent Holder</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE32569</td>
<td>Protective Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>7316036</td>
<td>Padset for Protective Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>7225471</td>
<td>Removable Optical Assembly for Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>6292953</td>
<td>Interchangeable Latch System</td>
<td>Gentex</td>
</tr>
<tr>
<td>6279172</td>
<td>Custom Fitting Assembly for Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>5584073</td>
<td>Integrated Helmet System</td>
<td>Gentex</td>
</tr>
<tr>
<td>5522091</td>
<td>Sighter’s Protective Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>5396661</td>
<td>Helmet Visor Operating Mechanism</td>
<td>Gentex</td>
</tr>
<tr>
<td>5226181</td>
<td>Mounting Design for Night Vision Mount and Goggle Assembly</td>
<td>Gentex</td>
</tr>
<tr>
<td>4908877</td>
<td>Ballistic Helmet Body</td>
<td>Gentex</td>
</tr>
<tr>
<td>4884301</td>
<td>Combination Chinstrap-Natestrap Assembly for Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>4847920</td>
<td>Dual-Visor Assembly for Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>4778638</td>
<td>Method of Making Ballistic Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>4748694</td>
<td>Spring Device for Earcup Assemblies of Protective Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>4713844</td>
<td>Protective Helmet with Face Mask Sealing Means</td>
<td>Gentex</td>
</tr>
<tr>
<td>4700410</td>
<td>Pneumatic Adjustment Means for Earcups in Helmets</td>
<td>Gentex</td>
</tr>
<tr>
<td>4596056</td>
<td>Helmet Shell Fabric Layer and Method of Making the Same</td>
<td>Gentex</td>
</tr>
<tr>
<td>4432099</td>
<td>Individually Fitted Helmet Liner</td>
<td>Gentex</td>
</tr>
<tr>
<td>4412358</td>
<td>Individually Fitted Helmet Liner and Method of Making the Same</td>
<td>Gentex</td>
</tr>
<tr>
<td>4145338</td>
<td>Custom-Fitted Helmet and Method of Making the Same</td>
<td>Gentex</td>
</tr>
<tr>
<td>4290149</td>
<td>Method of Making and Individually Fitted Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>42392106</td>
<td>Individually Fitted Helmet and Method of and Apparatus and Making the Same</td>
<td>Gentex</td>
</tr>
<tr>
<td>4170042</td>
<td>Readily Releasable Powered Visor-and-Lock Assembly for Helmet</td>
<td>Gentex</td>
</tr>
<tr>
<td>6804829</td>
<td>Advanced Combat Helmet System</td>
<td>Lineweight LLC</td>
</tr>
</tbody>
</table>
Table B: Patents Pertaining to Motocross Helmets

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
<th>Patent Holder</th>
</tr>
</thead>
<tbody>
<tr>
<td>D5545502</td>
<td>Helmet</td>
<td>Troy Lee Designs</td>
</tr>
<tr>
<td>D499213</td>
<td>Helmet with Visor</td>
<td>Troy Lee Design</td>
</tr>
<tr>
<td>7181777</td>
<td>Shield Mounting Device for Helmet</td>
<td>HJC Co. Ltd.</td>
</tr>
<tr>
<td>6892400</td>
<td>Helmet Having opening Type Chin Protection Bar</td>
<td>HJC Co. Ltd.</td>
</tr>
<tr>
<td>6763526</td>
<td>Air Vent Structure for Helmet</td>
<td>HJC Co. Ltd.</td>
</tr>
<tr>
<td>6748607</td>
<td>Breath Guard Assembly for Helmet</td>
<td>HJC Co. Ltd.</td>
</tr>
<tr>
<td>6598238</td>
<td>Jaw Protecting Apparatus of Helmet</td>
<td>HJC Co. Ltd.</td>
</tr>
<tr>
<td>D495838</td>
<td>Helmet</td>
<td>Arai Helmet</td>
</tr>
<tr>
<td>7207071</td>
<td>Ventilated Helmet System</td>
<td>Fox Racing, Inc.</td>
</tr>
<tr>
<td>D476779</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>D471675</td>
<td>Helmet Chin Cover</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>D460219</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>D457691</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>D446357</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>6910228</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>6421841</td>
<td>Inside Pad for Helmet Using this Inside Pad</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>6417491</td>
<td>Shield Panel and Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>9256797</td>
<td>Helmet and Method of Removing the Same</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>6226803</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
<tr>
<td>6105172</td>
<td>Helmet</td>
<td>Shoei, Co., Ltd.</td>
</tr>
</tbody>
</table>

1.4 Map for the Rest of the Report

The remainder of the report will outline several aspects of this project. The project design will include details about the three alternative designs as well as how they were combined to create the final design. An in-depth analysis of each subunit of the final design will be presented in this section as well. In addition, a description of the final prototype, as well as its testing and results will be documented. Following this, the report will discuss realistic constraints of making the prototype helmet as well as any safety issues that have been considered. The impact of engineering solutions on this project as well as life-long learning acquired throughout the design process will be discussed as well. The project budget will be presented along with each team members’ contribution to the project thus far. A conclusion will summarize the project and references, acknowledgements, and an appendix will be attached at the end of the report.

2. Project Design

The proposed traumatic brain injury reducing army combat helmet has several key design features such as a custom made Kevlar shell, a layer of expanded polystyrene foam, and a lockable positionable chin guard. These features will be integrated into the
design to provide ballistic, impact, and facial protection, respectively. While protection is of high importance when designing a combat helmet for military use, the comfort of the user must also be considered throughout the design process. The cooling ability, shape, and weight of the combat helmet all affect how comfortable the user will be while wearing it. The three following alternative designs were made to incorporate each aspect of comfort into the design of the traumatic brain injury reducing army combat helmet.

The creation of a cooling mechanism to help relieve the accumulation of heat in a worn helmet is a task that is seemingly left alone in modern military helmets. Upon inspection of any of the helmets, there seems to be no true cooling property, although it could be argued that the newer lightweight helmets trade off protection for less mass and subsequently less heat generated around the head. The most likely reason why cooling has not been pursued is that it often trades protection away. For example, cooling in any type of non-combat helmet is generally accomplished by cutting holes in the helmet itself to allow the heat to rise upwards continually. This is not possible in a combat helmet because one a hole has been added to the material, the area around that hole now becomes the weakest structurally, thereby adding a potential risk of mechanical failure if a force is directed near this area. Also, the confidence of a soldier with holes in his/her helmet would most likely be undermined due to the creeping thoughts of shrapnel or a bullet going through the opening.

Thus, a material must be added that does the cooling. In commercial use an item commonly referred to as an ice pack may help in this situation. Ice packs are simple containers with either purified water or gel refrigerant that can be frozen and then added to an area that will be cooled. They are also used therapeutically to help ease soreness in the body. Adding a sheet of these after the layers of expanded polystyrene can have the benefit of a cooling device without trading any protection. Although refrigerant contains better cooling properties, its potential toxicity in the case of a spill makes it a poor choice. Therefore, purified water is a much better choice for this design.

The ice packs are in a reinforced bag and these small bags will be joined together to form a sheet of these ice packs. Because this sheet is made up of individual bags, it can be flexed to fit to the contours of the helmet. This sheet must be put in a place where it can be easily taken off and refrozen when necessary. Therefore, the layer right before the padding touching the head would be an optimal area to add this. The head padding would have to be removed, but since they already can be taken off in the currently used helmet design this should not be a problem. Also, the ice pack layer should not touch the head of the user because not only will the user’s head become too cold when in direct contact, the ice will melt rather quickly compared to when it is not in direct contact. Depending on the size of the sheet and the thickness of the ice, the amount of cooling this mechanism may provide varies from an hour to several hours. However, even when the ice is melted, the water will still remain cool for a long time due to water’s specific heat capacity and latent heat properties. Although this may not provide full cooling for an entire day, it is still much better than any cooling provided by any other combat helmet on the market. In addition, it may be viable for the user to have two sheets of ice packs so that the initial sheet can be replaced after about half a day’s work. Of course, this
would mean that a soldier must have access to a freezer when off duty in order to re-freeze his/her sheets of ice, but this should not be a large problem since they may be initially stored in a freezer that contains meat or other frozen foods if no other refrigeration facilities are in the area.

The client expressed a concern over the shape of the current Advanced Combat Helmet and how it occasionally caused soldiers to wear the helmet improperly, thus reducing the effectiveness of its protection. The client explained that under certain combat situations that called for lying on one’s stomach on the ground, many soldiers complained about helmet comfort. Since the back of the ACH is low, the rim and neck strap tend to dig into the soldiers’ necks, causing discomfort. To adjust this, many soldiers simply wear their helmets backwards, as the rim on the front of the helmet is higher and thus more comfortable. While it might improve comfort, this practice significantly reduces the protection provided by the ACH.

Since the neck needs to be protected, it is not reasonable to simply design the shell of the helmet to have a higher back rim. Instead, raising the back rim in addition to adding a neck guard would provide neck protection as well as comfort. To ensure ballistic protection, the neck guard will be made out of the same Kevlar material that the shell is made out of. Padding will also be placed on the inside for comfort. To accommodate to the various body positions a soldier may be in, the neck guard will be attached to the back of the helmet with a pin or a hinge. This will allow the neck guard to move along with the movements of the user. If the user is lying down, the neck guard will move up into the inner part of the helmet, placing minimal force on the neck. When the user stands up, the neck guard will move back down to its original position. These movements and the corresponding neck guard positions are shown in Figure 1.

Since the Advanced Combat Helmet is currently worn by all combat soldiers, this neck guard design will be accommodating to the variety of situations that a soldier may find themselves in. If they are required to lie on the ground, they will retain full head protection because the helmet will be worn properly, instead of backwards. If the soldier needs to jump up and stand quickly, the neck guard will simply fall back into its protective position. The neck guard is ideal in many situations due to the fact that it will move along with the user’s movements.

This design is not perfect however, as there are several negative aspects of this design. One problem is the removal of the neck strap that is currently part of the retention system. The strap design will have to be altered to securely affix the helmet to the user’s head. An issue that could possibly occur while the user is lying on their stomach is if the neck guard moves up far enough to dig into the user’s head on the inside of the helmet. The occurrence of this situation would depend on the exact position the user is lying in, including the angle of extension of the head, but would cause discomfort to the user.
The third design is a lightweight helmet, thinner helmet. The helmet will maintain similar shape to the others described, but be made on a slightly smaller scale with thickness and some padding sacrificed to lessen its heaviness. Previous military helmets made have received bad reviews from soldiers due to their heaviness and bulkiness. In addition, if the helmet is too large, it may reduce range of view and put the soldier at risk.

Various aspects of the helmet can be revised to make it lighter, less bulky, and provide a better range of view for the soldier. The current Advanced Combat Helmet (ACH) has a 0.400 inch thick shell. With a slight reduction of thickness, the heaviest component of the helmet can be greatly reduced. The new helmet would have a 25\% reduction in thickness, resulting in a 0.300 inch thick shell. The shell is composed of a Kevlar matrix which is solid and dense, but provides very good protection against ballistics. With a reduction of thickness, some performance and protection would be lost in the case of ballistic impact, but there needs to be a balance between comfort and performance. In addition, the shaping and sizing of the helmet will be revised. The helmet will have a slightly smaller radius to allow for less padding in the system. The same thickness of polystyrene will be used in the helmet than in the previous designs. The polystyrene will aid against traumatic brain injury causing impacts. However, the comfort padding thickness will be lessened to additionally lighten the weight of the helmet and reduce bulkiness. The brim and side panels of the helmet will be moved upwards by about an inch to provide for a better field of view and a decrease in Kevlar material use.

The various modifications discussed will provide the soldier with a lighter and easier to carry helmet. Since the helmet will be slightly smaller, it will be less bulky and easy to store and carry by hand. The thinner helmet, with less padding around the
soldier’s head, may also be cooler in the desert sun compared to the bulkier helmet. The helmet will provide the soldier with an enhanced field of view due to the cut back design of the helmet. Negative aspects of these modifications include the lessened protectiveness of the helmet. A thinner Kevlar shell will not provide as much ballistic protection as the previous thicker one. In addition, less padding may provide less support for the soldiers head and be less comfortable.

The optimal design combines these alternative designs by incorporating a neck protection and lightweight design while still providing ballistic protection and reducing the risk of traumatic brain injury. Neck protection will be added in the form of the neck guard to provide comfort and protection. A lightweight design will most likely weigh more than the currently used ACH, but the improved chin and neck guards as well as the cooling system are vast improvements upon the previous design and therefore should not be left out of this design. A cooling system was present in the alternative designs, but is not included in this optimal design. The use of cooling packs similar to ice packs is not a feasible addition to this design. The packs would have to be placed between layers of padding, yet be removable in order to put them in the freezer. An added layer of material would aid in making the helmet bulkier and heavier as well as being an inconvenience for the user.

2.1 Final Design

2.1.1 Objective

The Traumatic Brain Injury Reducing Army Combat Helmet is designed to improve upon the Advanced Combat Helmet (ACH) used by the United States Army. The Army has a contract with Gentex Corporation to manufacture the helmets used by Army personnel. The current helmet is used by almost every combat soldier in the Army to protect their head from any trauma they may incur while under combat situations. As warfare practices have progressed from projectile fire to the common use of explosives, the helmets used in these situations have remained basically unchanged. Improvised explosive devices (IEDs) are one of the most dangerous threats to Army personnel in the current wars in the Middle East because the soldiers are not equipped with enough protection for the new technology. Figure 2 shows a picture of the current Advanced Combat Helmet.
Previous helmet designs focused on ballistic protection to reduce the effect of projectiles on the user’s head. However, the current issue with helmets concerning IED blasts is that since the helmet is limited to ballistic protection, impact forces on the head are causing traumatic brain injury (TBI) in many of the soldiers that survive these explosions. Since the ACH is lacking impact protection, this design aims to add impact protection while retaining ballistic protection.

Motocross helmets are praised for their impact protection abilities. The client expressed interest in investigating how the motocross helmets differed from the ACH, and whether or not the design could be incorporated into the Traumatic Brain Injury Reducing Army Combat Helmet. Several aspects such as padding and retention will be adapted from various motocross helmet models.

The complete design of the Traumatic Brain Injury Reducing Army Combat Helmet will have several components. The outer Kevlar shell will provide ballistic protection, as used in the current ACH. Beneath the outer shell will be a layer of expanded polystyrene foam to provide impact protection. Retention foam padding will be placed on the inner surface of the helmet to provide for user comfort and a secure fit. The helmet will be secured on the user’s head using a chin strap suspension system.

An innovative addition to the current ACH design was implemented in this design. To protect the user’s face, a movable locking chin guard was added to the front of the helmet. A schematic of the helmet design is shown in Figure 3. Three dimensional images of the helmet with the chin guard and neck guard are shown in Figure 4.
Figure 3. Complete helmet design.

Figure 4. 3D views of helmet from the (a) front, (b) side, (c) back, and (d) bottom.
2.1.2 Subunits

2.1.2.1 Outer Shell

The outer shell is composed of the Kevlar 29 Aramid composite. Table C shows some mechanical and chemical properties of Kevlar 29. Even compared to tempered steel, which has a Yield Strength of about 250 MPa, Kevlar 29 can withstand over ten times as much strain.

<table>
<thead>
<tr>
<th>Property</th>
<th>Kevlar 29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.44</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>7</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>2920</td>
</tr>
<tr>
<td>Ultimate Strength (MPa)</td>
<td>3620</td>
</tr>
<tr>
<td>Maximum Elongation (%)</td>
<td>3.60</td>
</tr>
<tr>
<td>Tensile Modulus (GPa)</td>
<td>70.3</td>
</tr>
<tr>
<td>Specific Heat Capacity (J/g°C)</td>
<td>.340</td>
</tr>
<tr>
<td>Thermal Conductivity (W/m-K)</td>
<td>.0400</td>
</tr>
<tr>
<td>Maximum Service Temperature (°C)</td>
<td>149 – 177</td>
</tr>
<tr>
<td>Shrinkage (%)</td>
<td>≤ .100</td>
</tr>
</tbody>
</table>

Due to the relatively weak protection the modern Advanced Combat Helmet has for the sides and back of the head, a new helmet shell will be made based on a mold. Creation of Kevlar 29 is based on a composite reaction whose two reactants is a Kevlar 29 cloth weave and Epoxy resin. Figure 5 is the chemical reaction that describes this composite reaction.

Figure 6 shows the reasoning behind the creation of a new outer shell design. The helmet protects the entire side of the user’s head down to the entire ear. This is a stark contrast to the Advanced Combat Helmet, which is shown in Figure 5.
Figure 7 shows a startling realization that most of the side and lower back of the head is exposed to damage. By completely shielding every part of the brain, this will ensure a decrease in Traumatic Brain Injuries compared to the current helmet outer shell. Figure 8 shows an example of a force hitting the back of the head coming from the ground. This is a very possible example of an Improvised Explosives Device common in...
modern-day Iraq. The soldier has his/her head turned away from the IED because he/she has no idea where the blast will come from. The Advanced Combat Helmet will offer protection to the upper part of the back of the head, but the lower portion will suffer the entire force of the blast, which will cause the user to suffer a closed head injury, which causes the brain to hit the side of its own skull and cause tissue damage. The lower back of the head contains the cerebellum, which may permanently alter the way the soldier moves about in the world if damaged. With the new outer shell design, the cerebellum will be insulated by the helmet, and in the worst case scenario only the neck will be unprotected. However, this can also be avoided if the neck guard attachment is worn when the user is in an upright position.

The PASGT helmet, the predecessor of the Advanced Combat Helmet, is of similar strength as the ACH and has 19 layers of Kevlar [3]. Therefore, the new shell must match at least that amount of layers. However, weight is a large concern, so if any new layers are added then the amount will be less than three or five, depending on how much thickness a single layer adds on to the total bulk of the helmet. Although adding more layering is an important aspect of the helmet design, there is no real merit to adding much more because this will not really decrease the change of a Traumatic Brain Injury.
by much if any. The true focus of this design is to increase the range of protection in the sides and back of the head.

2.1.2.2 Expanded Polystyrene Layer

The middle layer of the helmet will be composed of an expanded polystyrene (EPS) shell due to its excellent impact absorption properties. As mentioned in the introduction, the main purpose in the design of this helmet is to protect against TBIs. With a recent study published in the *The New England Journal of Medicine*, nearly 15 percent of army infantry soldiers deployed in Iraq reported injuries with loss of consciousness or altered mental status [4]. Previous models of military helmets including the new ACH do not provide enough padding for absorption of impacts from ballistics, vehicle crashes, and falls. EPS was chosen due to its properties and success in bicycle helmets.

EPS is a lightweight plastic material that has special properties due to its structure. It is inexpensive to manufacture and therefore can be used as a disposable
insert in the military helmet. The EPS foam is composed of individual cells of low density polystyrene. The main component of EPS is styrene (C₈H₈), which is derived from petroleum or natural gas by a reaction between ethylene (C₂H₄) and benzene (C₆H₆). Styrene is then polymerized by heat and then needs an inhibitor such as oxygen to stop the reaction. To make the low-density, loosely attached cells, the polystyrene must be suspended in water to form droplets. A suspension agent is then added to the water to prevent the droplets from sticking together. The beads of polystyrene that are produced by suspension polymerization are tiny and hard and require special blowing agents, such as propane, to make them expand. [6]

EPS is commonly used in bicycle helmets, as shown in Figure 9, due to its lightweight properties and excellent impact absorption capabilities. EPS is a high density foam and somewhat hard. In a bicycle crash, upon impact of the user’s head within the helmet, the EPS slightly crushes and cracks, absorbing some of the impact force and decreasing the deceleration. EPS would serve as a great material in a military helmet. In the design, a 0.5” layer of EPS is molded to the form of the helmet. The EPS shell is then inserted into the outer shell of the helmet where it can be fastened in with Velcro adhesive. This EPS layer is disposable and replaceable if a soldier is to damage it in an accident. In addition, the EPS layer is compatible with the padding system which will be discussed further. The EPS shell will have Velcro adapters so that the adjustable padding system can be connected within the EPS shell. The EPS is virtually weightless. It will add no additional weighted burden to the soldier, while providing excellent cushioning on heavy impacts.

In summary for the EPS shell, the lightweight system will provide an inexpensive, yet effective means to decrease TBIs in various accidents. The EPS shell can be

![Figure 10. Equilibrium forces on EPS](image)
produced on a large scale basis inexpensively and be available for replacement at the military bases. In Figure 10, the force diagram of the EPS shell can be seen.

2.1.2.3 Retention Padding

The retention pads are a very important part of the helmet design. While the Kevlar shell protects from projectiles and the EPS layer protects from impact forces, the issue of user comfort cannot be ignored. While the weight of the complete helmet will be kept at a minimum, it still exerts a force upon the user’s head. In order to alleviate the head of discomfort caused by the protective materials coming in contact with the head, inner comfort padding will be attached to the inside surface of the helmet.

The current padding system in the ACH is similar to the one shown in Figure 11. Pads known as Zorbium™ Action Pads (ZAP) made out of polyurethane foam [7,8] are placed on the inner surface of the helmet shell. They are held in place with hook and loop fasteners, allowing the user to remove and replace them if necessary. This also allows the user to adjust the placement of the pads for customizable comfort.

Some specifications of the materials used for the pads are put in place by the Army. The woven material covering the pads and contacting the head must wick moisture away from the user’s head and absorb it. The inner padding material should provide standoff, comfort, protection, and stability. The fastening material should be made of a loop-type material and allow the pad to be attached to the inside of the helmet shell. The Army requires that the material have a peel strength of no less than 2.8 lb/in width (~ 0.5
kg/cm width). The pads should be able to withstand multiple compressions without failing or showing degradation. [10]

The padding design used in this helmet design will be similar to what is used in the current helmets. However, since a layer of EPS foam has been added to this design, the hook and loop fasteners will be adhered to the EPS instead of the outer shell. The retention padding kit shown in Figure 12 was obtained from Gentex Corporation. These pads are the same as what is currently used in the ACH, so they will perform to the same standards as described above. A cross-sectional schematic of one pad is shown in Figure 13.

The pad system in this design will be successful for its purpose due to the pad’s material properties and static equilibrium forces of the subunit. Figure 14 shows the equilibrium forces acting on the pad system. The force of the user’s head will be counteracted by the reactive force the foam will exert on the user’s head. This force is an

![Figure 12. ACH retention padding system. [11]](image1)

![Figure 13. Cross-sectional view of one pad attached to helmet shell.](image2)
intrinsic property of the foam material to expand to its uncompressed state. The force of the pad pulling on the hook and loop fastener will be counteracted by the hook and loop fastener material, holding the pad onto the shell. The reactive force of the adhesive will counteract the opposite force of the fastener.

2.1.2.4 Suspension System

Based on all current suspension kits available, the Gentex Corporation X-Harness 4-Point Retention System was chosen. Figure 15 is a diagram of this suspension system. This system was eventually chosen due to several important factors. One of the most important reasons for this choice is that it was approved by the U.S. Army for ground and airborne operations in July of 2005 [12]. Early design ideas for the suspension system pointed to the use of a chin strap used in helmets designed to prevent brain injuries rather than bullets due to any inherent design goals of preventing traumatic brain injuries. However, this route posed two negative consequences. First of all, non-military suspension systems are obviously not approved by the U.S. military, which would make the entire project at risk of being unapproved for active combat. Secondly, the chosen suspension system has four tension wires coming out of the helmet, which helps reduce the tension in each wire and therefore reduces the tension the head has to feel when the straps are on tight. Therefore, this choice is actually better for preventing brain injuries because the larger amount of wires sharing the tension helps even the forces out rather than concentrating them in at a single point. Lastly, although this suspension system is designed for the Advanced Combat Helmet, only four holes needed to be drilled in to the helmet in order to fit, so it was be relatively easy to translate these four screw holes into the new helmet.
Figure 15: Diagram of Gentex X-Harness 4-Point Retention System [13]

Figure 16: Free Body Diagram of X-Harness 4-Point Retention System

Figure 16 is a free body diagram of the suspension system flattened out. Note that because the chin strap is shown on a two-dimensional plane, the x-direction is positive in both the left and right directions due to the curvature of the straps when placed on a head. The y direction is not affected by this. As shown in the diagram, the total tension placed
on the straps is cut by one-fourth due to the four straps connecting to the helmet where the T vectors are located.

The suspension system is assumed to be in equilibrium. Based on the static equilibrium equations, the total tension on the straps can be calculated.

\[
\begin{align*}
\sum F_x &= 0 \\
T \cos \theta_1 + T \cos \theta_2 + T \cos \theta_3 + T \cos \theta_4 - 2N &= 0 \\
1 &= 4(\cos \theta_1 + \cos \theta_2 + \cos \theta_3 + \cos \theta_4) + 2N \\
\sum F_y &= 0 \\
T \sin \theta_1 + T \sin \theta_2 + T \sin \theta_3 + T \sin \theta_4 + C &= 0 \\
1 &= 4(\sin \theta_1 + \sin \theta_2 + \sin \theta_3 + \sin \theta_4) - C
\end{align*}
\]

N and C are the normal forces exerted by the cheeks and chin, respectively. T, N, and C are dependent on how tight the suspension system is strapped to the individual. The maximum published tension the straps can withstand is 115 lbs, or 512 N [14]. Measuring the actual tension in the straps proves difficult because the normal force N is not concentrated at a point in the free body diagram but rather distributed. However, due to the elastic properties of materials, measuring the strain, or percent elongation, or a segment can help determine how much tension is on the segment. Although the actual force is not necessary, how close it comes to the maximum is important knowledge. Unfortunately, the maximum strain of the straps is not published. Therefore, if the forces on the straps were to be tested, the maximum percent elongation of the straps must be obtained by stretching them until they break. This would require a test pair of chin straps. Once the maximum strain is calculated, another pair of chin straps is put on normally on the helmet and set tightly. Then the strain is measured and compared to the maximum strain. Since the elastic region on a stress-strain curve is linear, the force can be mathematically derived. Several different tensions can therefore be calculated to see which trial is the optimal tightness while lowering the stresses as much as possible without compromising the suspension. Strain is calculated based on the following equation.

\[
\text{strain} = \frac{\text{maximum length} - \text{initial length}}{\text{initial length}}
\]

One final note on the choice of this suspension system is the design of the chin segment. As shown in Figure 5, it has two segments, which reduces the amount of stress on the chin and therefore makes it a more comfortable fit. Stress is calculated based on the following equation.

\[
\sigma = \frac{\text{Force}}{\text{Area}}
\]

Since the area around the chin is increased, the stress acting on the chin is therefore decreased.
2.1.2.5 Chin Guard

The chin guard on the helmet provides a range of protection and purpose for the soldier. First and foremost, the chin guard protects a significant portion of the soldier’s facial region against ballistics such as bullets, fragments, or shrapnel. In previous models, such as the ACH, no facial protection is provided. The chin guard also protects against sudden impacts such as falls, vehicle accidents, etc. The distributed force of the incoming impact throughout the chin guard may prevent some mouth and jaw injuries along with reducing TBIs. The last main purpose of the chin guard is the maintenance of the helmet’s stability and position on the soldier’s head. Previous models, such as the ACH, do not provide a quick system to securely fasten the helmet to the soldier’s head. The ACH uses a chin strap to fasten the helmet to the soldier’s head which may need adjustment. The ACH simply rests on the soldier’s head, and the chin strap prevents the helmet from sliding around or falling off.

Figure 17. Side view of helmet with chin guard down (left) and up (right).
Figure 18. Front view of helmet with chin guard down.

The chin guard has two positions as can be seen in Figures 15 and 16. The inactive position is when the guard is rotated up and resting on the top of the helmet. The soldier can then push a button on the guard to release its hold and rotate it downward across the face towards the chin where it can snap in place. Once the guard is snapped in place, the helmet can be securely fastened to the soldier’s head via the helmet and chin guard combination. The chin guard prevents the helmet from rotating left and right or tilting up and down. The guard also protects against the helmet lifting up off the soldier’s head. For means of visualizing and understanding this concept, one can relate to a motocross helmet which surrounds the head and has the facial and chin protection as well. While the designed helmet does not have as large a size and coverage of a motocross helmet, one can relate to the amount of coverage and snug fit a motocross helmet provides in relation to a bicycle helmet, which can serve as a rough analogy to the ACH. When the chin guard is in its upright position, the soldier has the option to use a chinstrap to secure the helmet to his head since the guard is not there for support.

The outer shell of the chin guard is composed of the same composite the shell of the helmet is made of: Kevlar. The chin guard is processed and molded into an appropriate form and size for the helmet created. The color of the chin guard is the same as the outer shell. The only other component of the chin guard is the padding system. Unlike the outer shell of the helmet, the chin guard has only comfort/support padding.
Figure 19. Equilibrium forces on chin guard.

The guard does not have an expanded polystyrene (EPS) layer as the outer shell does. The EPS layer was omitted to conserve space, provide a chin guard that is not bulky, and provide enough clearance to clear the soldier’s face when the chin guard is changed from upright to down positions or vice versa. The comfort/support padding is the same padding used in the outer shell, but smaller. The padding is glued with a strong adhesive to the inside surface of the chin guard. The chin guard is connected to the outer shell by a simple pivot system. The guard can be released by a push button system that will release the lock that holds the guard in place. The movement of the guard down over the chin activates the lock mechanism and secures the guard in place.

In summary for the chin guard system, the guard serves multiple purposes on the helmet. It provides stability and a secure fit to the soldier’s head. More importantly, it provides partial facial, chin, and mouth protection against ballistics and impacts from vehicle crashes and falls. This distribution of impact may protect against TBIs resulting from impacts at the face or chin region. The chin guard is innovative and not seen before in the military helmet. In Figure 19, the force diagram of the chin guard can be seen.

2.1.2.6 Testing

After building the prototype helmet, an Advanced Combat Helmet was used to perform comparison testing. The Advanced Combat Helmet was manufactured by Gentex Corp. and will possess the same quality and specifications required by the US Army. This helmet was donated to the team.

A drop test was used to simulate impacts on a flat surface. Testing equipment was modeled after equipment used by various helmet testing laboratories and research centers, as outlined in the US Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure [15]. A headform was mounted inside the helmet to simulate the presence and weight of a human head. An accelerometer was located inside the headform and attached to a DAQ. Acceleration and velocity data was recorded using a LabVIEW program. The test apparatus used a cable system to drop the
helmet onto a flat anvil. The helmets were tested at various heights to obtain various velocities. A variation of this test setup is shown in Figure 20. This test will simulate the acceleration and forces experienced by a human head inside a combat helmet being propelled onto buildings, vehicles, and other surfaces after being thrown from an IED explosion.

After testing the prototype helmets and the Advanced Combat Helmet, g-force data was compared and analyzed. According to DOT, the “accelerations in excess of 400 g or cumulative dwell times in excess of 2.0 ms above 200 g or 4.0 ms above 150 g shall be recorded as failures.” [15] If the prototype helmet does not meet the 150 g specification, it will be considered a failure. The prototype should have the lowest g-force that is obtainable, so several tests were performed to verify this.
2.2 Prototype

Three prototype outer shells were built in order to provide adequate amounts of data based on several falling velocities. The first helmet built is made of pieces of Kevlar cut into triangles and then hardened together. Figure 21 shows the hardened triangle helmet before being cut.

![Prototype 1 Triangle Design](image)

**Figure 21. Prototype 1 Triangle Design**

A triangle design was initially used because the second technique, the pinwheel, was much more difficult to implement. Therefore, the triangle design allowed the team to start helmet creation about a week and a half before the second design method was correctly implemented. Cutting each Kevlar layer requires a Kevlar sheet about 24” x 25” and requires eight “arms” that were draped over the shell. Figure 22 shows the cut layers of the second prototype before hardening. Each layer has been cut with eight protruding segments. Prototype three was also cut using the same methodology.
Figure 22. Pinwheel Design

Figure 21 shows that when the Kevlar hardens, it does not match the shape of a standard helmet. The Kevlar layers harden in a similar way to the triangle layers, meaning that all three helmets must be trimmed down using a hand mechanical jigsaw. This process can take about one to two hours per helmet if accuracy is desired. Figure 23 shows the trimmed second helmet after cutting.

Figure 23. Pinwheel Design
Fourteen inch cubes of Expanded Polystyrene of one pound density were cut down using a Freehand Router, a tool consisting of a heated wire that can be bent to any shape. First the cube was cut down into a cylinder with a size similar to the helmets’. Figure 24 shows the foam block before it was cut. The marked circle will be the dimensions of the cylinder once cut out.

Once the block was cut down into a cylinder, the top was rounded so that it could roughly fit into a helmet. The cylinder was then cut around the middle, slightly under the bottom of the earcups. This piece was then carefully hollowed out with the tool. Final smoothing of the foam was worn down by coarse sandpaper. Figure 25 shows an Expanded Polystyrene cutout ready to be inserted into a helmet. In this picture, it is held slightly thicker than the final product, at about 6/10”. The foam was cut down to about 3/10” in order for the padding system to be attached via velcro circles. In addition, testing requires a headform to be inserted into the helmet, which is another crucial reason for the EPS trimming.
The final step before testing was attaching the Gentex X-Harness suspension system onto the helmets. In order to do this, four screw holes were drilled into four points of the helmets. This was performed with a hand drill with size I drill bit. The drill bit wore down fairly quickly, so two or three were needed depending on the bits’ initial sharpness. The required screws are in the kit that comes with the suspension system. However, they were too small to fit on all helmets due to Kevlar layering. Binding screws with longer shafts were purchased at a hardware store to attach the suspension system at these points. The pinwheel helmets had eight layers of Kevlar and were able to use the original screws, but the triangle helmet was slightly thicker and required longer screws. Once the suspension system is in place, then four slits must be cut into the outer shell of the EPS shell in order to compensate for the suspension system straps. The foam was then sanded down to 3/10” and hook and loop circles were added onto the foam, as shown in Figure 26. These circles only stuck well when using epoxy-based glue as an adhesive. Hook and loop was used because the helmet padding sticks to it. Note that this was done for all three helmets. Lastly, Figure 27 shows the helmet with the chin guard. It takes about 15 hours to complete a single helmet not including about eight hours for the Kevlar to harden.
Figure 26. Prototype with EPS and Velcro

Figure 27: Prototype Model
Testing involved attaching the helmet to a headform with an internal accelerometer. Figure 28 shows the testing apparatus. This drop test simulates the user while experiencing an impact to the head. The testing equipment was raised to a specific height that corresponded to a specific impact speed. Data for 8, 10, 12, and 15 ft/s were collected to compare the original ACH to the prototype helmets as well as the Expanded Polystyrene to the original helmet padding. In general, the results showed that Expanded Polystyrene reduced accelerations on the head by about 50%. Figure 29 is a comparison of the prototype helmets with EPS, the ACH with padding, and the prototype helmets with padding. At 15 ft/s, the ACH with pads is about 205 G’s while the prototype with EPS is about 95 G’s, a decrease of 54%. This is because as velocity increases, helmets with EPS increase acceleration slowly while helmets without EPS begin to experience exponential growth, which shows EPS as a very important acceleration reducer in higher impact encounters.

In addition, Figure 28 compares the prototype helmet with the ACH at different velocities with only pads inside. The results are fairly similar and show that in terms of mechanical impacts, there is not a significant difference in quality between the helmet currently in use and the helmets created in the lab. At 10 ft/s the results are nearly identical, although at higher speeds the ACH begins performing better. The highest recorded speed has the ACH performing about 16% better than the created helmets.
Figure 29. Comparison of Helmet Testing

Figure 30. ACH and Prototype acceleration data
Since Figure 30 shows that the prototype helmet performs similarly to the ACH, the prototype with pads can then be compared to the prototype with pads and EPS to show a relationship between our prototype and the ACH. Figure 31 shows that the prototype with pads and EPS performs significantly better than the prototype with pads only. At the ACH test standard velocity of 10 ft/s, the prototype with pads and EPS experiences a g-force 27% lower than those experienced by the prototype with pads only. Since these results can translate to compare the prototype with pads and EPS to the ACH with pads only, it is apparent that the prototype performs much better than the ACH does at all velocities. It should also be noted that as velocity increases, the difference in performance is extremely high, thus showing that the prototype design would perform better in high velocity impacts than the ACH would.

It is known that EPS degrades after it experiences an impact. In order to simulate this, the helmets were dropped several times. Figure 32 shows the data for these drops. The graph shows that as the number of impacts increase on the same helmet, the amount of g-force increased for all helmets tested. This figure is crucial in showing that even though EPS degrades as the number of impacts increase, the prototype still provides more protection than the ACH would. While the rest of the helmets were dropped three times, the 15ft/s helmet was dropped several more times to determine when it would exceed the 150 G standard set for the ACH. Figure 33 shows the EPS degradation data for that helmet after six impacts. It is shown that at least five impacts were needed in order to exceed the standard.

![Comparing Prototype with Pads to Prototype with Pads and EPS](image)

**Figure 31. Prototype performance with pads and with pads and EPS.**
The most important conclusion based on the collected data is that helmets with Expanded Polystyrene shells appear to increase acceleration linearly while helmets
without EPS experience acceleration increases much faster. In addition, as the material degrades with prolonged hits it’s important to either switch the EPS layer out for a new one or completely replace the helmet. The current military policy is to replace a helmet after one major impact so EPS degradation does not become a problem. Although it has been shown that Expanded Polystyrene does decrease the amount of acceleration and therefore forces that affect the head, the original question of brain injury reduction is not yet answered.

One of the most used ways to diagnose brain injuries is the Glasgow Coma Scale. The GCI is an observational method that classification based on a victim’s verbal, motor, and eye reactions to stimuli. The victim is then scored from 3 to 15 and put into a category of either Mild, Moderate, or Severe brain injuries. Already there is a problem comparing our data to a system such as this because it compares data to an observation. There is no real effective way to say that “x amount of forces reduced produces a y increase in the GCI.” In addition, the relationship is much more complicated than a simple one-to-one relationship, such as “an x percentage of forces reduces an x percentage of brain injuries” because when a force impacts a helmet even at a single point, it sends a wave of energy throughout the entire head that emanates from the point.

Since this safety system is modeled after commercial helmets that use EPS, such as bicycle helmets and motocross helmets, similar conclusions may be derived based on data pertaining to the commercial helmets. Many of these studies are population based and compare mortality rates. For example, one 20 year study from 1982 to 2001 estimated that motorcycle helmets decrease mortality rates by 74%. [22] However, this study is binary and only counts life and death as two possible outcomes and does not comment on brain injuries.

Medical textbooks do show that decreasing the intensity of an impact will decrease the probability of certain types of brain injuries. The most obvious is the open brain injury, also called the penetrating brain injury, where the skull has been breached. In addition, one effect of a brain injury called a countercoup effect, which causes the brain to hit the skull and rock back and forth, is caused by inertia, which is largely based on the initial impact amplitude. Therefore, although there are currently no studies to mathematically equate a certain decrease in impact force to a decrease in brain injuries because that involves a qualitative comparison to quantitative data, a large decrease in acceleration that the brain experiences will almost certainly decrease brain injury probability by a significant margin.

One final note on the prototype is the temperature inside the helmet. Polystyrene is an insulator, which will trap heat. Although initially the helmet temperature will remain cooler, it will heat up quickly based on the user’s activity level. However, it will not necessary be any warmer than the original Kevlar helmets because heat is not be removed by the Kevlar either. In addition, the head will not be in contact with the polystyrene due to the padding system, so there is a small amount of airflow occurring. Early on in the project one of the proposed designs included a layer of crushed ice between the polystyrene and the helmet. This was ultimately dropped because if that was
added something else would have to be removed because helmet space is not wasted at all. Additionally, no holes could be cut into the helmet for ventilation for obvious safety reasons and there are no cooling solutions on the market that are easy to employ.

When reflecting back on the project, several changes would be made. Ideally, specific machine-manufactured EPS shells would be used for precise fitting, rather than shaping them by hand. Similarly, a machine-manufactured chin guard that was fitted to the outside of the shell would be desired over the current guard. As shown in Figure 34, the desired curvature was not achieved when this was made by hand. Another change that would be considered in future work would be to design the EPS differently so the neck guard would fit in. The neck guard was originally supposed to be added to the final prototype, but there wasn’t enough room for it to move with the EPS layer inside as well. Ideally, the chin strap suspension system would also be slightly different. Instead of a buckle fastener, a rubber-coated D-ring fastener would be preferred in order to minimize noise.

3. Realistic Constraints

The most important aspect of this helmet is for it to be reproducible on a large scale basis. In addition, the helmet must be within a reasonable price range of current models on the market. A very expensive helmet will serve no purpose in the military if thousands have to be ordered at a cost much steeper than the current models. An expensive helmet would drastically affect the military’s budget since every soldier needs one. In addition to being affordable on a large scale basis, the helmet must sell itself have a convincible purpose as to why it should be used rather than the current models. As discussed before, the helmet designed can protect soldiers against TBIs in combat.
situations, which according to statistics, has been a common injury in military combat in recent years. For this reason, the new helmet is a better option for the soldier’s safety in comparison to the current ACH.

The manufacturability of the helmet would not be much different from current models. A similar Kevlar outer shell is used in this design meaning there would not be much change in manufacturing except for size and thickness changes. The chin guard could be produced in the same manner as the outer shell, using the same Kevlar material. The EPS inner protective shell could be inexpensively mass produced as well. The padding system can be affordably purchased and added to the helmet. Padding systems are inexpensive since they have been on the market for years. The addition of the padding to the helmet would not cost much labor either. The chin strap is an inexpensive addition as well. No parts of the helmet pose a threat as challenging to manufacture or budget in respect to existing helmets on the market.

Environmental conditions for the helmet are of utmost importance and lengthy. The helmet and its components must be able to withstand the various harsh environmental conditions of the desert and its elements. There shall be no structural, visible, or operational degradation to the helmet when it is subjected to seawater. All components should be intact and there should be no softening, peeling, or other damage to the material. The helmet shall be flame resistant and not melt or soften in a small flame. In addition, the helmet shall not exhibit damage when exposed to high temperature storage or use. Its components should remain structurally and operationally unchanged as well. The same results are expected of cold temperature storage and use. Also, when exposed to temperature shock, the helmet and all components should not exhibit any structural or operational damage.

The helmet and its components should not be affected by altitude either, such as in mountains or on a plane. The helmet and its components should not be affected by excessive vibration either. Parts should remain intact and not become loose or disassemble. Minor damages to paint or surfaces of the shell are expected with excessive wear of the user. The helmet and padding system shall be resistant to excessive sweat and water absorption and drying. The pads should be resistant to sweat along with bacterial and fungi growth. The helmet and components should be resistant to excessive and abusive use including fastening and removing of the helmet. The helmet and components should remain intact and undamaged from being dropped.

The helmet as a system should be suitable for military situations. The helmet should not fail the soldier in terms of sacrificing his position. The helmet should be able to be camouflaged with surroundings. The helmet should also be as quiet as the surroundings and not make noise or any unwanted sounds. The helmet should be able to be quickly put on and fastened on the soldiers head in emergencies in fast acting situations. The helmet should fit its soldier’s head appropriately based on the size of the helmet and the padding system used. The soldier should be able to use the helmet and the system easily and quickly without training or any lack of understanding. The padding system should be easily adjustable for the soldier to exchange new pads or replace a
damaged EPS shell. Importantly, the helmet should fit the soldier’s needs including comfort. The soldier should be able to wear the helmet for extended periods of time without being bothered by the pads, chin strap, chin guard, or weight of the helmet. The helmet is made of Kevlar, a light weight composite, along with the light weight EPS, and light weight comfort pads. The helmet shall be balanced properly so that it is comfortable for the soldier and it does not slide or change position. The helmet shall fit securely to avoid movement, but yet not tight enough to cut off circulation to the neck, head, or face. There should be no sharp or rough edges exposed to the soldier that could produce a rash or excessive irritation over time. The helmet shall be able to be washed and cleaned without damage to any of the parts.

In addition, the helmet should be resistant to a 9mm bullet round and to a certain extent some shrapnel. The most important use of the military helmet on the battlefield is to protect the soldier’s head from enemy fire and explosions. The helmet should be able to withstand some of these forces. The durability and life of the helmet are of utmost importance. The helmet has to be able to withstand the demands of the soldier and combat environment. The cost of the device failing in certain situations could result in injury or even death.

4. Safety Issues

There are many safety issues that must be addressed when designing a helmet for use in military combat situations. Thermal stability, mechanical safety, biological hazards, and combat safety are some examples that must be considered. A balance must be made between design features and the safety of the user and their environment before the helmet can be deemed appropriate for combat use.

One of the biggest safety issues with anything that will be used in countries in the Middle East concerns thermal stability. With average temperatures ranging from around 10° C to over 40° C throughout the year [16], the materials used to build the helmet must be able to withstand constant exposure to a warm environment. The main addition to the ACH design is the layer of expanded polystyrene foam. In addition to having excellent compressive properties, polystyrene also has a very high melting temperature of 240° C [17]. This property ensures there will be no issues with the foam degrading or melting while being used in the helmet under extreme temperature conditions.

There are several components that have been addressed to make sure the helmet design will not have any mechanical safety issues. One of the reasons Kevlar is used as the material for the outer shell of the ACH is its strength when exposed to an outside force. The Kevlar shell reduces much of the concern of the mechanical safety of the helmet due to the fact that it has been used for many years in the ACH and other military combat helmets due to its excellent ballistic protection. As long as the manufacturing process produces a defect-free Kevlar shell, it will be assumed that the shell is mechanically safe. Similarly, the EPS padding layer is not of mechanical concern due to its previous use in bicycle, motocross, and motorcycle helmets. EPS was incorporated
into this design because it has exceptional compressive properties. For this reason, EPS mechanical failure is of minimal concern for this design.

Focuses on design safety must be placed on biological hazards because the helmet will be worn by a human being. The materials used that will be touching any part of the user’s face, neck, and head must be non-toxic. While it is impossible to accommodate for every single user, the material must also be non-allergenic to avoid any interactions of the material with the skin. It is for these reasons that a non-allergenic, non-toxic fabric will be used to cover the comfort padding. The padding material used must also prevent mildew, mold, and bacteria from accumulating. Polyurethane foam in the ZAP padding kid exhibits these properties, thus reducing the biological hazards associated with padding inside the helmet.

There are also many combat safety issues that must be considered when designing a helmet for military use. Soldiers in combat constantly need to conceal themselves from their enemies. Revealing their positions could put them in extreme danger, which is why all combat equipment is specially designed with this safety issue in mind. The color of the helmet will be similar to the olive green used on the current ACH. The paint used will be non-reflective and have the same visual properties as that of the ACH. The shape of the helmet will accommodate for the use of camouflage coverings over the outer shell as well. The chinstrap will also have a special design to reduce noise. The D rings used to fasten the chin strap will be coated with rubber to eliminate the chance of two metal rings hitting each other and creating noise that could potentially reveal the position of the user. All parts of the helmet will be securely fastened to create minimal noise while being worn. These combat safety hazards are a very important part of the design of this helmet and could be life-or-death design flaws if not addressed.

Lastly, there are some safety concerns involving the creation of a Kevlar helmet. The epoxy and curing agent may cause respiratory issues and skin irritation from long-term exposure. Therefore, the bare minimum safety requirements for handling these chemicals should be working under a fume hood using latex gloves. The chemicals will seep through plastic gloves so those do not meet the safety requirements. Although a fume hood helps remove most of the harmful fumes in the air, if curing Kevlar is a long-term action then breathing protection in the form of a surgeon’s mask or even a gas mask is highly recommended to protect the user. Finally, when the Kevlar hardens, the edges can be extremely sharp and will cut naked skin several times with microscopic cuts. Therefore, great care should be taken when handling.

5. Impact of Engineering Solutions

Traumatic Brain Injuries in fields of live combat are extremely common, with [18] revealing the startling statistical data even in modern day scenarios.

“The Defense and Veterans Brain Injury Center (DVBIC) has reported that 59% of an ‘at risk’ group of injured soldiers returning from Afghanistan or Iraq to Walter Reed (2003-2004) suffered at least a mild
TBI while in combat. Further characterization of 433 war fighters revealed that the TBI was moderate or severe in more than half the group. The TBI was due to a closed head injury in 88%.”

This article states that over half of the soldiers placed in a situation with any change of a traumatic brain injury will suffer from one. Therefore, if this project is successful even slightly, the rate of injuries could be decreased by a statistically significant amount with very little effort.

The idea of war has in recent decades become less of an issue in the whole-scale public arena due to the abolition of the draft. Now that the army is purely made up of volunteers, new recruits are difficult to obtain compared to past generations. The lingering phantom of injury, whether permanent or not, or even death, must undoubtedly weight heavily upon anyone willing to bear arms. Equipment that can be statistically proven to decrease the chance of brain injury compared to anything currently in use may spur recruitment numbers if the data is adequately advertised. In addition, the cost of healthcare is always a great burden on society. Even if an injured soldier has his/her healthcare costs waived by the military, ultimately the taxpayer will pay the bill. With a decreasing pool of available members of the Armed Forces in developed countries, a decrease in the amount of casualties will help counter the thinning ranks. Depending on the situation, even a slight increase of a chance of a piece of equipment preventing injury at a critical moment may change the entire outcome of a battle. Any new piece of equipment that could potentially prevent such healthcare costs even slightly will prove to be a very smart move economically in the long run, even if the initial cost of restocking the entire army with new helmets is a large initial cost. Since the outer shells of modern helmets are made of Kevlar Aramid, the material may be recycled in order to help reduce the cost of the product.

There are currently no real methods of cooling for a military helmet on the market for good reason. Several great engineering challenges obstruct the design of a cooling system. For example, putting a hole in a structure weakens it. In addition, the area around the hole becomes the weakest part of the structure. In a device built around protection, this is not an option. In addition, the morale of the soldier using the helmet would decrease due to the possibility of a bullet piercing through the hole, however small of a probability that may be.

Although Kevlar itself is an expensive material mainly due to its complex synthesis reaction involving expensive chemicals such as highly concentrated sulfuric acid, it is relatively safe and consumes little energy, making it relatively “green” compared to other synthesis reactions. The epoxy resin is the most hazardous item on the synthesis list and may cause skin irritants or may induce an allergic reaction, which therefore means it must be used in a well-ventilated area.
6. Life-Long Learning

The largest area of technique throughout this project is in the method of “fiberglassing.” In its most basic terms, fiberglassing is the creation of a composite material by the means of a chemical reaction. Although the original material used in this technique was fiberglass, the technique also works on Kevlar Aramid and carbon fiber. The general description of fiberglassing is seen in [19].

“Fiberglass is actually a textile. It comes on a bolt like a big, white bedsheet. The stuff that makes it hard (like a boat) is the resin. Resin is a liquid and is applied as a coating to the fiberglass. Unlike most household coatings, the resin requires a hardener. The hardener is also a liquid which, when added to the resin, causes a reaction which allows the resin to cure. When the resin (plastic) hardens in and on the fiberglass (reinforcement,) you have a reinforced plastic (like a boat.)”

As previously mentioned, there are three types of materials used in the fiberglassing technique. Fiberglass provides a good balance of mechanical properties such as its tensile strength. Carbon fiber is the mechanically strongest of the three, with the largest tensile strength and Modulus of Elasticity. Kevlar Aramid fiber provides weaker mechanical strengths than carbon fiber, but is stronger against abrasion and is lighter in weight. Therefore, Kevlar is the best choice for this project in particular due to its superior ballistics qualities. Specifically, Kevlar 29 is used because it is the most lightweight of the Kevlar weaves and is best suitable for body armor of all types. Table D shows some properties for Kevlar 29 and is based on data found in [20].

<table>
<thead>
<tr>
<th>Property</th>
<th>Kevlar 29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.44</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>7</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>2920</td>
</tr>
<tr>
<td>Ultimate Strength (MPa)</td>
<td>3620</td>
</tr>
<tr>
<td>Maximum Elongation (%)</td>
<td>3.60</td>
</tr>
<tr>
<td>Tensile Modulus (GPa)</td>
<td>70.3</td>
</tr>
<tr>
<td>Specific Heat Capacity (J/g-°C)</td>
<td>.340</td>
</tr>
<tr>
<td>Thermal Conductivity (W/m-K)</td>
<td>.0400</td>
</tr>
<tr>
<td>Maximum Service Temperature (°C)</td>
<td>149 – 177</td>
</tr>
<tr>
<td>Shrinkage (%)</td>
<td>&lt;= .100</td>
</tr>
</tbody>
</table>

An Aramid fiber is also a very important type of material for the success of this project. Aramid stands for aromatic polyamide, as shown in Figure 35. The strength of this molecule comes from the chain molecules are in the same direction as the fiber, which increases the strength of the chemical bond in that direction and allows for a high degree of orientation. Aramids are also relatively resistive to heat and will not weaken under normal temperatures on Earth.
7. Budget

The acquisition of both an Advanced Combat Helmet and a motocross helmet were very beneficial to the creation of the prototype. These helmets were inspected to see how the materials were fastened together. More importantly, a comparison of the padding between these two helmets was of great interest to our client. These helmets were be acquired via donations, which drastically reduced the overall cost of the project. Normally each has a value of about $400 so finding a donation decreased the overall price by around 40%.

As for the creation of the prototype, because the majority of the materials are composites, the Fibre Glast Developments Corporation is a great resource for these types of materials. An epoxy resin is chosen due to its superior characteristics over polyester resins and also due to its superior adhesive compatibility with Kevlar. The total order for the epoxy, curing agent, resin pumps, and releasing agents total $456.30. This amount includes the resin, curing agent, and mold preparation buffer solutions to ensure that the mold itself will not stick to the composite. This manufacturer does not sell the appropriate Kevlar material used for ballistics protection, Kevlar 29. Therefore, ArmorCo was chosen as the manufacturer for the fabric. Kevlar 29 is for $44.55 per yard. Eight yards were bought in order to ensure that there is enough to make at least 19 layers of Kevlar for the outer shell plus extra for the chin guard. Current helmets as well as the retired PASGT helmets contained around 19 layers of Kevlar so that will be considered the norm until further testing either confirms or denies this number. In addition to the Kevlar, some heavy-duty Kevlar shears were purchased from ArmorCo, totaling in $424.39 for this manufacturer.

The mold to create the outer shell was the donated ACH. It provided a base to place the Kevlar and Epoxy on and allowed the two to react and form a composite structure. In addition, the location of the outer shell creation must be well-ventilated. The Materials Science Engineering department was contacted to obtain a laboratory with a fume hood for this process.

The suspension system used by the prototype is the X-Harness 4 point suspension system made by Gentex Corporation. This suspension system is chosen because it has...
been certified for use by the military, and can be easily fitted to the custom made outer shell. Currently this must be purchased directly from Gentex mainly due to the company providing this item directly to the military for use in combat. Each harness is assumed to be about $100 but thanks to Gentex four samples along with four sets of padding were donated. This kit is used by the current ACH model and is called the ZAP ¾” Pad Hook Kit. The expanded-polystyrene layer was bought in 14 inch blocks of one pound density. Five blocks were purchased for $20 each, totaling $122.12 with shipping. The EPS cutting tool along with its power supply will be purchased from the Hot Wire Foam Factory for $130.58. Orders were also placed to Central Stores and Dick Blick Art Supply to obtain supplies necessary for composite work.

Originally, only one testing helmet was going to be made. However, since three were made and testing was done in a contracted facility, the final budget was slightly higher than expected. Since both helmets were donated, the total budget is $1800.77. Since about three prototype helmets have been made, there is no real estimated way to determine a decrease in mass-production. The original budget of creating one prototype helmet is about $1200, and this could be scaled down to the estimated mass-production 35% cost of about $420. There are no estimated prices on ACH according to Gentex due to Contract obligations. However, buying a single ACH from another supplier is about $450 to $500.

Table E. Budget for Prototype

<table>
<thead>
<tr>
<th>Part</th>
<th>Manufacturer</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin/ Mold Setup</td>
<td>Fibre Glast Developments</td>
<td>$456.30</td>
</tr>
<tr>
<td>Kevlar 29</td>
<td>ArmorCo</td>
<td>$424.39</td>
</tr>
<tr>
<td>Expanded Polystyrene</td>
<td>Foam Pack Industries</td>
<td>$122.12</td>
</tr>
<tr>
<td>EPS Cutting Tool</td>
<td>Hot Wire Foam Factory</td>
<td>$130.58</td>
</tr>
<tr>
<td>Suspension System and Retention Padding</td>
<td>Gentex Corporation</td>
<td>Donated</td>
</tr>
<tr>
<td>ACH</td>
<td>Donated</td>
<td></td>
</tr>
<tr>
<td>Motocross Helmet</td>
<td>Donated</td>
<td></td>
</tr>
<tr>
<td>Molding Clay and Supplies</td>
<td>Dick Blick Art Supply</td>
<td>$32.96</td>
</tr>
<tr>
<td>Beakers, Gloves, funnels, brushes, spray bottle</td>
<td>Central Stores</td>
<td>$34.42</td>
</tr>
<tr>
<td>Helmet Testing</td>
<td>RIH Orthopaedic Foundation</td>
<td>$600.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$1800.77</strong></td>
</tr>
</tbody>
</table>
8. Team Members’ Contribution to Project

Kristin Ohanian

Kristin has been responsible for contacting the clients and keeping them informed about the design process. She has organized most of the group meetings and meetings with the clients. She has been in contact with several contacts from various companies. She has done extensive work designing the neck guard. She has also compiled, proofread, and edited all reports written by the group.

Regarding information researched and written in the group reports, Kristin wrote the Statement of Need and contributed to the introduction and specifications for the Statement and Specifications Report. For the Project Proposal Report, Kristin wrote the background and purpose for the introduction. She also contributed to the objective and method sections of the project description. Kristin did research concerning the testing of helmets and created several images used throughout the proposal report.

Kristin was responsible for the introduction and the neck guard section of the Alternative Designs Report. She also created the neck guard drawing used in that report. In the Optimal Design Report, Kristin wrote the introduction and safety sections as well as the neck guard and comfort padding subunit sections and any associated images. Kristin also planned out a great amount of the timeline mentioned in this report.

Kristin placed many parts orders for companies including Team Wendy, Central Stores, Fibreglast, Dick Blick Art Supplies, and ArmorCo. She worked closely with Shawn Thomas from Team Wendy to develop a test plan. She also researched many testing facilities and arranged for the helmet testing to be performed at the RIH Orthopaedic Foundation. Kristin also contacted Gentex and got the retention padding and suspension systems donated to the team.

Regarding building the prototype, Kristin worked hard on making several molds and outer shells. She worked on the practice mold and after researching better molding techniques, made molds for all three helmets. Kristin practiced layering Kevlar and helped make the triangle shell and first pinwheel shell. Kristin experimented with the clay to make several neck guard and chin guard molds. She researched EPS companies, foam cutting tools, and IED blast forces. She also scrubbed the inside of several shells to remove the mold components. Kristin also spent a large amount of time cutting and sanding five EPS blocks into EPS shells for the helmets. She also fixed the foam cutting tool after it broke several times.

To prepare for testing, Kristin went to several hardware stores to find screws to hold the suspension system on some of the helmets. Kristin helped prepare all helmets for testing and went to the RIH Foundation to observe and help with testing all the helmets. She then compiled and analyzed all testing results. Kristin helped make the final presentation and edited the final report.
**Jim Veronick**

The chin guard and EPS foam inner shell were mostly researched, outlined, and written upon in each of the papers by Jim. The idea of the chin guard satisfies the needs of adding protection to the soldier’s face and the overall stability of the helmet on the soldier’s head. In the situation where there is an applied force to the soldier’s head, such as in a vehicle accident, the chin guard will help keep the helmet situated properly on the soldier’s head so that the force will be applied as evenly, and the least dangerously, as possible.

Jim also researched the EPS foam for its properties at satisfying our need to reduce the risk of head trauma from sudden impacts on the soldier’s head. The EPS foam layer is commonly found in bicycle helmets, and is a great addition to a military helmet. The content of the chin guard and EPS foam layer was written by Jim and can be viewed in each of the former documents including the proposal, alternative designs, and optimal design reports. In addition, he wrote the alternative design section on the light weight helmet, which was an attempt to make the helmet less bulky and heavy for the soldier to increase ease of use and carrying. Jim also set up most of the presentation on the proposal.

Jim also spent much of his time working on the appropriate images for our design reports including Microsoft Visio and Autodesk Inventor. Becoming somewhat familiar with Autodesk Inventor was a daunting task as it is a very complex program and he had never used it before.

In terms of making the helmet, Jim spent much of his time making the Kevlar fabric cutouts for both the helmet shell and the chin guard. Jim helped assemble multiple helmets which was a very lengthy task. Jim also made the proper measurements and a cut out design for the chin guard, which was then stenciled to the Kevlar fabric and cutouts were made. Jim made the appropriate chin guard shape by draping it over one of the helmets and raising it slightly with a layer of clay.

Additionally, Jim and Kristin went to RIH Labs where they assisted in drop testing the various helmets and an ACH. Jim helped make the final presentation in addition to writing most of the Operator’s Manual.

**Damian Frankiewicz**

Damian proposed the notion of creating the Kevlar outer shell rather than using a currently existing one. He also researched composite aramid reactions and the materials needed to correctly create a ballistic helmet, including the correct Kevlar weave. He created the preliminary budget for the Proposal Report and a second draft of the budget for the final report. Damian compiled a full list of patents and previous work done by others. He found manufacturers for composites and Kevlar 29 raw materials, including Fibre Glast and ArmorCo. He found the chin strap part that will be used in the prototype. Damian also included several entries into timeline for prototype building.
Damian created the free body diagram of chin strap. He also created the diagram of optimal helmet shell versus the current one in use. He wrote the alternate design section on cooling. He also wrote the Introduction, Conclusion, Safety Issues, Impact of Engineering Solutions, and Life-Long Learning sections of various papers. In addition, he wrote the Prototype section of the final report as well as the corresponding sections on the final presentation.

In terms of parts ordering, Damian created the first parts orders for Fibre Glast and ArmorCo to order the initial materials for the first helmet prototype. Damian was also in contact and helped order the Expanded Polystyrene blocks from Foam Pack Industries.

In terms of helmet creation, Damian created the first few models during the early weeks of the project. For the first triangle design, Damian cut many of the triangles out of the Kevlar. In addition, he cut and trimmed two of the helmets using a jigsaw at the machine shop. He also cut all of the holes in every helmet. Damian also cut, cured, and trimmed the entire third prototype helmet. Damian also helped mold, cure, and harden the chin guard for the final display prototype. Lastly, he helped sand down the Expanded Polystyrene molds so that the padding could fit inside for testing purposes. This includes the final EPS used for the display model.

9. Conclusion

Current helmets used by the United States military are not specifically made to prevent traumatic brain injuries. In addition, the recent Advanced Combat Helmet used by the Army raises several criticisms for its decrease in head protection in the back and side of the head as well as a large reported rate of discomfort by soldiers in Iraq. With the creation of a replacement helmet that may offer more protection against impacts that is more comfortable to wear at the same time, a product that may be both economically viable as well as one with a higher chance to save a human life is a large possibility. The three primary goals provided by the client are an increase in the prevention of a traumatic brain injury, an increase in comfort so that the soldier will more likely wear his/her helmet correctly to ensure maximum protection, and increase the area of protection around the sides of the head and the cerebellum, which the current Army helmet has decreased compared to past models. The unique insight into motocross helmet design provided by one of the contacts gives a different perspective on the necessary design specifications and provides a new look into an area plagued by large numbers of traumatic brain injuries according to recent reports on the subject. In addition, the added protection of the sides of the brain and cerebellum by increasing the length of the helmet sides and also adding a chin guard will increase the chance of preventing a random bullet from striking the soldier’s head. Lastly, the improvements made in this prototype will be meaningless if the user of the helmet does not wear it appropriately, including the buckling of the chin strap suspension system. Providing attention towards comfort will help ensure that the helmet will be worn safely more often than the present.
Padding material and design are important aspects in the prevention of traumatic brain injuries. This material must absorb a large amount of the energy produced by a high force impact to the helmet which may move the brain in its own skull and damage it due to this sudden and violent movement. A large part of this design includes a helmet that fits very snugly on the head it is protecting, so that the head and helmet move as one unit with no unnecessary spacing in between. One primary difference in the design of this helmet compared to others is the inclusion of a layer of expanded polystyrene, a high-energy absorbing foam material often used in helmets for contact sports such as motocross or football. This is the primary method of fulfilling the design requirement of reducing brain injuries by decreasing the amount of force hitting the skull and allowing the brain to move about and injure itself by hitting its own skull. In addition, a suspension system and padding kit that is currently being used will be chosen for both comfort and reliability. The results show a 30-50% decrease in acceleration felt by the head. Although there are currently no mathematical correlations between force reduction and brain injury reduction, the acceleration decrease will logically decrease the probability of traumatic brain injuries.

Both a motocross helmet and an Advanced Combat helmet were obtained through donations and the ACH was tested and compared to the prototype to see if the design specifications were met. Overall, the proposed cost of one prototype will be about $1150, which can make it economically viable when produced on a larger scale and standardizing and cutting the cost of manufacturing. However, no other helmet on the market can provide the amount of protection against traumatic brain injuries, meaning the project provides a competitive edge against other products.

10. References


11. Acknowledgements

The group would like to thank Gregory Lutkus for formulating the idea for this project and for assisting with the medical and military research. We would also like to thank Denise Panosky for relaying Greg’s idea to the biomedical engineering department and for assisting with medical research. We would like to thank Dr. Theresa Hennessey for allowing us to use her lab to do our composite work. We would like to thank Shawn Thomas from Team Wendy, LLC for information regarding TBIs and for helping to develop a test plan. In addition, we thank Richard Long and Gentex Corporation for donating three sets of suspension systems and padding. We would also like to thank David Paller and Ryan Rich from the RIH Orthopaedic Foundation for performing the helmet testing. We would like to thank the School of Engineering for providing financial support for our project. We would also like to thank Dr. John Enderle and David Price for their input, assistance, and support throughout the design process.

12. Appendix

12.1 Updated Specifications

Primarily, the focus of this design was to prevent TBI caused by rapidly changing atmospheric pressures cause by IED explosions. A layer of protective material was going to be placed beneath the Kevlar shell to decrease the effect of atmospheric pressure changes on the brain tissue, as the current ACH does not provide any such protection. However, after much research it has been determined that this objective is beyond the capabilities of the senior design program. The focus will be placed on preventing TBIs from impact forces and implemented as outlined in this report.

The weight of the finished prototype will vary from the original weight specifications stated in the Statement and Specifications Report. Those values were obtained from the US Army, but do not incorporate the neck guard, chin guard, and EPS layer that has been added to the design. The group will not try to vary from these values, but since the Kevlar shell will be made by hand, not by the industrial machinery used by
Gentex, some variance will occur. The final prototype used does not weigh much more than half a pound compared to the original helmet.

The Statement and Specifications Report included specific ballistic limitations to the helmet as well. Again, since the group will be making the Kevlar shell by hand, these limits may not be attained by the prototype. However, if the helmet was mass produced for field use using industrial machinery, these limitations would be upheld. Due to the brain injury limitations of the project, there was no focus or resource allocation towards the discovery of the ballistic properties of the prototype.