

A Nonlinear Finite Element Model of the Human Eye to Investigate Ocular Injuries From Night Vision Goggles

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ABSTRACT

Airbags have saved lives in automobile crashes for many years and are now planned for use in helicopters. The purpose of this study was to investigate the potential for ocular injuries to helicopter pilots wearing night vision goggles when the airbag is deployed. A nonlinear finite element model of the human eye was created. Ocular structures such as the fatty tissue, extraocular muscles and bony orbit were included. The model was imported into MADYMO and used to determine the worst-case position of a helicopter pilot wearing night vision goggles. This was evaluated as the greatest Von Mises stress in the eye when the airbag is deployed. The worst-case position was achieved by minimizing the distance between the eyes and goggles, having the occupant look directly into the airbag, and making initial contact with the airbag halfway through its full deployment. Simulations with the goggles both remaining fastened to and breaking away from the aviator helmet were performed. Finally, placing a protective lens in front of the eyes was found to reduce the stress to the eye but increase the force experienced by the surrounding orbital bones. The finite element model of the eye proved effective for evaluating the experimental parameters.

INTRODUCTION

For many years, airbags have saved lives in automobile crashes, and are now being used in helicopters. A military study has shown that many pilot fatalities are avoidable through the use of cockpit airbag systems (Wieter and Curran, 2000). It has been shown that five out of six injuries are due to aircrew members striking structures within the cockpit: cyclic, collective, instrument panels, glare shields, doors and gun sights. A forward and lateral cockpit airbag system can provide protection from these major strike hazards inside the cockpit.

With advancements in technology, soldiers are now using more sophisticated equipment. One example is that helicopter pilots now wear night vision goggles (NVGs) to facilitate distinguishing images at night. Although the use of airbags in helicopters may reduce the number of fatalities to

helicopter pilots, the scenario in which the pilot is wearing NVGs when the airbag is deployed raises new injury concerns. Such a scenario may place pilots at a high risk for ocular injuries. If serious enough, an ocular injury could render a pilot no longer able to serve in the military. The associated economic costs can be enormous. The purpose of this study was to investigate the potential for ocular injuries to helicopter pilots wearing NVGs when an airbag deploys. The primary objective was to determine a worst-case position for future laboratory experiments. This objective was accomplished by modeling the interaction between night vision goggles mounted on the pilot's helmet and an airbag.

Many finite element (FE) models of the human eye have been presented in recent years (Bryant and McDonnell, 1996; Coquart et al., 1992; Hanna et al., 1989; Hoeltzel et al., 1992; Kobayashi et al., 1971; Pinsky and Datye, 1991; Sawusch and McDonnell, 1992; Shin et al., 1997; Vito and Carmell, 1992; Woo et al., 1972; Wray et al., 1994). Bryant and McDonnell (1996) constructed an FE model of the human cornea undergoing a four-incision radial keratotomy procedure. After comparing materially nonlinear to linear models, it was stated that the nonlinearity was very important and should be included in any such models. Hoeltzel et al. (1992) determined that the cornea could be considered to behave very nearly as a membrane, with little ability to resist bending stresses. Pinsky and Datye (1991) also argued that the shear and bending rigidity of the cornea are several orders of magnitude smaller than the in-plane, or membrane rigidity. Sawusch and McDonnell (1992) sought to investigate how the stress created by intraocular pressure and a four-incision radial keratotomy procedure was distributed and how it affected corneal curvature. As a first attempt to investigate the anisotropic behavior of the cornea, Shin et al. (1997) performed membrane inflation tests to examine the distribution of strain in the human cornea. In summary, most of these models were of the cornea only, to help better predict the change in corneal refraction from corrective surgeries. Accordingly, material properties concerned only with small deformations near physiological conditions, far from globe rupture, were included.

One group constructed a finite element model of the entire globe to investigate ocular impacts from grinder debris and airbag injuries after radial keratotomy procedures had been performed (Kisielewicz et al., 1995, 1996, 1998; Uchio et al., 1999). Nonlinear, isotropic material properties of the sclera and cornea were gathered from uniaxial tensile strip tests performed up to the point of rupture. Surrounding ocular components such as the bony orbit, fatty tissue, and extraocular eye muscles were not modeled. Experiments which involved inflating human cadaver eyes up to rupture illustrated the importance of the extraocular muscles (Burnstein et al., 1995). Tests were conducted on cadaver eyes by inflating the globe via the optic nerve until rupture. These tests showed that the globe ruptures most frequently at the muscle insertion sites.

This paper presents a nonlinear FE model of the human eye, which was constructed as an improvement on previous models. The geometry of ocular structures and tissue material properties up to rupture were gathered from the literature. These material properties enable the model to predict rupture of the globe. A globe rupture is the most severe ocular injury, most likely resulting in complete blindness in that eye. Previously neglected ocular components such as the orbital fatty tissue, extraocular muscles, and bony orbit were included in this model. The model was imported into MADYMO (The Netherlands Organization for Applied Scientific Research, Troy, MI) to simulate the helicopter airbag deployments. A 50th percentile male hybrid III dummy was used to model the helicopter pilot. Night vision goggles were obtained from the Army, their dimensions measured, and modeled in MADYMO. A parametric study was conducted to determine the worst-case position and orientation of a helicopter pilot wearing NVGs when an airbag is deploys. The position resulting in the greatest Von Mises stress in the finite element eye model was established as worst case. This position was then recommended for future laboratory testing. The advantage of this approach is that the model can be used to investigate experimental parameters prior to very expensive laboratory testing. In addition, simulations with the NVGs both remaining fastened to

and breaking away from the aviator helmet were performed. Finally, the effectiveness of having the pilot wear eye protection was investigated. A protective lens was placed between the NVGs and the finite element eye. The stress induced in the eye and forces to surrounding orbital bones were compared with and without the protective lens in place.

METHODOLOGY FOR FE EYE MODEL DEVELOPMENT

The geometry, material properties and types of elements used to define the FE eye model are provided in the current section. Validation of the eye model with experimental results found in the literature is also provided.

Geometry

The varying thickness of the cornea and sclera were obtained from the literature (Woo et al., 1972) and used in the FE model. Both the cornea and sclera are nearly spherical, with a radius of 7.8 mm and 12 mm, respectively. The cornea varies in thickness, from 0.52 mm at the apex to 0.66 mm at the limbus. The sclera also varies in thickness, from 1 mm at the posterior pole, decreasing to 0.55 mm at the equator, then increasing to 0.8 mm at the limbus. Inside the protective shell formed by the cornea and sclera, is the lens. Physical dimensions of the lens were also taken from the literature (Duke-Elders and Wybar, 1961). The lens has a 9 mm diameter and maximum thickness of 3.6 mm. The ciliary body and zonules attach to the sclera just behind the limbus, and are responsible for holding the lens in place (Takahashi, 1994). The ciliary body and zonules were grouped together as a single structure, referred to as the ciliary body throughout this study. The ciliary body was modeled with a thickness of 0.2 mm.

The bony orbit surrounding the globe can be approximated as a pyramid, with the base serving as an opening for the eye and the apex directed towards the brain (Sauerland, 1994). The dimensions and attachment locations of the six extraocular muscles controlling eye movement were chosen to match those in the literature (Takahashi, 1994). All six muscles were modeled with a thickness of 0.2 mm. In addition, the superior oblique muscle was "looped" through the trochlea, which was fastened between the medial wall and roof of the orbit. The inferior oblique muscle was attached between the orbital floor and the sclera. The remaining five muscles were connected between the sclera and the posterior pole of the pyramidal orbit.

ANVIS-6 aviator NVGs and SPH-4B flyer's helmet (ITT Industries Night Vision, Roanoke, VA) were obtained to gather geometrical properties. The NVG dimensions, including mass, were recorded and modeled. There are several different sizes of helmets available to the aviator. A helmet was fitted around the MADYMO rigid headform model for the 50th percentile male. A rigid connection between the head and helmet was assumed. The cockpit geometry itself was not specifically modeled, as the primary objective was to determine a worst-case position for interaction between the airbag and NVG. For this purpose, a variety of different initial angles and distances were modeled.

Material Properties

Large deformations, and possibly globe rupture could occur upon impact with the NVGs. Therefore, previously established nonlinear elastic stress-strain curves of human corneal and scleral tissue up to rupture were chosen (Figure 1) (Uchio et al., 1999). The mass density of the cornea and sclera was unknown, so the mass densities of the major components of each were used. The mass densities of water, protein, and collagen have been reported as 999, 1500, and 1800 kg/m³ respectively (Kisielewicz, 1998). Accordingly, the mass density of the cornea and sclera was approximated as 1400 kg/m³ for the model (Table 1). This is an average of the values reported for

collagen and water. When nonlinear material properties are entered into MADYMO, the Poisson's ratio is not entered.

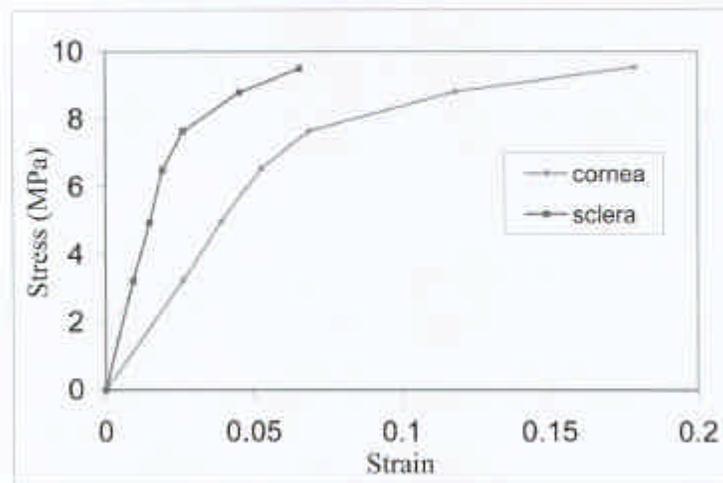


Figure 1. Stress-strain curves of the cornea and sclera (Uchio et al., 1999).

Table 1. SUMMARY OF MATERIAL PROPERTIES USED.

Structure	Material model	E (MPa)	Poisson's ratio	Density (kg/m ³)
Cornea	Nonlinear elastic	(Figure 1)	NA	1400
Sclera	Nonlinear elastic	(Figure 1)	NA	1400
Six muscles	Linear elastic	11.0	0.40	1600
Ciliary body	Linear elastic	11.0	0.40	1600
Fatty tissue	Linear elastic	0.047	0.49	999
Vitreous	Linear elastic	0.042	0.49	999
Aqueous	Linear elastic	0.037	0.49	999
Lens	Rigid	NA	NA	315
Orbit/Trochlea	Rigid	NA	NA	NA
Goggles	Rigid	NA	NA	Whole mass = 0.546 kg
Helmet	Rigid	NA	NA	NA

All remaining ocular structures were defined as either rigid or linear elastic. The fatty tissue surrounding the eye was approximated as nearly incompressible "soft" human tissue with a Young's modulus of 47 kPa and a Poisson's ratio of 0.49. These values have been used to construct FE models of the human buttocks (Todd and Thacker, 1994; Bidar et al., 2000). The water-like aqueous and gel-like vitreous were then given Young's moduli of 37 and 42 kPa, respectively, slightly softer than the fatty tissue. Young's modulus values were assigned to the aqueous and vitreous because no fluid-type elements existed within MADYMO. Based on the high water content of these tissues, a Poisson's ratio of 0.49 was used, making them nearly incompressible. In addition, the density of each structure was set equal to that of water, 999 kg/m³, also justified by the high water content.

No information describing the material properties of the ciliary body or extraocular muscles was available in the literature. Therefore, approximations were made as follows: Based on their high water content, which is less than that of the aqueous humor, a Poisson's ratio of 0.40 was chosen for the ciliary body and extraocular muscles. The tensile strength of collagen from rat tail tendon varies between 50 and 100 MPa, depending on the specimen age (Kisielewicz et al., 1998). The tensile strength of the ciliary body and extraocular muscles were therefore assigned a value of 11 MPa as an initial approximation. This approximation is supported by the fact that the ciliary body and extraocular muscles have a large amount of collagen, but not as much as rat tail tendon, which is often considered to be an excellent source of pure collagen. The mass density of each structure was also approximated as 1600 kg/m³, which is greater than the cornea and sclera but less than that of pure collagen. Finally, these structures were defined as tension-only materials unable to support any compressive loads. This was done to better represent only the passive strength of muscle tissue.

The lens was approximated as rigid relative to the other ocular structures. The mass density of the human lens has been found to vary between 200 and 430 kg/m³ (Kisielewicz et al., 1998). Therefore, an average value of 315 kg/m³ was selected to model the lens. The bony orbit, NVGs and helmet were also modeled as rigid objects.

Element types

All components of the model, both deformable and rigid, were meshed using I-DEAS (Structural Dynamics Research Corporation, Milford, OH). The cornea was meshed with a total of 64 linear, or 1st order, triangular membrane elements and 41 nodes, while the sclera required 400 such elements and 193 nodes (Table 2). To define a nonlinear material in MADYMO, triangular, rather than quadrilateral shaped elements had to be used. Membrane elements were chosen based on the assumption that the cornea and sclera only support in-plane, or membrane forces. No resistance to bending exists with these elements. In this way, the corneo-scleral shell is modeled to behave much like a water balloon.

Table 2. SUMMARY OF FINITE ELEMENTS USED.

Structure	Element type	Element order	Number of Elements	Number of Nodes
Cornea	Membrane	Linear triangles	64	41
Sclera	Membrane	Linear triangles	400	193
Lens	Rigid	Rigid triangles	16	10
Ciliary body	Tension-only membrane	Linear triangles	32	32
Six muscles	Tension-only membrane	Linear triangles	338	251
Aqueous	Solid	Trilinear brick	72	123
Vitreous	Solid	Trilinear brick	80	125
Fatty tissue	Solid	Trilinear brick	160	294
Orbit/Trochlea	Facet	Rigid quads	94	104
Goggles	Facet	Rigid triang/quad	16/65	75
Helmet	Facet	Rigid triangles	246	139

As already mentioned, MADYMO does not contain fluid-type elements. Therefore, solid elements were used to model the aqueous and vitreous. The water-like fluid that occupies the anterior

chamber of the eye, or aqueous humor, was meshed with a total of 72 solid trilinear brick elements and 124 nodes. The gel-like fluid contained in the posterior chamber of the globe, or vitreous, was modeled with 80 such elements and 125 nodes. The lens was meshed with 16 rigid elements and 10 nodes. The ciliary body was meshed with triangular membrane elements so as to connect between the lens and sclera (Figure 2). In total, 32 elements were needed to create the ciliary body, connecting between 8 nodes of the lens and 24 nodes of the sclera.

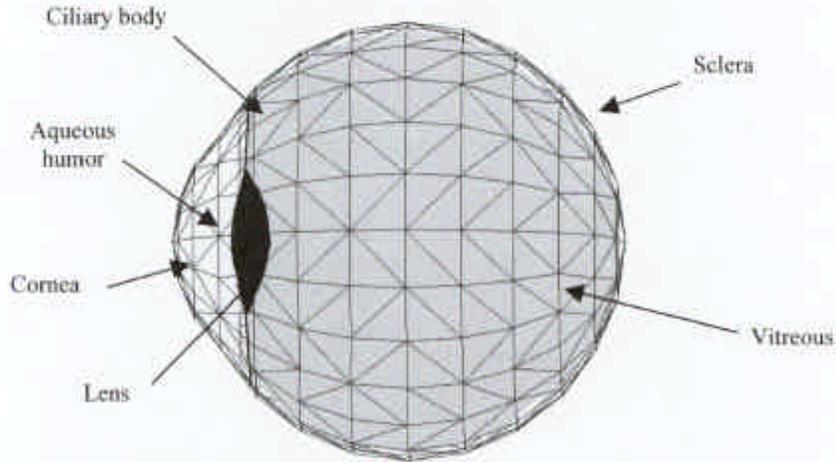


Figure 2. The ciliary body fastening the lens to the sclera.

Next, the procedures used to mesh external structures such as the muscles, fatty tissue, orbit, NVGs and helmet will be discussed. All six extraocular muscles were meshed using triangular membrane elements (Figure 3). For reasons already discussed, triangular shaped elements were chosen to leave open the possibility of including nonlinear material properties for the extraocular muscles.

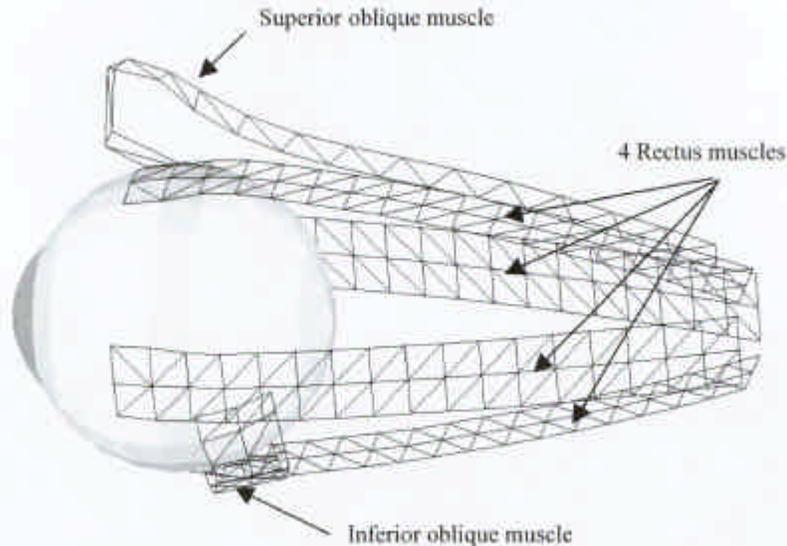


Figure 3. Lateral view of meshed extraocular muscles attached to sclera (left eye).

Each of the four rectus muscles was meshed with 68 elements and 48 nodes. Of each set of 68 elements, four of these were used to attach each muscle to 6 nodes of the sclera. Using several nodes and elements to attach each muscle to the sclera reduces the stress concentration created at these locations. Meshing of all six extraocular muscles included 338 elements and 251 nodes.

The fatty tissue was modeled to provide a more accurate boundary condition compared to previous research (Kisielewicz et al., 1998). This involved meshing the fat with a total of 160 solid trilinear brick elements and 294 nodes. The bony orbit consisted of four walls and the trochlea. A total of 94 facet elements and 104 nodes were used to mesh the orbit and trochlea. Finally, the orbit was rigidly attached to the Maydmo facet headform model. This was done so as to create 25 mm between the medial or nasal walls of the left and right orbits, if a right orbit was to be modeled.

The NVGs and helmet were considered to be rigid, therefore facet elements were used to represent their geometry. A total of 81 facet elements and 75 nodes were used to mesh the NVGs. In total, 246 triangular facet elements and 139 nodes were used to mesh the helmet.

Validation of FE Eye Model

The FE eye model was developed for the purpose of utilizing it in a parametric study to determine the worst-case position upon impact with NVGs. It was not developed to investigate specific injury mechanisms. To look for trends, the results predicted by the model were compared to results found experimentally in the literature.

Previous experiments have been performed impacting human eyes with baseballs (Vinger et al., 1999). Baseballs with a 73.8 mm diameter, 143.9 g mass, and 24.7 m/s velocity caused the corneo-scleral shell to rupture after being impacted. Similarly, the FE eye model also predicted globe rupture when the identical impacting baseball was simulated in MADYMO. Tests with steel rods being projected at enucleated porcine eyes have also been conducted (Scott et al., 2000). The porcine eye was chosen because of its availability and similarity to the human eye in size and anatomical structure. Steel rods with a 9.53 mm diameter, 45.5 g mass, and 4.0 m/s velocity did not produce globe ruptures upon impact. The FE eye model successfully predicted that globe rupture would not occur under the same conditions.

The finite element eye model was created using exact geometric and material properties gathered from the literature. Experiments on eyes, utilizing advanced instrumentation to quantify *in situ* measurements, are currently being developed. These measurements will lead to further validation of the model.

PARAMETRIC STUDY WITH MADYMO

The primary objective of this study was to determine the worst-case position of the eye that induced the greatest Von Mises stress in the corneo-scleral shell upon impact with the NVGs. Von Mises stress was used as the evaluation parameter because it is a good assessment of the average stress level. A 50th percentile male dummy was used in all simulations to best represent an average of the USA adult male population. This dummy was positioned with the left arm at its side and the right arm between its legs (Figure 4). This position represents that of a helicopter pilot during flight. Next, a MADYMO FE airbag model with a volume of 35 L was chosen to best represent the 60 L airbag deployed from the helicopter control panel. Both airbags had leading edge velocities above 180 mph, making them very aggressive. No dynamic crash pulse was applied to the simulations in order to simplify the analysis and to compare the simulated results with experimental results performed in a laboratory.

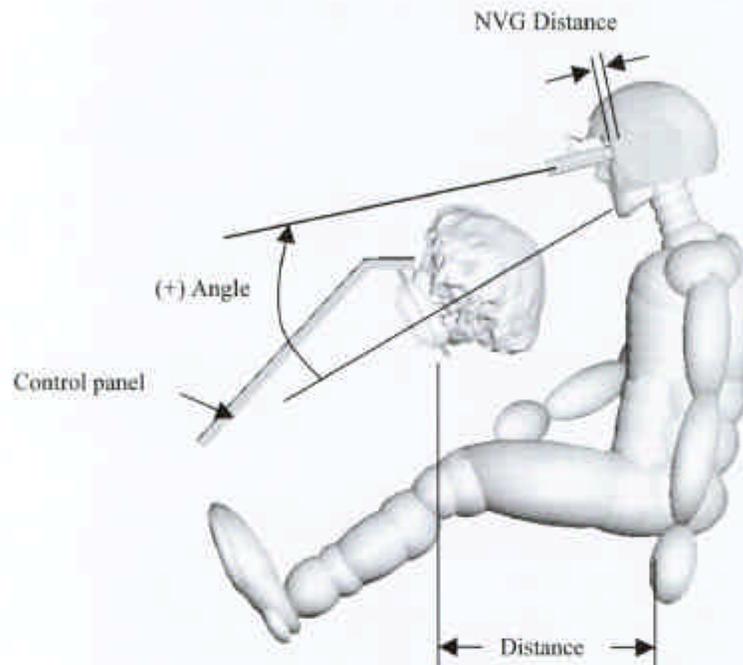


Figure 4. Three parameters varied to determine the worst-case position (airbag deploying at time = 10 ms after trigger).

Three parameters were examined to establish the worst-case position. First, the distance between the eye and the NVGs was varied (Figure 4). The impacting surface of the NVGs was brought to within one millimeter of the apex of the cornea. The airbag was deployed and the maximum Von Mises stress was recorded. This same process was repeated, moving the NVGs away from the cornea in 5 mm increments.

Second, the horizontal distance between the occupant and the airbag module was varied. The range of horizontal distances was as follows. First, the dummy was placed at a distance where the NVG's were out of the airbag's reach. Then, the distance between the dummy and airbag module was decreased in increments of 50mm.

Third, the angle between the line-of-sight and the normal to the airbag module was varied. The line-of-sight is also the anterior-posterior axis of the globe. For each of the above horizontal positions, the dummy's lower neck bracket was varied to create different angles between the line of sight and the airbag. The greatest angle between the line of sight and airbag that caused the airbag to push the goggle upwards and away from the eye was used as the upper limit. For example, when the dummy is looking straight ahead, or horizontally, the airbag comes into contact with the underside of goggle, causing it to flip up rather than down. Once this limit was determined, the angle was decreased in increments of 6 degrees.

In addition to varying the above three parameters to determine the worst-case position, simulations with both the NVGs remaining fastened to and breaking away from the helmet were performed. Finally, a protective lens was modeled and placed between the NVG and the eye (Figure 5). A simulation with the lens, assumed to be rigid, was carried out under the worst-case position of the dummy and orientation of the eye.

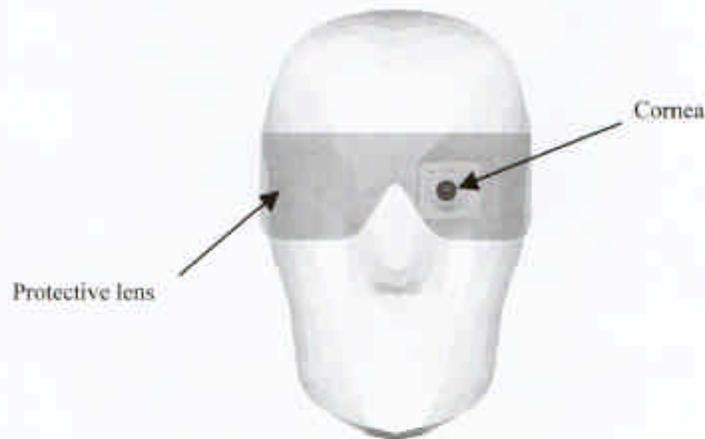


Figure 5. Protective lens placed in front of the eye.

RESULTS AND DISCUSSION

First, a minimum 1 mm distance between the NVG eyepiece and the apex of the cornea was used and then increased in 5 mm increments. On the fifth run, or 21 mm away from the cornea, no contact resulted between the NVGs and the cornea. This was because the NVGs swing upwards toward the eye, about the revolute hinge joint at the attachment to the helmet. The NVGs would continue to miss the eye at distances beyond 21 mm. Therefore, no simulations were performed beyond this distance. For each simulation with a different goggle distance, the maximum stress occurred at the point of impact with the goggle (Figure 6). Among all of these simulations, the minimum distance of 1 mm produced the greatest stress (Figure 7). Though 1 mm is too close to be a realistic estimate of the actual distance between the corneal apex and NVGs, this distance is possible was used in all remaining simulations as a worst-case estimate to determine the overall worst-case position.

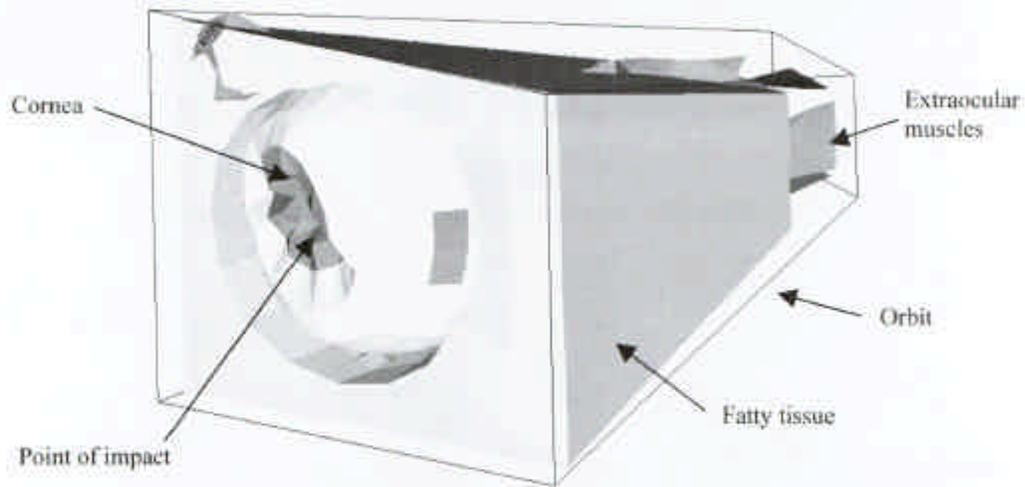


Figure 6. Deformed globe after being impacted with the goggle.

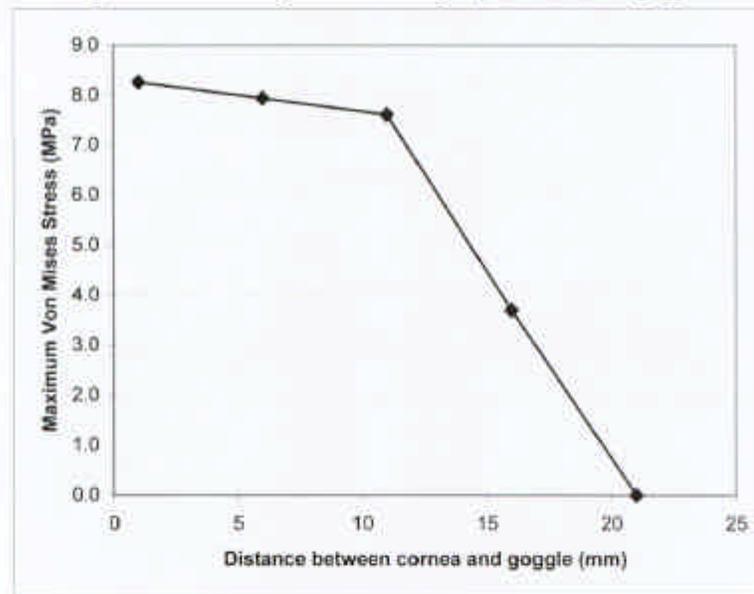


Figure 7: Maximum Von Mises stress in the eye versus goggle distance.

Second, the horizontal distance between the dummy and the airbag module was decreased in increments of 50 mm. Third, for each of the above positions, the dummy's lower neck bracket was varied to create different angles between the line of sight and the airbag. A worst-case distance between the dummy and the airbag became apparent after plotting the data (Figure 8). At each angle simulated, this horizontal position of the dummy produced the greatest stresses, always occurring at the point of impact with the goggle. This position was at neither of the extremes, but rather at the second furthest position from the airbag. Two more intermediate points were determined at -6 and 0 degrees to check for extreme discontinuities in this worst-case distance curve. None were observed and therefore no additional positions were tested.

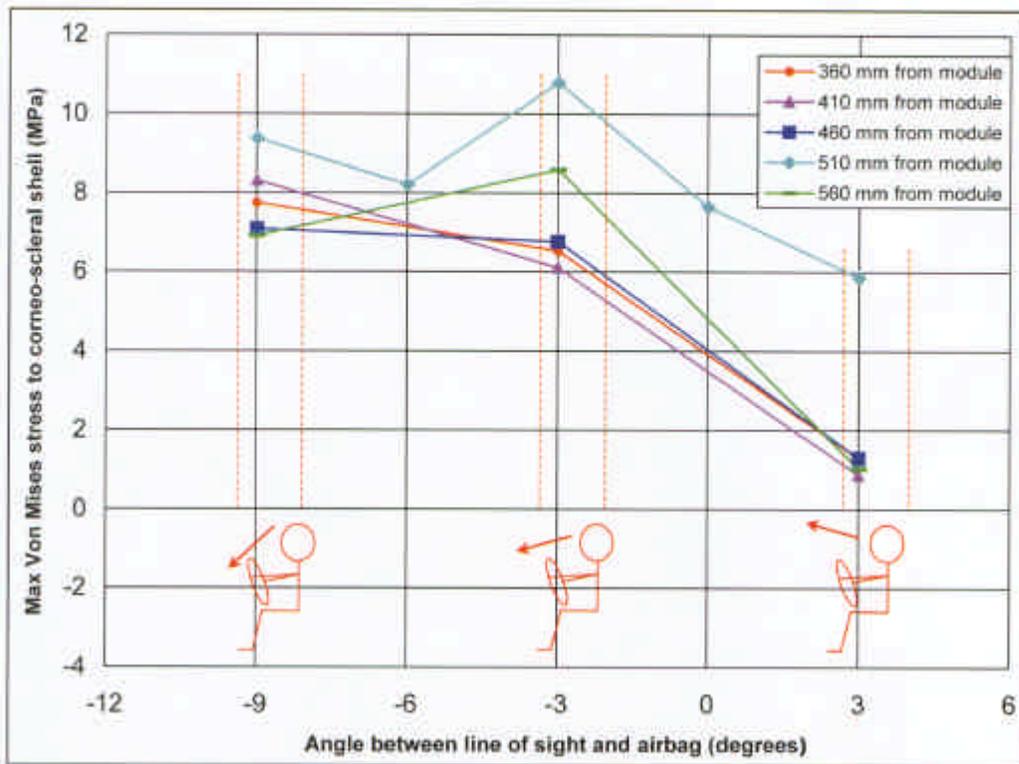


Figure 8. Maximum Von Mises stress as a function of sitting position and line of sight.

The maximum stress experienced by the corneo-scleral shell was 10.8 MPa and occurred when the dummy was sitting 510 mm from the airbag module, looking at -3 degrees from the airbag. This angle was also at neither extreme, but instead in the middle of the range of angles simulated. With the dummy placed in this worst-case position and line of sight, it is looking almost directly into the center of the airbag. The airbag also begins to come into contact with the NVGs approximately half way through its deployment. One possible explanation for this stage of deployment resulting in the maximum stress is that at half way through its deployment, the airbag is transferring a combination of membrane and punch-out forces to the NVGs.

The NVGs also made contact with the eyebrow region of the headform (Figure 9). Contact force between the NVGs and the eye and between the headform and the eye were calculated for the worst-case position. The contact force to the eye was 14.1 N for the worst-case position. The contact force to the eyebrow region of the frontal bone was 1255 N. The large discrepancy in these two forces can be explained by the different material properties. The orbital fatty tissue provides a large amount of damping behind the eye, allowing the eye to compress into the orbital volume under loading. In contrast, the headform model is rigid, contributing to the much larger contact force.



Figure 9. Goggle impact causing the eye to turn upward, then hitting the forehead.

Impacting the skull bones with a 1.0 in² cylindrical impactor has determined the force required to cause fractures (Schneider and Nahum, 1972). The frontal bone was impacted in the forehead region and had a fracture force of 5780 N. An orbital bone, the zygomatic bone, required 1450 N to fracture. Therefore, the 1255 N force induced to the eyebrow region by the NVGs may cause fracture. This level of force is significant enough to require attention in future laboratory experiments.

As already illustrated, the NVGs rotated around the revolute hinge and missed the eye when placed at distances greater than 21 mm. However, pilots most often place the NVGs at 20 to 25 mm from their corneas. Therefore, with the dummy in the worst-case position, the NVGs were placed at 20 mm from the cornea and allowed to break away from the helmet. After breaking off, the NVGs impacted the FE eye, inducing a maximum stress of 4.0 MPa. This stress is less than the 10.8 MPa with the NVGs placed at 1 mm from the cornea. Finally, a rigid protective lens was placed between the eye and NVGs. Again, the NVGs and cornea were separated by 20 mm with the dummy in the worst-case position. The NVGs were allowed to break away from the helmet, pushing the protective lens into the ocular region. The protective lens barely made contact with the eye, experiencing a maximum stress of 2.2 MPa, approximately one half of the 4.0 MPa previously found without the protective lens. In contrast, the contact force to the eyebrow region of the headform model increased to 1760 N, greater than the 1255 N force generated in the worst-case scenario without a protective lens. This interaction seems logical as the protective lens shields the eye and transfers the energy to the orbital bones, which protect the globe from impacts with objects larger than the orbital opening.

CONCLUSIONS

The primary objective of this research was to determine the worst-case position and orientation of a helicopter pilot wearing night vision goggles when the airbag is deployed. In this worst-case position, the greatest Von Mises stress in the finite element eye model resulted. This position was then used to help guide experimental tests. From the findings of this study, the following worst-case scenario was recommended for testing (Figure 10):

- 1) Orient the pilot so as to look directly into the airbag.
- 2) Allow the airbag to begin making contact with the NVGs in the middle of its deployment stage.
- 3) Place the NVGs as close the eyes as possible.

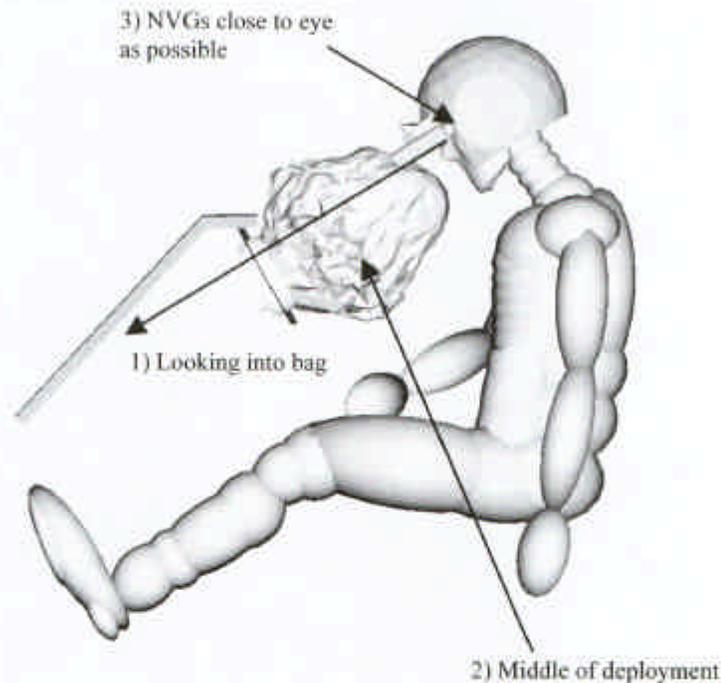


Figure 10. Worst-case position and orientation of pilot recommended for testing.

Rather than recommending specific distances between the globe and airbag module, the above normalized recommendations were provided. These recommendations were all made with respect to the airbag used in MADYMO but can still be applied to the actual airbag used in the helicopters. Specific distances relative to the airbag module would not be valid and should not be recommended until the actual airbag is modeled with MADYMO.

In addition to satisfying the primary objective of this study, simulations with the NVGs remaining fastened to and breaking away from the helmet were performed. Finally, placing a protective lens in front of the eyes was found to reduce the stress to the eye but increase the force experienced by the surrounding orbital bones.

The FE eye model proved effective at evaluating the experimental boundary conditions. The model includes material properties up to rupture making it suitable for large deformation applications. With modeling of surgical incisions, it could be used to study the additional risks associated with vision correction procedures (Radial Keratotomy, Laser Assisted in-Situ Keratomileusis, etc.). More accurate material and geometric properties of the orbital bones could be incorporated to investigate blowout fractures or other orbital injuries. Finally, the protective lens design could be optimized to distribute the impact force over the largest area or the strongest bones in the orbit.

ACKNOWLEDGEMENTS

This work was funded by the United States Army Aeromedical Research Laboratory (USAARL). The information presented in this paper does not represent an official Army position or policy. The authors are also thankful for the technical support provided by The Netherlands Organization for Applied Scientific Research (TNO), Altair, and Structural Dynamics Research Corporation (SDRC).

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DISCUSSION

PAPER: A Nonlinear Finite Element Model of Human Eye to Investigate Ocular Injuries from Night Vision Goggles

PRESENTER: *Erik Power, Conrad Technologies, Inc.*

QUESTION: *Rob Salzar, UVA*

Two things, two questions. Friction between the night vision goggle and the eyeball, address that.

ANSWER: I'll address that. It's a good point. The friction between the eyeball and night vision goggle was simulated by taking a contact function already within Madymo for the airbag to skin, say skin on the forehead. So it was skin to airbag.

Q: Okay. The other one, the countermeasures of the night vision goggles you said that you modeled that as rigid. Was it that big a deal to just make them stiff but not rigid?

A: The safety lens or the night vision goggle?

Q: The countermeasure, the safety lens.

A: We could in the future put in material properties of PVC or whatever material property is used, plastic. But just for the time available for now it's always rigid.

Q: I understand. My experience with the countermeasure is that they are deforming, those things really do dent in and they're not really protecting the eye so much as a rigid lens. Are you going to continue this work?

A: Not me personally. I finished this up for my Master's.

Q: Are you going to stay on for the Ph.D.?

A: Currently I am working at Conrad Technologies, Inc. I might pursue a Ph.D. in the future. Thanks.

Q: *Guy Nusholtz, Daimler Chrysler*

How did you model the slip between the helmet and the head?

A: The helmet was rigidly attached to the head. It was a fixed under condition to the CG of the head.

Q: How many people drive with helmets bolted to their head?

A: They don't.

Q: The way the goggles come into the eyes you can see that they are just pivoting without any translation. I think that might end up changing your results quite a bit because you will have loading of the airbag directly on the helmet.

A: Most definitely. That's a good point. It's a difficult thing to address. There are so many different sizes of heads. But the occupant does adjust straps around the head to reduce as much of the slack as possible.

Q: You just want to get a general trend without trying to come back for the entire population?

A: Yes.

Q: *Kelly Kennett, Exponent*

I just wanted to comment on what Rob was mentioning. We actually ran some tests with pistons from pneumatic tools being shot into eyes and they're going to have a diameter which I suspect is very similar to the night vision goggles. And he's right, the lenses of these protective glasses do deform quite a bit and they actually really almost fold around the end of these pistons. And I think that you're probably vastly over estimating their protective effect from this blunt impact. They're not going to transfer as much load to the orbit as you think.

A: Yes, that's a good point.

