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USAARL REPORT NO. 69-3

AN EVALUATION OF OPHTHALMIC PLASTIC (CR-39) LENSES IN THE U. S. ARMY AVIATION ENVIRONMENT

By

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U. S. ARMY AEROMEDICAL RESEARCH LABORATORY

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Thirty rated U. S. Army aviators with various types of refractive errors were selected to wear-test both clear and tinted plastic (CR-39) ophthalmic lenses for a period of six months. Subjective evaluations were made in the areas of impact resistance, scratch resistance, weight, optical clarity, comfort, cleaning ease, resistance to breakage, and accumulation of foreign material. User acceptance was quite good. Lens scratching was not found to be a significant problem. Favorable recommendations are made concerning the general use of plastic ophthalmic lenses for U. S. Army aviation personnel.

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ABSTRACT

Thirty rated U. S. Army aviators with various types of refractive errors were selected to wear-test both clear and tinted plastic (CR-39) ophthalmic lenses for a period of six months. Subjective evaluations were made in the areas of impact resistance, scratch resistance, weight, optical clarity, comfort, cleaning ease, resistance to breakage, and accumulation of foreign material. User acceptance was quite good. Lens scratching was not found to be a significant problem. Favorable recommendations are made concerning the general use of plastic ophthalmic lenses for U. S. Army aviation personnel.

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AN EVALUATION OF OPHTHALMIC PLASTIC (CR-39) LENSES IN THE U. S. ARMY AVIATION ENVIRONMENT

INTRODUCTION

In recent years, there has been some criticism voiced concerning the safety aspects of standard ophthalmic crown glass lenses. With approximately thirty-three percent of all Army personnel required to wear prescription spectacles, and an additional fifteen to twenty percent authorized to wear plano tinted spectacles, it becomes readily apparent that the entire realm of ophthalmic devices is one of extreme importance to the Armed Forces.

Except for special orders, Army spectacle lenses are fabricated from untreated standard ophthalmic crown glass. These lenses have proven to be optically acceptable, and afford the wearer a measure of eye protection that the non-spectacle wearer does not enjoy. There are numerous cases on record indicating that an eye would have been lost or at least seriously impaired, had the individual not been wearing ophthalmic lenses. It is important, however, to consider whether the untreated crown glass is offering the military aviator the best possible eye protection available and is the most suitable material for providing ophthalmic lenses.

To increase the protective capability of glass lenses, special techniques can be employed. At present, there are two methods for increasing the break-resistance of standard ophthalmic crown glass. These are:

a) increasing the minimum thickness to 2.2 millimeters, thus increasing the strength of the lens as a direct result of increasing the amount of glass; and/or,

b) by hardening, or tempering, the glass through the process of heating, then rapidly chilling. The outer shell of glass is rapidly cooled first, thereby compressing the inner "core" of the lens.

Peters[1] and Silberstein[2] have reported that this hardening process does significantly increase the impact resistance of the glass to certain missiles. They also point out that this resistance gain is often lost, or reduced, by the presence of scratches, pits or chips on the lens surface.

Stewart[3] also reported that although the hardening process does provide an increased resistance to certain impacts, it also creates a potentially dangerous situation, should the outer shell be penetrated or deeply scratched. His studies show that should this occur, the compressed inner portion of the lens tends to burst into sharp pointed, dagger-like pieces. He further reports that untreated crown glass has poor resistance to large (17 mm and 23 mm steel balls) missiles, while exhibiting more than 2.5 times greater impact resistance than heat-treated glass lenses to small (1 mm steel balls) missiles.

Eye protection can be achieved through the use of ophthalmic materials other than glass. Nugent and Graham[4] have written a brief history of the development of plastic (CR-39) lenses and describe them as being at least ten times as resistant as glass to welding spatter and flying particles from grinding wheels. The problem of lens fogging is also strikingly reduced with plastic lenses.

Keeney and Duerson[5] discuss the advantages and disadvantages of plastic lenses in a report describing their evaluation of several types of plastic material. For example, they report that the plastic transmits five to eight percent more light, and that the tendency to fogging is reduced sixty to seventy-five percent.

Williams and Stewart[6] studied eye protection from small missiles and report that plastic lenses offer more resistance to penetration by steel BBs than any treated, or untreated, glass lens tested. They state: "It can be said that eye armor is a definite asset to the protection of eyes and any optically suitable material possessing encouraging ballistic properties, such as plastic CR-39, could be considered a valid candidate for such purposes."

Ballistics research conducted by Bryant[7] involved the use of two types of missiles (center and ring contact) to determine the impact resistance of 1.8 mm non-tempered glass, 2.2 mm tempered glass, 3.0 mm tempered glass, 2.0 mm plastic and 3.0 mm plastic. He found that the 2.0 mm plastic was equal to or better in impact resistance than the best glass lens evaluated (3.0 mm tempered).

In light of these studies showing that the eye protection afforded by glass can be improved upon, especially in the combat environment, we recommend that the Army seriously consider the use of resin (plastic) material for ophthalmic lenses.

Critics of the plastic lens program have indicated several problem areas concerning the use of this material. The major objections are:

a) Technical difficulties in manufacturing, cutting and edging, and the final laboratory assembly.

b) Higher initial cost.

c) Greater care required in handling.

d) A tendency to warp.

e) Problems in the selection of a tint dye that will meet the military specifications for neutral grey sunglasses.

f) A higher susceptibility to surface scratching than ophthalmic crown glass.

Apparently, some technical problems have existed in the manufacture and laboratory assembly of plastic lenses. Indications are, however, that recent improvements in the manufacturing technique and the use of machinery specifically designed for plastics (in lieu of attempting to utilize existing machinery designed for glass) have virtually eliminated this objection.

At present, the per unit cost of plastic somewhat exceeds that of untreated glass, particularly in the higher powers. However, the cost differential when compared to treated glass is considerably less. Increased production of plastics is expected to reduce this cost to a range equivalent to untreated glass. Future technology, such as a proposal by the Army for a machine to produce an optically acceptable lens in a matter of seconds from the raw material stage, will very likely reduce the cost below that of glass.

The remainder of the objections were difficult, if not impossible to answer, due to the lack of sufficient information. In particular, there were no data pertaining to the use of plastic lenses by U. S. Army aviation personnel. These individuals have specific requirements associated with the use of spectacles

while flying. The lenses should afford maximum eye protection, be lightweight, break-resistant, transmit maximum light, have low reflectance, resist fogging, and be available in a neutral density, low-transmittance sun lens.

Recent changes in the medical requirements for entry into U. S. Army primary flight training now allow individuals with certain correctable refractive errors to enter the program. This means that more aviators will now be depending upon ophthalmic lenses than ever before.

As a result of these predicted ophthalmic requirements, USAARL decided in May, 1968 to conduct an evaluation of plastic lenses worn by personnel on flight status. Coordination with the Optometry Consultant to the Surgeon General, representatives of the Plans, Supply, and Operations Division, Office of The Surgeon General, and the U. S. Army Medical Optical Activity in Denver, Colorado, resulted in general endorsement of the project with the Optical Activity providing the necessary ophthalmic materials.

METHODOLOGY

Volunteer subjects for the study were selected aviation personnel on flying status. Subjects were selected to provide a cross-section of visual deficiencies (i. e. presbyopes, myopes, hyperopes, astigmats) to be included in the study. Due to the time span of the evaluation, only individuals who expected to remain in the local area for a period of six months were considered.

Thirty personnel were selected as subjects, with twenty-eight requiring corrective lenses. The prescriptions of the corrective lenses were validated by accepted optometric methods. The two subjects not requiring corrective spectacles were chosen to participate in order to evaluate plano tinted lenses, and in order to include the military specialty of helicopter door-gunners. Individuals in this environment are usually subjected to more abrasion-producing situations than any other aircrew member.

Those subjects requiring corrective lenses were each provided with one pair of clear plastic lenses mounted in the standard military cellulose acetate frame, and a second pair of tinted lenses (15 percent transmission, neutral density) mounted in the standard military metal gold-filled flying goggle. They were instructed to wear one pair of glasses or the other as often as possible, preferably all their waking hours.

All the participants were briefed about the project with special effort being made to avoid creating any bias. It was carefully explained that the spectacles (frames and lenses) were to be treated in a manner not unlike that accorded previously worn spectacles having glass lenses. It was pointed out that any optical device required a certain amount of reasonable caution and care in handling, and that these spectacles were no different in this respect.

In addition, a typed slip of paper concerning the care of the plastic lenses was issued to each individual. The paper read as follows:

> "A few simple precautions can extend the useful life of these plastic lenses.
>
> 1. Don't wipe lenses when dry; blow off dust, lint, and rough particles.
>
> 2. For best results, wash lenses with soap and water.
>
> 3. Blot lenses dry and wipe them lightly with a clean cloth or tissue.
>
> 4. Never use silicone treated cloth or lens tissue on your plastic lenses."

They were then told that they would be contacted in approximately six months to return to the laboratory to complete a questionnaire and submit their lenses for inspection.

RESULTS

Although an effort was made to choose subjects who would remain in the Ft. Rucker area for the full six-month period, six of the thirty had departed at the termination of the project. One of the six was contacted the day of departure and he was mailed the questionnaire to be completed. The remaining five could not be contacted sufficiently soon to be included in the report.

Of the twenty-five who completed the entire evaluation program, twenty were rated aviators, three were helicopter door gunners, and two were technical observer professional personnel on aircrewmember flight status.

Refractive error distribution:

Hyperopia	3
Compound Hyperopic Astigmatism	6
Mixed Astigmatism	6
Myopia	4
Compound Myopic Astigmatism	4
Plano Sphere	2

There was a total of nine presbyopes with additional bifocal power ranging from +1.00 to +2.00 diopters.

Age

The age of the participants ranged from twenty-six to fifty-six with the mean being slightly more than thirty-eight.

Status

Eight were civilian instructor pilots and the remainder were active duty military.

Sex

All subjects were male.

Wearing Time

At the time the spectacles were dispensed to the subjects, they were asked to wear either the clear or tinted pair as often as possible, preferably all their waking hours. Actual wearing time was distributed as follows:

Plastic	- Clear	-	58.12 percent
	Tinted	-	31.00 percent

Glass (lenses previously prescribed)	-	Clear	- 7.16 percent
		Tinted	- .92 percent

Note that the wearing time does not equal one hundred percent. The subjects were asked to estimate their wearing time of each type of lens and a few of them did not account for the entire wearing period.

Flying Time

The average monthly flying time for the group was forty-four hours.

An effort was made to give some numerical value to the critical areas of comparison between previously worn glass lenses and the plastic lenses. A rating scale was developed as follows:

Plastic Strongly Superior	(+ 3)	
Plastic Moderately Superior	(+ 2)	
Plastic Slightly Superior	(+ 1)	
Neither Superior	(0)	Neither Superior
	(- 1)	Glass Slightly Superior
	(- 2)	Glass Moderately Superior
	(- 3)	Glass Strongly Superior
	(X)	Insufficient Information to Answer.

The subjects were told to refer to the above rating system when answering the following nine specific areas of comparison. A plus sign indicated a preference for plastic and a negative for glass. The value shown is the mean

numerical rating by the group in their response to these questions.

1. Weight + 2.72
2. Comfort (Include the effect of the lenses on the way the frame stayed in position on your face.) + 1.92
3. Scratch resistance + 0.23
4. Optical clarity (Did one type of lens seem to make objects viewed through them more clear?) + 0.92
5. Cleaning ease -0.24
6. Resistance to breakage + 2.48
7. Safety features (including shattering) + 2.64
8. Resistance to normal accumulation of dirt, lint, etc. + 0.76
9. Absence of unwanted light (i.e. reflections, glare) + 0.48

When asked if they had noticed any scratches on either pair of their plastic lenses, ten indicated that they had not, and the remaining fifteen answered affirmatively. The latter group was then asked to rate the degree of scratching according to one of these classifications:

a) Present, but not annoying.

b) Slightly annoying.

c) Moderately annoying.

d) Very annoying, but usable under combat conditions.

e) Very annoying and not considered usable.

Of the fifteen answering "Yes" when asked if they had noticed any scratches on either pair of their plastic lenses, eleven preferred choice (a) indicating that they had noticed some scratches but they considered them as not annoying. Of

the remaining four, two chose (b) indicating that the scratches were slightly annoying, one chose (c) - moderately annoying, and one chose (e) - very annoying and not considered usable.

In response to the question: "Please briefly describe the method(s) used to clean the plastic lenses, both in the field (if applicable) and during ordinary use", all but one subject stated that they used soap and water, when available, for cleaning and a soft tissue or cloth for drying.

In reference to cleaning during field use, statements included "spit and a handkerchief", "wiped with a dry handkerchief, tee-shirt, or sleeve of flight suit if nothing else available", "slapped with a handkerchief folded several times", "used my undershirt dry", "wiped off sweat with a handkerchief", and "moisture from breath and handkerchief."

When answering the question: "Did the plastic lenses chip, crack, loosen or fall out of either of the frames? How did this compare with previous experience with glass lenses?" - forty-four percent of the participants stated that they had no problems. The remainder indicated that they had problems, but not with the lenses. Virtually all the problems were linked to the standard metal flying goggle containing the tinted lenses. These problems included a tendency for a lens to "pop out" when the temples were spread and this caused a twisting of the eyewire, screws lost from the eyewire, temple screws lost or very loose, and the frame falling from the face due to lack of proper tension by the library-style temples. Several subjects volunteered the information that the frame problems they encountered were fewer than when they wore the frame with glass lenses.

The final question asked the subject to state whether he did or did not recommend that plastic lenses be adopted for use throughout Army Aviation. A brief comment was also requested.

Twenty-four of the twenty-five participants indicated that they liked the plastic lenses and wanted them as standard issue.

Some of the comments were:

> "Due to comfort and less weight, ease of maintenance and more light, I would strongly recommend that these glasses be adopted." (Here it might be noted that the term "glasses" used by this subject is perhaps no longer apropos.)

"Less trouble to keep on with perspiration."

"Exceptional wearing quality as far as weight of complete glass and frame. No soreness of nose and ears. Visibility in deep woods very good, even in subdued light."

"The clear pair was dropped on rough concrete (directly on the lens face) from 5 or 6 feet. The only damage (other than a near heart attack for the user) was a one-thirty-second inch scratch on one lens."

"I can think of at least 5 times that my glass lenses would have been broken."

"The light weight added immeasurably to the wearing comfort. The shatterproof feature was also a significant psychological factor, as was the general resistance to breakage. The only area in which I see need for improvement is in scratch resistance. This is not an important shortcoming and is far outweighed by the advantages."

The lone dissenter stated: "I don't believe the plastic lens will stand the treatment aviators will give them."

DISCUSSION

The impact-resistance characteristics of plastic lenses have been reported in the literature [3-7]. There appears to be no doubt that this type of lens can offer a degree of eye protection not available in untreated ophthalmic glass lenses, or even case hardened safety lenses. During interviews with the subjects subsequent to the completion of the questionnaire, it was apparent that the safety features of spectacle lenses were very important to them. Almost every subject revealed a paramount concern for personal safety and many had learned that the lenses could be accidentally abused and still remain usable. In one case, the pilot's tinted plastic lenses were knocked from his face when he leaned out of the aircraft window. They fell approximately fifteen feet to a concrete ramp and were retrieved by a much-relieved owner in perfect condition.

In another instance, the clear lenses mounted in the standard cellulose

acetate frame were stepped upon. The individual returned the spectacles to the Laboratory for repair. Examination revealed that the temples were bent completely out of position, but the lenses sustained no damage.

Although there has been a reported tendency of the plastic lens to warp, there were no instances found during this project. No doubt, the tendency of a plastic lens to warp is increased through the use of a metal frame, wherein pressure can be exerted more easily. Since the possibility of warping does exist, laboratories should use care to avoid this problem in the final spectacle assembly stage.

One of the primary problem areas concerning plastic lens usage in aviation is the light transmission characteristics of plastic sunglasses. In the performance of his mission, the aviator is often subjected to long periods of bright sunlight. Not only does this cause ocular fatigue and discomfort, but can adversely affect his dark adaptation capability should he be required to fly at night. It is generally agreed that a neutral density lens having fifteen percent light transmission is the best overall design for protection of the aviator. The technical specifications established for this lens are set forth in MIL - L - 36460, dated 6 December, 1965, and entitled: "Lens, Ophthalmic, Neutral Absorption."

To date, this Laboratory has evaluated tinted lenses from three major optical manufacturers. These lenses were externally dyed, i.e. the polished clear lens was dipped in a solution of acetone, water, and dye. In this process, the dye is absorbed uniformly over the entire exposed lens surface. The overall transmission characteristics are determined by the length of time the lens is allowed to remain in the solution, and the absorption characteristics of the dye.

The other acceptable method of dyeing plastic lenses is termed the internal method, and is accomplished by adding the dye to the plastic in the molten, pre-cast stage.

The external or dip-dye method appears to hold the most promise for use in the military, especially by the small division-operated optical teams. These air-mobile single vision laboratories are severely limited by weight and space. If the dip-dye process were available, these teams would need only stock clear lenses, dyeing them to meet sunglass requirements. In addition, the use of plastic lenses would enable them to carry twice the lens stockage with no increase in weight.

Unfortunately, all the tinted lenses submitted to this Laboratory for

evaluation have shown some undesirable light transmission characteristics. The X-Y coordinates have been found to be acceptable in all cases. However, a spectrophotometric analysis of the transmission throughout the visual spectrum has shown, in each case, a tendency to allow excessively large amounts of red light to pass. Specifically, in the vicinity of 620-630 millimicrons the transmission rises rather dramatically from the fifteen percent range to values between seventy and eighty percent and stays there for the remainder of the visual spectrum. Analyses conducted by both this Laboratory and the Naval Submarine Medical Laboratory have shown that these lenses do not meet MIL - L - 36460. It is encouraging to note that recent developments in research presently being conducted by several optical and chemical manufacturers indicate that this particular dye problem will possibly be resolved in the near future.

In the field of aviation, the combat mission requirements are often such that any tint other than neutral absorption could possibly be detrimental to the aviator.

One of the primary goals of this project was to determine the ability of CR-39 lenses to withstand the environment and abusive exposure during a period of normal use by aviation personnel. When the subject returned at the end of the six-month trial period, his lenses were visually inspected for scratching. Although somewhat crude, it had been decided that if inspection revealed anything worse than "hairline" scratching, the lenses would be returned to the U. S. Army Medical Optical Activity for analysis with a "Hazemeter". This instrument quantifies the degree of scratching based upon the transmission of light through the lens. Compensations are made for the dioptric power of the lens.

Since two of the subjects received only plano tinted lenses, and two other subjects were not able to make their lenses available for inspection, a total of forty-four pairs of lenses were evaluated. Slightly over forty-five percent of these (20) showed a complete absence of scratching upon visual inspection. The same percentage showed a presence of hairline scratches only. Two pairs of lenses each had one or two small (one thirty-second of an inch in length) fairly deep scratches which did not interfere with vision and would not have been measurable on the "Hazemeter". The final two pairs of lenses showed extensive scratching in the central area and were vertically oriented. Further questioning concerning these scratches disclosed that one pair had been repeatedly placed on a desk top resting on the convex (front) surface. The second pair was being carried on an aviator's belt in a conventional plastic case when he placed the aircraft seat belt around his waist (and over the case) and tightened. The subject stated that the next time he wore the lenses, he noticed the extensive scratches.

It is readily apparent from the study that the present spectacle case is not satisfactory for plastic lenses. Prior to any full scale use of plastic ophthalmic lenses by aviation personnel, a case should be designed specifically for this use.

In terms of scratching, this evaluation has shown that following a six-month wearing period, over ninety-five percent of the lenses were either completely scratch-free, classified as only hairline or had one or two small, random, deep scratches. Surprisingly, the overall subjective rating of scratch resistance by these subjects that normally wear glass lenses was slightly in favor of plastic. In light of the methods which the subjects reported they used for cleaning the lenses, it is rather remarkable that a larger percentage of scratches did not occur.

When asked to compare the weight of the plastic lens with that of previously worn glass, the plastic was almost unanimously rated as strongly superior. The weight of the plastic lens is approximately one-half that of glass with the same prescription. Closely allied with the subject of weight is that of comfort. Plastic was rated as being moderately better in this area. No doubt, the weight reduction contributed immeasurably to the overall comfort and reduced the tendency of the frame to slide down on the nose, or fall off the face. The retention problem is especially acute with the present metal flying goggle.

It is estimated that the clear plastic lens transmits from four to six percent more visible light than a comparable glass lens. It was this fact which dictated the question concerning optical clarity. Although none of the subjects were told of this characteristic beforehand, several made it a point to mention the apparent increase in clarity during a discussion following completion of the questionnaire.

Although the majority of participants did not notice any difference, a few indicated that the plastic was slightly more difficult to clean. Specifically, it should be noted that it is more difficult to remove grease from the plastic lens.

In terms of both actual and psychological value to the military, the plastic resistance to breakage and safety features (including shattering) are the most valuable assets. The reaction of the subjects to these features of plastic lenses is readily apparent when noting that almost all of them rated the plastic as strongly superior. This is also evident from reading their comments and listening to their statements.

In response to the query regarding resistance to the accumulation of dirt, plastic was chosen as being a little better than glass. This question was inserted

because one of the authors had previous experience with plastic lenses and had observed that his plastic lenses appeared to require less frequent cleaning. Although it might be reasoned that the plastic would have a static charge and thus be more difficult to keep clean, this was not found to be the case.

Responding to the question concerning the presence of unwanted light, such as glare and reflections, the subjects again were slightly in favor of plastic. There is, however, no clear choice since a large number did not notice this problem with either type of lens. Since all glass lenses are anti-reflection coated, it appears this additional process and cost would be unnecessary if plastic lenses are adopted.

There was no evaluation of the fogging characteristics of plastic since the proper weather conditions were not encountered during the test period.

Tinted glass bifocal lenses for Army aviators have a reduced amount of tint in the bifocal area. This enables the aviator to more rapidly adjust from the bright sky luninance to the relatively dark instrument panel of the aircraft. Although the plastic bifocal test lenses did not have this feature, it is anticipated that it could be provided in plastic with no difficulty.

RECOMMENDATION

Based upon the results of this evaluation, this Laboratory recommends that the plastic lens be adopted for use by U. S. Army Aviation personnel. Should future studies concerning the use of plastic lenses by non-aviation personnel result in similar findings, it is our opinion that plastic lenses should be adopted as the standard Army ophthalmic lens.

SUMMARY

Thirty U. S. Army personnel on flying status were chosen to participate in an evaluation of plastic (CR-39) ophthalmic lenses. Following a six-month wearing period, evaluation of the compatibility of plastic lenses to the Army aviation environment and user acceptance was made. In this study, lens scratching was not found to be a major problem. The results also show a decided wearer preference for the plastic lenses over the standard ophthalmic crown glass. Recommendation is made that plastic lenses be considered standard for Army aircrewmembers.

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