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Polycarbonate Ophthalmic Lenses for Ametropic Army Aviators Using Night Vision Goggles

By
John K. Crosley

Sensory Research Division
Visual Sciences Branch

August 1988

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United States Army Aeromedical Research Laboratory
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U.S. Army aviators use the AN/PVS-5 Night Vision Goggles (NVG) with a modified faceplate which enables wearing of corrective spectacles, when required. The next generation NVGs, the Aviator Night Vision Imaging System (ANVIS), permit spectacle wear by design. With only glass lenses available to the aviator requiring optical correction, there is a potential for eye injury from broken glass should the goggles accidentally be displaced. This report documents studies to (1) compare the impact resistance of glass, CR-39 (plastic), and polycarbonate lenses to simulated NVG tubes, (2) establish the approximate forces necessary to cause glass lens breakage by displaced NVG tubes, and (3) determine the performance of polycarbonate lenses in the aviation environment. Results demonstrate the significant improvement in impact-resistance afforded by polycarbonate ophthalmic lenses, verify the relatively low forces necessary to cause NVG displacement and subsequent glass lens breakage, and establish the feasibility of prescribing polycarbonate lenses for use by aviation personnel.

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Introduction

The role of aviation in U.S. Army night operations has been enhanced greatly by the introduction of the AN/PVS-5 Night Vision Goggles (NVG) (Figure 1). Although the NVGs were not designed specifically for aviation application, they now are considered a vital part of Army air operations and their use greatly expands the overall combat capability of the aviator.

Initially, the AN/PVS-5s suffered from many shortcomings, some of which were specific to aviation. The inability to resolve all of these deficiencies in a cost-effective manner helped lead to the concept and development of the Aviator Night Vision Imaging System (ANVIS), AN/AVS-6 (Figure 2). These aviation-specific goggles currently are replacing the AN/PVS-5s, and provide the user with an improved product for night operations. Although the two devices differ in design, they share several common features. They both are attached to the helmet and are powered by integral

Figure 1. AN/PVS-5 Night Vision Goggles (original version).

Figure 2. Aviator Night Vision Imaging System (ANVIS).

batteries or aircraft power. In addition, when either of the goggles is mounted on the helmet in the worn position, a metal tube containing optics and electronics is located in front of each eye.

The AN/PVS-5s incorporate an adjustment which permits compensation for limited spherical refractive errors in the visual system of the user. The ANVIS goggles also have a similar adjustment. At the same time the ANVIS, unlike the AN/PVS-5s, was designed originally to permit the wear of corrective spectacles, when required. This can be important because a significant number of aviators required to wear corrective lenses need to compensate for astigmatism, as well as simple nearsightedness (myopia) or farsightedness (hyperopia). The "diopter" adjustment of the goggles does not correct for this nonspherical error.

Following an in-flight accident several years ago, personnel from the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, evaluated the AN/PVS-5 goggles to determine if they might be modified to eliminate some known deficiencies. These included lack of peripheral vision, inability to view maps, etc., except through the goggles, and the problem of correcting for astigmatism. The evaluation led to elimination of most of the facepiece material and a redesigning of the helmet attachment method. This "cutaway" version of the goggles (Figure 3) resolved the previously-identified problems. Removal of the facepiece material permitted peripheral vision, allowed the user to look under the goggles at maps, etc., and enabled corrective lenses to be worn when required. This last improvement was important especially to the older aviator who needed to wear bifocals for close viewing.

Although the "cutaway" version of the goggles was quite successful in resolving many problems, it unfortunately introduced a new one. The wearing of corrective spectacles meant the goggle tubes now were positioned in close proximity to the spectacle lenses. In an accident or incident, the forward thrust of the head and body could allow the goggles to strike a portion of the aircraft interior. The resultant forces generated likely would cause the NVG tubes to be displaced toward the eyes and strike the glass lenses. This impact could lead to lens breakage, resulting in serious eye injury.

The issue of eye injury potential and ophthalmic lens impact-resistance was placed in perspective in a paper presented by Rose

Figure 3. AN-PVS/5 Night Vision Goggles (cutaway version).

and Stewart in 1957. They performed a study of the relative impact-resistance of untreated glass lenses, glass lenses heat-treated to add strength, laminated glass lenses, and the then-new "plastic" lenses (allyl resin lenses now commonly referred to as CR-39*, a trademark of PPG Industries). They found that large steel balls (17 and 23 millimeters in diameter) striking the test lenses damaged untreated glass more frequently than treated glass. Impact from small (1mm) steel balls caused an opposite effect, with untreated lenses affording the greater protection. In comparison, they found even the unprotected cornea of the rabbit gave more protection from these small projectiles than treated glass lenses. The CR-39 was found to provide more protection from the small balls than any other materials tested. Stewart and Williams (1966) showed the size of the object impacting a lens was critical in determining the forces necessary to cause breakage. Their study involved the use of untreated glass, chemically-treated glass, and heat-treated glass lenses. It confirmed the earlier findings of Rose and Stewart that as the object size increased, the effectiveness of lens hardening became more apparent.

Wigglesworth (1971a, 1971b) examined thermally-treated glass and CR-39 for their comparative impact-resistance, and found increased thickness led to increased strength. Other observations were that there was wide variability between batches of lenses, that 2.0 mm thick thermally-toughened glass lenses were inferior to CR-39 with the extent of inferiority increasing with decreasing size of the projectile, and that 3.0 mm thick heat-treated glass lenses generally were more impact-resistant than CR-39 of the same thickness.

The U. S. Food and Drug Administration (FDA) (1971) issued federal standards requiring all ophthalmic lenses manufactured after 31 December 1971 to be impact-resistant, and specified the test to be administered to each of the lenses. This procedure involves dropping a 5/8-inch diameter steel ball 50 inches through a plastic tube onto the lens surface. In terms of force generated, this is not a very demanding test. It is the equivalent of dropping 2.4 ounces a distance of 1 foot.

Subsequent to the establishment of standards by the FDA, there was increased interest in the whole issue of eye protection (Dowaliby et al., 1972, Wigglesworth, 1972, Kors and St. Helen, 1973, Duckworth et al., 1978). The primary thrust of intervening studies has been to determine the relative resistance of various materials to impact by objects of differing sizes, and to validate the test procedure for measuring impact-resistance. Typically,

* See Appendix B.

the sizes of projectiles range from about one-tenth inch in diameter up to about three-fourths of an inch, and the method of delivery is usually a pneumatic gun or direct drop.

The U.S Army currently uses ophthalmic corrective lenses manufactured from two different materials, crown glass and CR-39. Military-issue lenses for all aviation personnel must be made from glass, in accordance with Army Regulation (AR) 40-63, Ophthalmic Services. Glass lenses are treated in one of two ways to enhance their impact-resistance and meet FDA standards. The first of these involves the steady application of heat until the melting point almost is reached, then quickly removing the heat and spraying the lens with jets of cold air to rapidly cool the exterior surface. The cooling differential between the lens surface and core creates a physical state of compression. When the inner core cools, it contracts and forms radial tension lines that pull against the surface layer. The result is an improvement in the lens resistance to breakage.

The second method of treating glass involves a chemical procedure. Lenses are immersed in a bath of molten potassium nitrate (KNO_3) for 16 hours. During this immersion, there is a chemical change in the lens structural integrity which results in an increase in the internal tensile strength. A lens so treated usually is slightly more impact-resistant than a heat-treated lens (Kors and St. Helen, 1973; Duckworth et al., 1978).

The other ophthalmic lens material used by the Army, CR-39, is lightweight (approximately 50 percent of the weight of glass) and has excellent optical characteristics. It is relatively easy to work with in the fabrication facilities, and, when coated, exhibits reasonably good scratch-resistance. Unlike glass, this material does not require special treatment for impact-resistance.

In the past few years, a new polycarbonate material has been introduced into the ophthalmic industry. Marketed commercially by the General Electric Company as Lexan*, this product has proven to have many desirable features. First, it is lightweight, weighing approximately 10 to 20 percent less than CR-39; second, it can be manufactured to meet exacting ophthalmic tolerances; and third, since the material blocks more than 99.9 percent of the ultraviolet (UV) light rays which are potentially harmful to the eyes, there is no need to add a separate UV coating, as currently is recommended for glass and CR-39 by many civilian practitioners.

Finally, and most important, polycarbonate lenses exhibit exceptional resistance to breakage from physical impact without any special treatment. This impact-resistance has been the subject of numerous studies (Goldsmith, 1974, Miller et al., 1979, Innes, 1982, Simmons, Krohel, and Hay, 1984). The safety aspects of this lens also have raised the issue of potential liability for the private practitioner when prescribing lenses for active individuals (Classe', 1986). One of the shortcomings of this material is that the untreated surface is soft. However, it is treated routinely with an abrasion-resistant coating which currently provides protection almost equal to CR-39's. Another limitation associated with polycarbonate lenses relates to the perception of peripheral distortion in the higher powers. However, the generally accepted upper limits for lens power encompass all prescriptions associated with aviation, and an estimated 95 to 97 percent of those throughout the remainder of the Army.

Until recently, the most common method used to manufacture the polycarbonate prescription lens blank involved a molding process. Manufacturers now have developed machinery which permits the lens to be surface ground in a manner similiar to glass. This, along with improved methods of cutting and edging the material, will serve to make it much more competitive with both glass and CR-39.

This study was divided into two phases. In the first phase, drop tests were conducted to determine the relative resistance of glass, CR-39, and polycarbonate ophthalmic lenses to impact by simulated night vision goggle tubes. Limited drop tests also were performed with actual night vision goggles. The second phase was designed to determine how well the polycarbonate lenses performed when worn in the operational aviation environment.

Method

Phase I--Comparative lens analysis

Instrumentation

An instrumented helmet drop tower was used to subject ophthalmic lenses to repeatable impact. This tower, located at USAARL, is used routinely to evaluate and reproduce aviator flight helmet damage. To replicate the damage of a helmet worn in an aircraft accident, duplicates of that helmet are attached to a modified version of a humanoid headform specified by the 1973 National Operating Committee on Standards for Athletic Equipment (NOCSAE) for evaluating football helmets. As shown in Figure 4, the head-neck connection of this headform was modified to increase its adjustability and permit mounting of the standard carriage assembly specified by the American National Standards Institute (ANSI) Z-90.1 (1971) method. A triaxial accelerometer, Endevco Model 2267C-750*, is positioned at the headform center of mass. The signal generated is amplified by a signal conditioner (Endevco

Figure 4. Headform shown after a drop test.

Series 4470)* and fed to a three-channel vector analyzer. The vector resultant of the three accelerometer signals then is transmitted to a Nicolet digital oscilloscope*. Kinetic energy is assumed to be equal to the drop weight of the headform plus carriage multiplied by the drop height in feet.

Cinematography

In addition to determining the resultant forces generated during use of the drop tower, all of the drops were photographed to permit slow motion analysis. The instrument selected for this purpose was the HYCAM, Model 41-0004, 16 millimeter motion picture camera* manufactured by the Redlake Corporation. This rotating prism camera is designed to operate at up to 11,000 frames per second (fps). However, in order to optimize film usage and to obtain desired detail, it was decided to photograph at 6000 fps. At this speed, it was possible to capture the moment of lens impact and observe the dynamics of the broken material.

Some of the drops were video recorded in addition to being filmed. The video used was the model SP2000 Motion Analysis System* manufactured by Spin Physics. This system is capable of recording up to the rate of 250 inches (2000 frames) per second.

The slow motion film and video of selected drops have been compiled and are located at USAARL. Results of the slow motion analyses are not specifically discussed in this report.

Lenses

The glass lenses used in this study were taken from standard stock and treated with a Kirk Model 20/30 chemical bath* to improve their impact-resistance, in accordance with FDA requirements. Chemically-treated lenses generally are considered to be slightly more impact-resistant than those heat-treated. The CR-39 lenses also were taken from current stock, but there is no procedure available to enhance their impact resistance. The polycarbonate lenses were procured by contract from a civilian contractor. The lenses provided were finished, uncut, single-vision blanks. Both lens surfaces were coated by the manufacturer to enhance abrasion-resistance.

All the lenses used in this study were "finished blanks," i.e., they were received with the prescription already ground and polished, but the frame shape had not been cut nor the edges beveled. The glass lenses were shaped and edged with an A.I.T. Model Mark V automatic bevel-edger*. The CR-39 and polycarbonate lenses were processed similarly with an A.I.T. machine having grinding wheels especially designed for their composition. When required, hand finishing for all the lenses was performed on a Universal Model CE-300 dual-wheel edger*. For this study, it was decided to use five samples each of three representative prescription powers; a moderate correction for myopia (-2.00 diopter), a moderate correction for hyperopia (+2.00 diopter), and plano (0.00 diopter).

Following preparation, the lenses all were mounted into the standard HGU-4/P aviator flight frame having "bayonet" (straight back) temples.

Test procedure

The procedure to impact the lenses in this study was somewhat different than that usually employed. Typically, a rigidly-held lens is impacted by an object propelled into it at a known velocity. In this investigation, a duplicate of the NVG tubes (Figure 5) was fabricated from aluminum and attached to the base of the USAARL drop tower. Similar to the NVGs, these simulated tubes were built to allow horizontal adjustment which permitted accurate alignment prior to each test impact. The headform attached to the drop tower served as a vehicle to support the test spectacles. Each of the spectacles was adjusted to properly fit

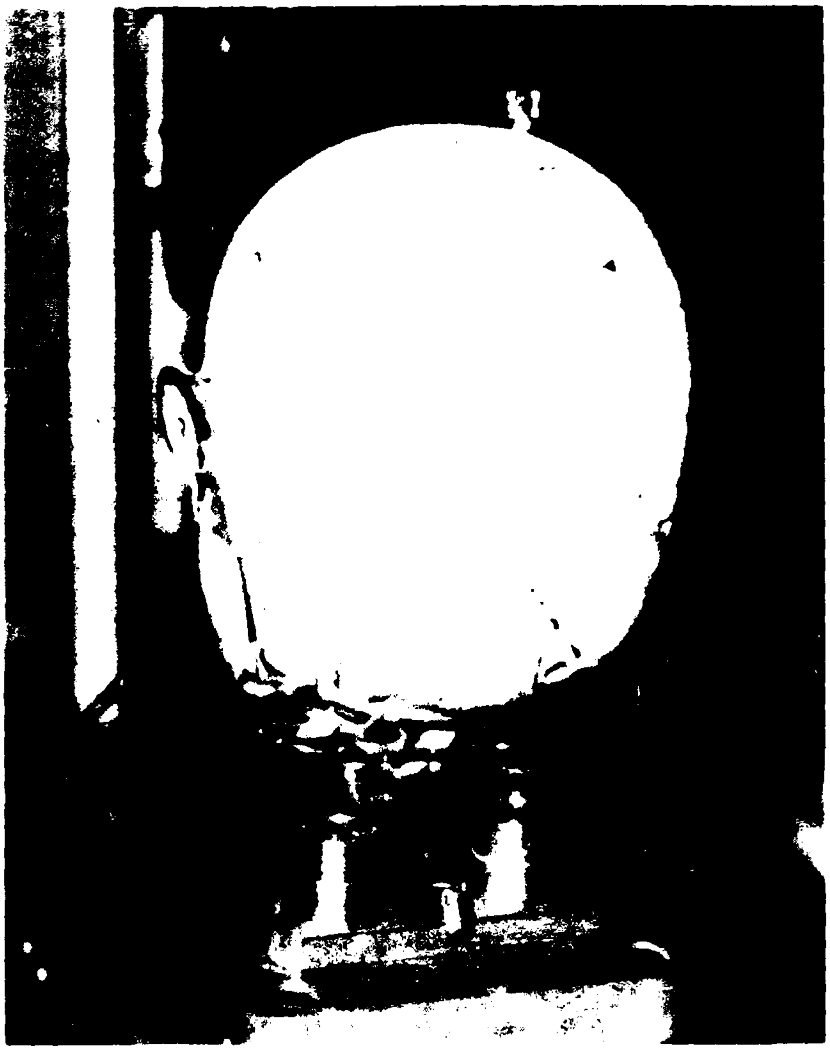

Figure 5. Simulated night vision goggles after a drop test.

the headform prior to being dropped. To ensure they did not shift on the inverted headform after being fitted, the temples were taped lightly in place. Once the spectacles and simulated NVG tubes were positioned properly, the headform was raised to a predetermined height, and prepared for dropping. Prior to actual release, cameras and lighting were positioned and the drop tower instrumentation calibrated. For each of the 3 different lens materials (glass, CR-39, and polycarbonate) there were a total of 15 drops completed, 5 drops for each of the 3 prescriptions.

The initial drop height for each lens was selected in accordance with an estimate of the forces necessary to break the lenses. Based upon the results of the first drop, the next drop height either was raised or lowered in an attempt to determine the minimum force necessary to just cause lens breakage. Using this "step method" (Wigglesworth, 1971a, 1971b), it was possible to approximate how each lens group would respond to the same type of impact, and to develop a relative comparison of the impact-resistance of each material by prescription range.

In the second study, the thicker "industrial" CR-39 lenses were dropped onto the simulated goggle tubes to determine their impact-resistance. Four lenses from each of the three prescription powers were tested to establish their relative performance.

In the final drop test, chemically-treated -2.00 diopter power glass lenses were mounted on the headform in the standard manner. Next, a standard-issue SPH-4 aviator helmet with actual NVGs attached was placed on the headform in the as-worn position (Figure 6). The goggles were complete except for the electronics. The ensemble was dropped twice onto the drop tower's flat base plate: the first time from 18 inches, and the second from 12 inches. Only two drops could be accomplished before the goggles became unusable.

Phase II--Field evaluation

To gain field experience, ametropic Army aviators were provided with polycarbonate lenses to wear during NVG-augmented night flight. They were requested to contact their local military eye clinic, or flight surgeon, who would forward prescription information to USAARL. In addition, articles describing the project were written in the monthly publications, Flightfax and Aviation Digest. A statement also was included in the Aviation Branch Update which is published by the Commanding General, Fort Rucker, Alabama, and provided worldwide to all aviators.

More than 500 aviators volunteered and were issued spectacles with polycarbonate lenses for these field trials.

Questionnaire

A questionnaire (Appendix A) was mailed to each subject after they had been wearing the lenses for 6 months. The purpose of the questionnaire was to obtain data regarding when the lenses were worn, their acceptability to the wearer, the number of hours flown with them, frequency and procedure for cleaning, how they were stored if they were not worn continously, perceived optical problems, and the incidence of scratching.

Figure 6. Headform wearing helmet with glasses under NVGs.

Results

Phase I--Comparative lens analysis

Lenses with "equal" center thickness

The results of this study are best demonstrated by directly comparing the performance characteristics of each lens material following impact with the simulated NVG tubes.

Table 1 shows the mean lens center thickness for each material, by prescription. There was no attempt to ensure the lens thickness would be the same for each sample. The lenses dropped were representative of what might be received when ordering from an optical laboratory.

Table 2 is a synopsis of the lens impact study. A total of 45 drops were performed; 15 for each of the 3 materials. The "estimated breakage threshold" is based upon the data from the drop tests and is an attempt to determine where lens breakage might first be encountered. The "foot-pounds" notation is a calculated level of energy generated at the drop height indicated. In addition to the calculated foot-pounds of energy expended, instrumentation in the drop tower facility permitted the recording of a peak energy level for each impact. These data also are shown in Table 2. The figure for the polycarbonate is only that associated with a drop from six feet, the limit of the test apparatus used. It should be noted none of these polycarbonate lenses was cracked or broken during the drop tests.

Table 1.

Mean center thickness of groups of lenses used during the impact study

Power (diopters)	Material	Mean center thickness (mm)
-2.00	glass	2.1
	CR-39	1.7
	polycarbonate	2.0
Plano	glass	2.2
	CR-39	2.6
	polycarbonate	2.1
+2.00	glass	3.2
	CR-39	3.0
	polycarbonate	3.6

Table 2.

Estimated drop height and associated energy level causing lens breakage

Material	Power (diopters)	Estimated threshold for lens breakage Drop height (in.)	Kinetic energy (ft-lbs)	Peak force (pounds)
glass	-2.00	4.0	3.5	229
CR-39	-2.00	5.0	4.4	393
polycarbonate	-2.00	>72	>63	>2800
glass	Plano	5.0	4.4	298
CR-39	Plano	8.0	7.0	479
polycarbonate	Plano	>72	>63	>2900
glass	+2.00	6.0	5.2	393
CR-39	+2.00	14.0	12.3	617
polycarbonate	+2.00	>72	>63	3000

Results of the lens impact study using simulated NVG tubes. The estimated threshold for lens breakage is based on the "step" method. The energy (foot-pounds) is a calculated figure based upon the drop height and the mass of the headform (including lenses). The peak force level was recorded on an oscilloscope and represents the maximum attained for each drop height listed.

Lenses with unequal center thickness

In general, impact resistance of ophthalmic lenses can be enhanced by increasing their center thickness. For the typical "dress lens" (the lens normally prescribed), the center thickness is approximately 2.0 to 2.2 millimeters. The "industrial" or "safety" lens center thickness is required by law to meet the American National Standards Institute (ANSI) Z87.1 (1979) standard which states it must be at least 3.0 millimeters.

Table 3 compares dress glass, dress CR-39, and industrial CR-39 for ability to resist impact with the simulated NVG tubes. Grouped by lens power, the mean height where initial breakage occured, and the associated foot-pounds of energy generated, are presented. In the minus lens group, the extra thickness of the CR-39 does provide improved impact-resistance. However, for the plano and plus powers, the difference is not as great. This is expected since the center thicknesses of the plano lenses, and especially the plus lenses, are closer to that specified for industrial thickness.

Although the comparison between glass and CR-39 was helpful, the comparison of greatest interest was between industrial thickness CR-39 and polycarbonate. Table 4 shows the results of this comparison (including dress glass) and clearly demonstrates the marked superiority of polycarbonate.

Glass lenses combined with actual NVGs

The lens drops using simulated NVG tubes gave a good approximation of the results one might expect from actual NVG/lens impact. However, in order to provide additional validation, it was decided to mount an actual set of NVGs on the headform along with chemically-treated -2.00 diopter power glass lenses. The combination then was dropped onto the solid baseplate of the drop tower. Two drops were performed; one from a height of 18 inches, and a second from 12 inches.

In the first drop, both lenses shattered and the frame was badly bent, while the goggles were relatively undamaged (Figure 6). The kinetic energy generated was 24.1 foot-pounds.

In the second drop, the same type of lenses were used. At this height (12") only one of the two lenses broke. This indicated the forces generated were very close to those necessary to initiate lens breakage. That is, higher drop heights likely would cause increased lens breakage, while lower drop heights likely would result in no lens breakage. The actual energy generated was 16 foot-pounds, roughly equivalent to walking briskly into a wall.

Table 3.

Comparison of lens breakage thresholds for glass, CR-39 (dress), and CR-39 (industrial)

Material	Power	Mean thickness (mm)	Estimated threshold for lens breakage: Drop height (in.)	Estimated threshold for lens breakage: foot-pounds (approx)
glass	-2.00	2.1	4.0	3.5
CR-39 (dress)	-2.00	1.7	5.0	4.4
CR-39 (indus)	-2.00	3.0	8.0	7.0
glass	Plano	2.2	5.0	4.4
CR-39 (dress)	Plano	2.6	8.0	7.0
CR-39 (indus)	Plano	3.1	11.0	9.6
glass	+2.00	3.2	6.0	5.2
CR-39 (dress)	+2.00	3.0	14.0	12.3
CR-39 (indus)	+2.00	3.2	14.0	12.3

Improvement in impact protection by substituting industrial thickness CR-39 allyl resin for dress thickness (standard-issue) glass lenses. Lenses were mounted on a headform and dropped to impact simulated night vision goggle tubes.

Table 4.

Comparison of lens breakage threshold for glass (dress), CR-39 (industrial), and polycarbonate (dress)

Material	Power (diopters)	Thickness (mm)	Estimated threshold energy to break lens (foot-pounds)
glass	-2.00	2.1	3.5
CR-39 (indus.)	-2.00	2.9	7.0
polycarbonate(dress)	-2.00	2.0	>63
glass	Plano	2.2	4.4
CR-39 (indus.)	Plano	3.1	9.6
polycarbonate(dress)	Plano	2.1	>63
glass	+2.00	3.2	5.2
CR-39 (indus.)	+2.00	3.2	12.3
polycarbonate(dress)	+2.00	3.6	>63

Comparison of energy required to break glass, industrial thickness CR-39, and polycarbonate lenses.

Phase II--Field evaluation

A copy of the questionnaire used to obtain data from the subjects in the study is shown in Appendix A. Since every subject did not answer every question, the number of respondents was slightly different for each question, varying between 213 and 228.

The mean age for this group was 34. The aircraft primarily flown were the UH-1 "Huey" (42 percent) and the OH-58 "Kiowa" (19 percent), with the AH-1 "Cobra" (8 percent) and "other" (30 percent) accounting for the remainder.

Only 28 percent of the pilots wore the polycarbonate lenses fulltime, while 17 percent wore them 75 percent of the time, 10 percent wore them 50 percent of the time, 17 percent for 25 percent of the time, and 28 percent only for flying.

Sixty-four percent of the pilots said they wear spectacles to improve distance vision, 11 percent to improve near vision, and 25 percent for both distance and near. The figure for near vision is somewhat confusing, since the purpose of the study was to provide lenses to be worn when flying with NVGs, and no provisions were made to provide for older aviators requiring a near-only prescription (presbyopia).

The calendar time the new lenses were worn varied, as might be expected. Of the respondents, 13 percent had worn them 1-3 months, 41 percent for 3-6 months, and 46 percent for longer than 6 months.

When questioned as to when the polycarbonate lenses were mainly worn, 32 percent of the pilots said they only wore them when flying with NVGs, while 37 percent wore them all the time they were flying, 15 percent wore them continuously, and 16 percent listed "other." The "other" category resulted in statements ranging from, "I lost my lenses," to "I never received my lenses." Without further information, it would be difficult to conclude anything from these latter figures.

The subjects liked their new lenses, with 92 percent saying they were equal or superior to their regular-issue glass lenses.

The mean number of hours flown with the polycarbonate lenses was slightly over 37, with a wide distribution ranging from 0 to over 500.

Since cleaning is an important part of ophthalmic lens care, the subjects were asked to comment on how frequently they performed this task. Most (41 percent) of the aviators cleaned them daily, with 17 percent reporting every 1 to 2 days, 6 percent every 2 to 5 days, 10 percent only on a weekly basis, and 26 percent went longer than 1 week.

The procedure for cleaning is as important as the frequency. The subjects were asked to discuss the methods they used, and most of their responses fell into four categories. Fifty-five percent reported using soap and water and drying with a towel; 30 percent used a dry handkerchief; 11 percent used lens paper, and the remainder used whatever was available (shirt, undershirt, etc.).

When questioned about the optical characteristics, such as distortion, 97 percent of the subjects reported their lenses were satisfactory. The most commonly mentioned problem apparently related to receiving a new prescription and experiencing the adjustment period often associated with this change. Two aviators reported their lenses "seemed smeared or milky." Although the reason for this is not known, it is possible they were not using soap and water or other degreaser to remove the normal accumulation of grease and oils. There has been no mention of "milkiness" as a specific problem for polycarbonate lenses in the published literature.

To determine how well the polycarbonate lenses withstood the rigors of field aviation, the subjects were asked if their lenses scratched, and if so, to describe the circumstances. Of the 217 responses, 84 percent reported no problem with scratching. There was no apparent pattern for those indicating scratching occurred. A cross section of the situations reported to lead to scratching included: being rubbed by the NVG tubes; dropping on the airfield concrete; carrying loose in the pocket with metal objects; being abraded by the plastic case; improper cleaning; laying down the frame on the convex lens surface; and "normal wear and tear."

In the questionnaire, the subjects were asked to provide "... any other information you would care to add." The responses ranged from none to a full handwritten page. The most common statement involved the lightness of the lenses, and the associated improvement in comfort. Several negative comments were made about the quality of the present frame issued to aviators. The temples provided in this study were roughly half of each style (bayonette or comfort cable) unless stated otherwise on the order form. There were numerous complaints about the bayonette temples not providing adequate retention on the face. This resulted in either allowing the frame to slide down on the nose or fall off the head and strike the ground. Other complaints involving the bayonette temple related to discomfort around the ears, and the fact that they adversely affect sound attenuation by breaking the earcup seal. Although not reported by the subjects, one shortcoming of the cable temple is it cannot be donned in flight without removing the helmet.

Discussion

The results of the drop tests dramatically demonstrate the superior ability of polycarbonate lenses, compared to glass or CR-39 lenses, to reduce the potential for eye injury when wearing NVGs. The "step" method used to compare the impact-resistance of the different materials is a valid one, even though it could be argued the sample size should have been larger. For example, the question of whether glass breaks upon impact with the simulated goggles at 4 inches or 6 inches becomes insignificant when not one polycarbonate lens broke <u>even when dropped from 72 inches.</u>

In this comparative lens study, there were a number of uncontrolled variables which could have had some minor bearing on the results. Among these were:

a. The impact point on each lens was not exactly the same in each trial.

b. There were some slight differences in the way the lenses fitted into the frame, even though the same individual cut, edged, and mounted all of the lenses.

c. The headform was not perfectly aligned in every drop due to slight wear and tear normally found in such devices.

d. The lens thicknesses varied somewhat.

e. The spectacle frames had minor variations which could possibly have affected lens retention.

f. There was some subjective variability associated with adjusting the frame to the headform "face."

g. The chemical tempering of the glass lenses probably varied somewhat even though accomplished by the same individual using the same equipment.

h. The shelf age of each lens was unknown.

In this study, all lenses were impacted against simulated NVG tubes. It is important to understand these lenses *would not* necessarily behave in a similar manner had they been impacted with an object of different size, shape, and/or weight. For this reason, it is difficult to compare the results of other studies with the present data. However, it should be noted in every known comparison of impact-resistance, the polycarbonate lenses significantly have outperformed both glass and CR-39 (Goldsmith, 1974; Miller et al., 1979; Innes, 1982; Simmons, Krohel, and Hay, 1984).

In roughly one-half of the drop tests in which one or both of the lenses survived, lens dislodgement occurred. This was not unexpected, since the standard flight frame has a shallow V-grooved eyewire that is uniform in design. Often, only minor impact was sufficient to cause the lenses to be displaced. It should be noted that so-called "safety frames," designed to retain lenses upon impact, incorporate a safety bevel for this purpose. This safety feature is achieved by simply ensuring the eyewire surrounding the lens has a wider inner flange or lip on the side next to the eye.

The field study was successful. Acceptance of the polycarbonate lenses by the wearers was excellent. Reduced lens weight with associated improved wearing comfort frequently was singled out by the respondents as an important feature.

The incidence of scratching reported during the field study (16 percent), though higher than desired, becomes a minor problem when considering the overall protection afforded. As mentioned earlier, polycarbonate lenses are relatively soft in the post-production state. Immediately after fabrication, they are coated with a scratch-resistant material to provide additional protection. With the dramatic increase in polycarbonate lens production over the past 3 years, there has been an industrywide increase in coatings research. The result of this research is expected to be the development of coatings that are more scratch-resistant than those currently in use.

Conclusions/recommendations

Polycarbonate lenses offer a significant improvement in protection for those individuals deemed to be at risk for eye injury, whether they be aviators or foot soldiers.

Based upon the present findings, it is recommended the following actions, listed in order of priority, be accomplished as soon as possible:

1. Provide polycarbonate lenses to all ametropic personnel flying with NVGs.

2. Make provisions to furnish plano polycarbonate lenses to emmetropic aviators flying with NVGs, upon request.

3. Provide one pair of polycarbonate lenses to all ametropic military personnel working in an "eye-hazardous" environment.

4. Make provisions to furnish plano polycarbonate lenses to emmetropic personnel working in an "eye-hazardous" environment.

5. Take steps to redesign the present aviator flight frame to incorporate a safety bevel.

6. Initiate action to redesign the case currently issued with aviator spectacles.

References

American National Standards Institute, Inc. Z87.1-1979. Practice for occupational and educational eye and face protection. New York, NY.

American National Standards Institute, Inc. Z90.1-1971. Specifications for protective headgear for vehicular users. New York, New York.

Classe', J. G. 1986. Optometrist's liability for ophthalmic lenses: The law after polycarbonate. The southern journal of optometry. 4(2): 46-43.

Department of the Army. 1986. Medical services ophthalmic services, Washington, DC. Department of Defense. Army Regulation 40-3.

Dowaliby, M., Griffin, J., Palmer, B., and Voorhees, L. 1972. A study involving glass safety lenses. American journal of optometry and archives of American academy of optometry. 49(2): 128-136.

Duckworth, W. H., Rosenfield, A. R., Gulati, S. T., Rieger, R. A., and Hoekstra, K. E. 1978. Strength of thin chemtempered lenses: Drop-ball testing. American journal of optometry and physiological optics. 55(12): 801-806.

Goldsmith, W. 1974. Projectile impact on glass and polymeric ophthalmic lenses and circular plates. American journal of optometry and physiological optics. 51(11): 807-831.

Innes, A. L. 1982. Impact resistance: An overview. Journal of the American optometric association. 53(8): 635-640.

Kors, K., and St. Helen, R. 1973. Base line fracture resistance studies of tempered and non-tempered glass ophthalmic lenses. American journal of optometry and physiological optics. 50(8): 632-640.

Miller, J. W., Kislin, B., Tredici, T. J., and Rahe, A. J. 1979. Polycarbonate versus CR-39 lenses: A field study. School of Aviation Medicine technical report: TR-79-42 School of Aviation Medicine, Brooks Air Force Base, TX.

National Operating Committee on Standards for Athletic Equipment. 1973. Standard method of impact test and performance requirements for football helmets. Kansas City, MO.

Rose, H. W., and Stewart, G. M. 1957. Eye protection against small high speed missiles. Transactions American academy of ophthalmology and otolaryngology. May-June: 404-410.

Simmons, S. T., Krohel, B. B., and Hay, P. B. 1984. Prevention of ocular gunshot injuries using polycarbonate lenses. Ophthalmology. 91(8): 977-982.

Stewart, G.M., and Williams, R. L. 1966. Ballistic study of safety spectacle lenses. Edgewood Arsenal technical memorandum (EATM) 121-1. U.S. Army Biophysics Laboratory, Edgewood Arsenal, MD.

U.S. Food and Drug Administration. 1971. Statement of general policy - use of impact-resistant lenses in eyeglasses and sunglasses. Federal Register (36 F.R. 8939 and 36 F.R. 18871).

Wigglesworth, E. C. 1971a. The impact resistance of eye protector materials. American journal of optometry and archives of American academy of optometry. 48(3): 245-261.

Wigglesworth, E. C. 1971b. A ballistic assessment of eye protector lens materials. Investigative ophthalmology. 10(12): 985-991.

Wigglesworth, E. C. 1972. A comparative assessment of eye protection devices and a proposed system of acceptance testing and grading. American journal of optometry and archives of American academy of optometry. 49(4): 287-304.

Appendix A

Questionnaire

U.S. Army Aeromedical Research Laboratory
ATTN: SGRD-UAS-VS
P.O. Box 577
Ft Rucker, AL 36362-5000

Date Mailed____________
Date Received____________
Lab Use Only

POLYCARBONATE SPECTACLE LENS SURVEY

PLEASE PRINT LEGIBLY

NAME____ RANK_________
(Last) (First) (MI)

AGE______ TYPE ACFT FLOWN MOST WITH NVG & SPECTACLES______________________________

1. Approximately what percentage of your waking hours do you normally wear corrective lenses? 100___ 75___ 50___ 25___ only when flying___

2. Lenses are worn to improve distance___ near___ both___ vision.

3. How long have you worn the new lenses? 1-3 mo___ 3-6 mo___ 6-9 mo___

4. The lenses were mainly worn: only when flying with NVG___; at all times when flying___; all the time___; other___ (if other please explain)

5. Were the new lenses as satisfactory as your current glass lenses? Yes_____ No_____. If no, please explain.

6. Approximately how many hours did you fly with NVG and the new lenses_______.

7. How frequently did you clean your test lenses? daily___ 1-2 days___ 2-5 days___ weekly___ other(state)___. What cleaning procedure did you use?

8. If you did not wear the lenses at all times, where did you store them during non-use? case___ other___ (if other, please describe)

9. Did you notice any distortion or optical problems with the new lenses? Yes___ No___. If yes, please explain.

10. Have the lenses scratched? Yes___ No___. If yes, please return them along with your prescription to the above address and a replacement pair will be provided. Please explain how you think the lenses were scratched and any other information you would care to add.

PLEASE PUT ANY GENERAL COMMENTS YOU CARE TO MAKE ON THE REVERSE SIDE.

PLACE THIS QUESTIONNAIRE IN RETURN ENVELOPE AND MAIL. THANK YOU.

Appendix B

Manufacturers' list

Becton, Dickinson and Company
Rancho Viejo Road
San Juan Capistrano, CA 92675

Nicolet Instrument Corporation
Oscilloscope Division
5225-2 Verona Road
Madison, WI 53711

Redlake Corporation
1711-T Dell Avenue
Campbell, CA 95008

Spin Physics
Eastman Kodak Company
3099 Science Park Road
San Diego, CA 92121-1101

Kirk Optical Company, Incorporated
Farmingdale, NY 11735

Gentex Corporation
P.O. Box 315
Carbondale, PA 18407

A.I.T. Industries
8221 North Kimball Avenue
Skokie, IL 60076

Universal Company
Hicksville, Long Island, NY 11801

Endevco
30700 Rancho Viejo Road
San Juan Capistrano, CA 92675-9990

General Electric
Plastic Sales Division
1 Plastics Avenue
Pittsfield, MA 01201

Initial distribution

Commander
U.S. Army Natick Research
and Development Center
ATTN: Documents Librarian
Natick, MA 01760

Naval Submarine Medical
Research Laboratory
Medical Library, Naval Sub Base
Box 900
Groton, CT 05340

Commander/Director
U.S. Army Combat Surveillance
& Target Acquisition Lab
ATTN: DELCS-D
Fort Monmouth, NJ 07703-5304

Commander
10th Medical Laboratory
ATTN: Audiologist
APO NEW YORK 09180

Commander
Naval Air Development Center
Biophysics Lab
ATTN: G. Kydd
Code 60B1
Warminster, PA 18974

Naval Air Development Center
Technical Information Division
Technical Support Detachment
Warminster, PA 18974

Dr. E. Hendler
Human Factors Applications, Inc.
295 West Street Road
Warminster, PA 18974

Under Secretary of Defense
for Research and Engineering
ATTN: Military Assistant
for Medical and Life Sciences
Washington, DC 20301

Commander
U.S. Army Research Institute
of Environmental Medicine
Natick, MA 01760

U.S. Army Avionics Research
and Development Activity
ATTN: SAVAA-P-TP
Fort Monmouth, NJ 07703-5401

U.S. Army Research and Development
Support Activity
Fort Monmouth, NJ 07703

Chief, Benet Weapons Laboratory
LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB-TL
Watervliet Arsenal, NY 12189

Commander
Man-Machine Integration System
Code 602
Naval Air Development Center
Warminster, PA 18974

Commander
Naval Air Development Center
ATTN: Code 6021 (Mr. Brindle)
Warminster, PA 18974

Commanding Officer
Naval Medical Research
and Development Command
National Naval Medical Center
Bethesda, MD 20014

Director
Army Audiology and Speech Center
Walter Reed Army Medical Center
Washington, DC 20307-5001

COL Carl F. Tyner, MC
Walter Reed Army Institute
of Research
Washington, DC 20307-5100

HQ DA (DASG-PSP-O)
5109 Leesburg Pike
Falls Church, VA 22041-3258

Naval Research
Laboratory Library
Code 1433
Washington, DC 20375

Harry Diamond Laboratories
ATTN: Technical Infor-
mation Branch
2800 Powder Mill Road
Adelphi, MD 20783-1197

U.S. Army Materiel Systems
Analysis Agency
ATTN: Reports Processing
Aberdeen proving Ground
MD 21005-5017

U.S. Army Ordnance Center
and School Library
Building 3071
Aberdeen Proving Ground,
MD 21005-5201

U.S. Army Environmental Hygiene
Agency
Building E2100
Aberdeen Proving Ground,
MD 21010

Technical Library
Chemical Research
and Development Center
Aberdeen Proving Ground,
MD 21010-5423

Commander
U.S. Army Institute
of Dental Research
Walter Reed Army Medical Center
Washington, DC 20307-5300

Naval Air Systems Command
Technical Air Library 950D
Rm 278, Jefferson Plaza II
Department of the Navy
Washington, DC 20361

Naval Research Laboratory Library
Shock and Vibration Infor-
mation Center, Code 5804
Washington, DC 20375

Director
U.S. Army Human Engineer-
ing Laboratory
ATTN: Technical Library
Aberdeen Proving Ground,
MD 21005-5001

Commander
U.S. Army Test
and Evaluation Command
ATTN: AMSTE-AD-H
Aberdeen Proving Ground,
MD 21005-5055

Director
U.S. Army Ballistic
Research Laboratory
ATTN: DRXBR-OD-ST Tech Reports
Aberdeen Proving Ground,
MD 21005-5066

Commander
U.S. Army Medical Research
Institute of Chemical Defense
ATTN: SGRD-UV-AO
Aberdeen Proving Ground,
MD 21010-5425

Commander
U.S. Army Medical Research
and Development Command
ATTN: SGRD-RMS (Ms. Madigan)
Fort Detrick, Frederick, MD 21701

Commander
U.S. Army Medical Research
Institute of Infectious Diseases
Fort Detrick, Frederick,
MD 21701

Commander
U.S. Army Biomedical Research
and Development Laboratory
ATTN: SGRD-UBZ-I
Fort Detrick, Frederick,
MD 21701

Director, Biological
Sciences Division
Office of Naval Research
600 North Quincy Street
Arlington, VA 22217

Defense Technical
Information Center
Cameron Station
Alexandria, VA 22313

Commander
U.S. Army Materiel Command
ATTN: AMCDE-S (CPT Broadwater)
5001 Eisenhower Avenue
Alexandria, VA 22333

U.S. Army Foreign Science
and Technology Center
ATTN: MTZ
220 7th Street, NE
Charlottesville, VA 22901-5396

Commandant
U.S. Army Aviation
Logistics School
ATTN: ATSQ-TDN
Fort Eustis, VA 23604

Director,
Applied Technology Laboratory
USARTL-AVSCOM
ATTN: Library, Building 401
Fort Eustis, VA 23604

U.S. Army Training
and Doctrine Command
ATTN: ATCD-ZX
Fort Monroe, VA 23651

U.S. Army Training
and Doctrine Command
ATTN: Surgeon
Fort Monroe, VA 23651-5000

Structures Laboratory Library
USARTL-AVSCOM
NASA Langley Research Center
Mail Stop 266
Hampton, VA 23665

Aviation Medicine Clinic
TMC #22, SAAF
Fort Bragg, NC 28305

Naval Aerospace Medical
Institute Library
Bldg 1953, Code 102
Pensacola, FL 32508

U.S. Air Force Armament
Development and Test Center
Eglin Air Force Base, FL 32542

Command Surgeon
U.S. Central Command
MacDill Air Force Base
FL 33608

U.S. Army Missile Command
Redstone Scientific
Information Center
ATTN: Documents Section
Redstone Arsenal, AL 35898-5241

Air University Library
(AUL/LSE)
Maxwell AFB, AL 36112

U.S. Army Research and Technology
Labortories (AVSCOM)
Propulsion Laboratory MS 302-2
NASA Lewis Research Center
Cleveland, OH 44135

AFAMRL/HEX
Wright-Patterson AFB, OH 45433

University of Michigan
NASA Center of Excellence
in Man-Systems Research
ATTN: R. G. Snyder, Director
Ann Arbor, MI 48109

John A. Dellinger,
Southwest Research Institute
P. O. Box 28510
San Antonio, TX 78284

Project Officer
Aviation Life Support Equipment
ATTN: AMCPO-ALSE
4300 Goodfellow Blvd.
St. Louis, MO 63120-1798

Commander
U.S. Army Aviation
Systems Command
ATTN: DRSAV-ED
4300 Goodfellow Blvd
St. Louis, MO 63120

Commanding Officer
Naval Biodynamics Laboratory
P.O. Box 24907
New Orleans, LA 70189

U.S. Army Field Artillery School
ATTN: Library
Snow Hall, Room 14
Fort Sill, OK 73503

Commander
U.S. Army Health Services Command
ATTN: HSOP-SO
Fort Sam Houston, TX 78234-6000

U.S. Air Force Institute
of Technology (AFIT/LDEE)
Building 640, Area B
Wright-Patterson AFB, OH 45433

Henry L. Taylor
Director, Institute of Aviation
University of Illinois-
Willard Airport
Savoy, IL 61874

Commander
U.S. Army Aviation
Systems Command
ATTN: DRSAV-WS
4300 Goodfellow Blvd
St. Louis, MO 63120-1798

Commander
U.S. Army Aviation
Systems Command
ATTN: SGRD-UAX-AL (MAJ Lacy)
4300 Goodfellow Blvd., Bldg 105
St. Louis, MO 63120

U.S. Army Aviation
Systems Command
Library and Information
Center Branch
ATTN: DRSAV-DIL
4300 Goodfellow Blvd
St. Louis, MO 63120

Federal Aviation Administration
Civil Aeromedical Institute
CAMI Library AAC 64D1
P.O. Box 25082
Oklahoma City, OK 73125

Commander
U.S. Army Academy
of Health Sciences
ATTN: Library
Fort Sam Houston, TX 78234

Commander
U.S. Army Institute
of Surgical Research
ATTN: SGRD-USM (Jan Duke)
Fort Sam Houston, TX 78234-6200

Director of Professional Services
AFMSC/GSP
Brooks Air Force Base, TX 78235

U.S. Air Force School
of Aerospace Medicine
Strughold Aeromedical Library
Documents Section, USAFSAM/TSK-4
Brooks Air Force Base, TX 78235

U.S. Army Dugway Proving Ground
Technical Library
3Bldg 5330
Dugway, UT 84022

Dr. Diane Damos
Department of Human Factors
ISSM, USC
Los Angeles, CA 90089-0021

U.S. Army Yuma Proving Ground
Technical Library
Yuma, AZ 85364

U.S. Army White Sands
Missile Range
Technical Library Division
White Sands Missile Range,
NM 88002

AFFTC Technical Library
6520 TESTG/ENXL
Edwards Air Force Base,
CAL 93523-5000

U.S. Army Aviation Engineering
Flight Activity
ATTN: SAVTE-M (Tech Lib)
Stop 217
Edwards Air Force Base,
CA 93523-5000

Commander
Code 3431
Naval Weapons Center
China Lake, CA 93555

U.S. Army Combat Developments
Experimental Center
Technical Information Center
Bldg 2925
Fort Ord, CA 93941-5000

Aeromechanics Laboratory
U.S. Army Research
and Technical Labs
Ames Research Center,
M/S 215-1
Moffett Field, CA 94035

Commander
Letterman Army Institute
of Research
ATTN: Medical Research Library
Presidio of San Francisco,
CA 94129

Sixth U.S. Army
ATTN: SMA
Presidio of San Francisco,
CA 94129

Director
Naval Biosciences Laboratory
Naval Supply Center, Bldg 844
Oakland, CA 94625

Commander
U.S. Army Aeromedical Center
Fort Rucker, AL 36362

Commander
U.S. Army Medical Materiel
Development Activity
Fort Detrick,
Frederick, MD 21701-5009

Directorate
of Combat Developments
Bldg 507
Fort Rucker, AL 36362

Directorate
of Training Development
Bldg 502
Fort Rucker, AL 36362

Chief
Army Research Institute
Field Unit
Fort Rucker, AL 36362

Commander
U.S. Army Safety Center
Fort Rucker, AL 36362

U.S. Army Aircraft Development
Test Activity
ATTN: STEBG-MP-QA
Cairns AAF
Fort Rucker, AL 36362

Naval Aerospace Medical
Institute Library
Building 1953, Code 102
Pensacola, FL 32508

Commander
U.S. Army Medical Research
and Development Command
ATTN: SGRD-PLC (COL Sedge)
Fort Detrick, Frederick
MD 21701

Chief
Human Engineering Laboratory
Field Unit
Fort Rucker, AL 36362

Commander
U.S. Army Aviation Center
and Fort Rucker
ATTN: ATZQ-T-ATL
Fort Rucker, AL 36362

President
U.S. Army Aviation Board
Cairns AAF
Fort Rucker, AL 36362

Commanding Officer
Harry G. Armstrong Aerospace
Medical Research Lab
Wright-Patterson
Air Force Base, OH 45433