Technical Report Documentation Page

1. Report No. FAA-AM-76- 5	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle VISUAL EVALUATION OF SMOKE-PROTECTIVE DEVICES	5. Report Date May 1976 6. Performing Organization Code
7. Author(s) John A. Vaughan and Kenneth W. Welsh	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P. O. Box 25082 Oklahoma City, Oklahoma 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	13. Type of Report and Period Covered OAM Report 14. Sponsoring Agency Code

15. Supplementary Notes

Work was performed under Task AM-B-76-PRS-13.

16. Abstract

This study was designed to determine the visual characteristics of smoke-protective devices for flight deck crews.

Visual measurements were made on five male subjects, who ranged in age from 35 to 54, while they were wearing each of the 26 devices tested. These measurements included (1) visual field, (2) visual acuity, (3) stereoscopic depth perception, (4) color vision, and (5) bifocal displacement.

Reduction in the temporal and inferior fields was found with some of the goggles-mask combinations. The data indicate that 30.8 percent of the test items degraded visual acuity below 20/20 at the 0.4-m distance, 15.4 percent at 0.76 m, and 7.6 percent at 6.0 m. Mean values of depth perception ranged from 2.4 percent to 404.4 percent over control. The three tinted goggles created no alterations in color perception. Bifocals worn with the oxygen mask were displaced upward; those worn with the one-piece test items were displaced downward.

Criteria for an acceptable smoke-protective device are discussed.

17. Key Words Vision, Smoke protection, Goggles, Oxygen mask	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price $3.00 PC .95 MF

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VISUAL EVALUATION OF SMOKE-PROTECTIVE DEVICES

I. Introduction.

Federal Aviation Regulations, Part 25.1439 b 4, state that protective eye equipment may not cause any appreciable adverse effect on vision and must allow for corrective lenses to be worn. A report by Harper[1] indicates that pilots with defective visual and oculomotor functions (excluding defective distant visual acuity that has been corrected by lenses) have a higher incidence of accidents than those with unimpaired vision. However, until aircraft accidents can be positively correlated with specific visual deficiencies, all of the visual functions evaluated in this study should be considered equally significant. The possibility exists that smoke-protective face masks might degrade vision to the point that safety is compromised. This investigation was designed to test the visual properties of such devices.

II. Materials and Methods.

Visual performance was evaluated for the 26 test items shown in Table 1. These test items were selected because they passed or indicated the potential to pass minimum acceptable level of gas protection as determined by investigators in the Protection and Survival Laboratory at the FAA Civil Aeromedical Institute. The 26 items consisted of five fullface (one-piece) and eight combination (goggles and oxygen mask) units. Five of the eight goggles were tested with two or more oxygen masks.

TABLE 1. Test Items

Test Item	Goggle	Respirator
01	Sierra 322-01	Puritan 114120-01
02	Sierra 322-01	Sierra 358-1030
03	Sierra 322-01	Sierra 358-1002
04	Sierra 322-01	Sierra 232-37
05	Sierra 322-20	Sierra 520-120
06	Puritan 118071	Puritan 114020-20
07	Robertshaw 595-900	Puritan ZM401-M36
08	Robertshaw 595-900	Puritan 114020-20
09	American Allsafe G202-13R	Sierra 358-1030
10	American Allsafe G202-13R	Sierra 520-120
11	H. L. Bouton 1970	Puritan 114020-20
12	H. L. Bouton 1970	Puritan 114120-01
13	H. L. Bouton 1970	Sierra 358-1030
14	H. L. Bouton 1970	Sierra 358-1002
15	H. L. Bouton 1970	Sierra 358-62
16	H. L. Bouton 1970	Sierra 520-120
17	H. L. Bouton 1970	Sierra 232-37
18	H. L. Bouton 1970	Eros Scott Intertech
19	Welsh 1083	Puritan 114020-20
20	Welsh 1083	Sierra 520-120
21	H. L. Bouton 552	Sierra 520-120
22	Robertshaw 900-002-066	
23	Robertshaw 900-700-062-01	
24	Scott 10100C2A	
25	Sierra 651-100-1	
26	Robertshaw 900-700-062-02	

The five male test subjects who participated in the study ranged in age from 35 to 54 years (mean 43.2 years). Three had uncorrected visual acuity of 20/20 or better at 6.0 m, 0.76 m, and 0.4 m, and the remaining two subjects wore corrective lenses to attain these acuity levels. Either nonprescription or corrective lenses were worn with each test item by each subject throughout the experiment with the exception of the visual field measurements.

To minimize experimental variability, all the tests were conducted with the subject's head in the Frankfort Plane, a standard reference plane for head position. It is defined as the position of the head when the upper border of the auditory meatus is horizontally aligned with the lowest point on the orbital margin of the maxillary bone. The device for positioning the head in the Frankfort Plane is shown by Figure 1. It consists of a metal ear bar inserted about 1.5 cm into the auditory meatus and adjusted to apply slight pressure on the upper surface of the ear canal. A curved bar in a horizontal plane with the ear bar is swiveled forward to touch the lower orbital margin of the maxillary bone. The pitch of the head was pivoted around the ear bar by an adjustable chinrest to align the tip of the curved bar with the lower orbital margin. The chinrest together with two cupped, adjustable occipital supports, formed a rigid 3-point craniostat.

FIGURE 1. Test subject with head positioned in the Frankfort Plane.

The wear angle of each test item is the angle between the frontal plane of the head and the transparent facepiece. This plane was recorded by marking two points along a plumbline—one on the upper part and the other on the lower part of a card attached to the test item, as shown in Figure 2. The head could then be repositioned in the Frankfort Plane by realigning the two points on the card with the plumbline.

FIGURE 2. Subject wearing goggles/oxygen mask combination; wear angle is marked by two points on a card attached to the side of the goggles.

A. *Peripheral Field of Vision.* Measurements were taken on a Ferree-Rand arc perimeter designed to measure the peripheral field 95.0° arc degrees on each side of a central fixation point. Luminance across the arc of the perimeter was 6.45 mL (6.0 fL). The test subject was instructed to keep his gaze on the central fixation point while the observer slowly moved a circular white test target (12 mm in diameter) from the periphery toward the fixation point and to signal when he became aware of the moving target. The peripheral field was measured both with and without the test items along 12 equally spaced meridians around the subject's visual field.

B. *Visual Acuity.* Tests were conducted at distances of 6.0 m, 0.76 m, and 0.4 m. The test symbols were Landolt "C" figures that varied in size to equate visual acuity levels of 20/40, 20/30, 20/25, and 20/20 at the three distances. The subject was asked to indicate the position of the break in the Landolt "C" (either left, right, up, or down) beginning with the top row of figures (20/40) and to read from left to right toward the bottom row (20/20). Measurements were made at an ambient luminance level of 53.8 mL (50.0 fL). Incorrect responses were recorded at each of the three distances. Subjects wearing bifocal lenses were allowed to look through the distant portion of the lenses if the bifocal portion interfered with distant vision.

C. *Stereoscopic Depth Perception.* Stereopsis was measured at 6.0 m with the standard Howard-Dolman apparatus. After donning a test item, each subject made five rod alignments by pulling a looped cord attached to a movable rod to align the rod with a stationary rod. The final separation between the two rods was read on a millimeter scale. Each subject, as his own control, made two series of five alignments without the test items. Ambient luminance was controlled at 53.8 mL (50.0 fL).

D. *Color Vision.* For test items with tinted facepieces, Dvorine Pseudo-Isochromatic Plates were used to detect changes in normal color vision. A Macbeth easel lamp produced a luminance of 23.7 mL (22 fL) on the plates. Four of the subjects read numbers on the 14 test plates presented in a random sequence, and errors were recorded. One test subject was found to have defective color vision and was not included in the sample.

E. *Bifocal Displacement.* Physical displacement of the spectacle frame by the test item was quantitatively determined. The subjects wore zylonite frames selected to fit their facial features. A strip of paper tape (1.0 x 35.0 mm) was placed on each spectacle lens 4.0 mm below the center of the pupil. After the subject donned the test item over the spectacles, his head was positioned in the Frankfort Plane and a fullface photograph was then taken with a Nikon 35-mm camera at a distance of 1.0 m. Each photograph was analyzed by measuring the distance from the center of the pupil to the edge of the tape with an optical reticle. The displacement, either up (+) or down (−) was multiplied by a magnification factor of 7.71 to represent real displacement values.

III. Results.

Mean values of the visual field showed that the superior field remained normal or only slightly reduced for all 26 test items. The temporal or lateral field was also normal when the subjects wore the one-piece masks or goggles with transparent side shields. Reduction in the temporal and inferior field with two-piece test items was caused primarily by the opaque material surrounding the facepieces of some of the goggles or by the upper portions of the oxygen masks. The inferior field was further decreased by those oxygen masks with prominent nasal cups that elevated the goggles on the face. The graph of the mean visual field of test item 08, shown in Figure 3, is an example of the impairment of both the temporal and inferior field. One-piece test items generally provided a larger inferior field of vision than did the goggles/oxygen mask combinations. Compensatory head movements when wearing the test items would tend to enlarge the useful field of vision but may be time consuming and disruptive to flight-deck duties.

The data of Table 2 indicate that 8 of the 26 test items (30.8 percent) degraded visual acuity below 20/20 at the 0.4-m distance. Acuity was somewhat less impaired at 0.76 m (4 of 26 test items, or 15.4 percent) and at 6.0 m (2 of 26 test items, or 7.6 percent). In all other cases,

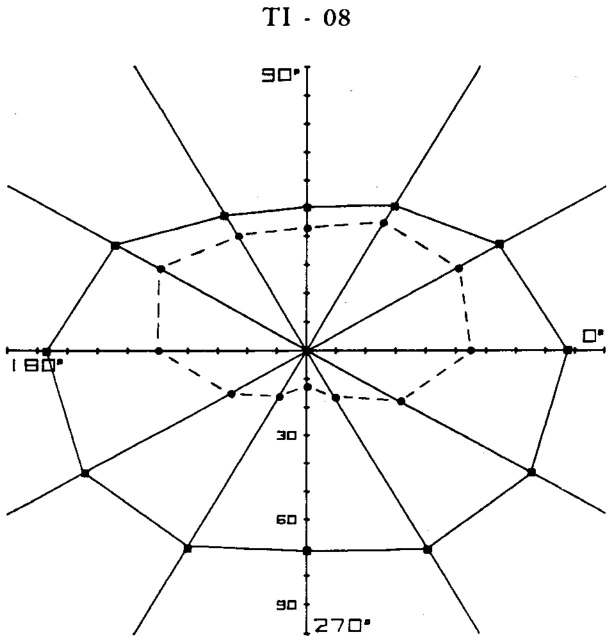

FIGURE 3. Mean values of the visual field for test item 08 (N=5). Broken lines are values with the test item. Solid lines are values without the test item (control).

TABLE 2. Visual Acuity

Test Item	Test Distance		
	6.0 m	0.76 m	0.40 m
01	-*	-	-
02	-	1/5**	3/5
03	1/5	-	1/5
04	-	1/5	1/5
05	-	-	2/5
06	-	-	-
07	-	-	1/5
08	-	-	-
09	-	-	-
10	-	-	-
11	-	-	-
12	-	-	-
13	-	-	-
14	-	-	-
15	-	-	-
16	-	-	-
17	-	-	-
18	-	-	2/5
19	-	-	-
20	-	-	-
21	-	-	-
22	-	-	-
23	5/5	5/5	5/5
24	-	-	-
25	-	-	-
26	-	1/5	2/5

* All test subjects (N = 5) had 20/20 visual acuity.
** Numerator of fraction indicates number of subjects with less than 20/20 visual acuity.

visual acuity was 20/20 (denoted by dashes in Table 2). The most likely reason for degraded acuity at the near position (0.4 m) and to some extent at the intermediate distance (0.76 m) was the distortion created when the goggles were pushed upward by the oxygen mask. This displacement caused the subject's line of sight to pass through the peripheral, rather than through the central, portion of the facepiece.

Results of the Howard-Dolham test for depth perception, shown in Table 3, were calculated in terms of the percentage of change from control. Mean values ranged from 2.4 percent for test item 17 (a goggles/oxygen mask combination) to 404.4 percent for test item 23 (a polyurethane hood). A close relationship was noted between test items that created high alignment disparities and those that degraded visual acuity (compare test items 02, 03, 04, 05, and 23).

TABLE 3. Depth Perception

Test Item	Mean Alignment Disparity (mm)	Change From Control (%)	Test Item	Mean Alignment Disparity (mm)	Change From Control (%)
01	34.6	146.8	14	21.6	9.3
02	42.6	195.4	15	19.2	5.6
03	49.8	246.8	16	19.2	31.6
04	30.8	100.4	17	17.6	2.4
05	48.5	211.9	18	24.1	16.7
06	20.2	20.7	19	18.8	22.2
07	31.4	77.6	20	21.0	4.8
08	27.4	95.3	21	23.2	47.9
09	20.3	19.4	22	18.8	14.4
10	23.6	35.7	23	67.9	404.4
11	20.0	17.0	24	20.9	8.6
12	21.7	23.5	25	24.4	30.5
13	17.2	9.2	26	36.8	119.2

Results of the color vision evaluation indicated that the three goggles with tinted facepieces (test items 06, 09–18) and the tinted fullface hood (test item 26) caused no alteration in color perception for the four test subjects with normal color vision.

Bifocal displacement for the 26 test items is shown in Table 4. The examples in Figures 4a and 4b illustrate the finding that bifocal displacement was upward (Figure 4a) with the 21 goggles/oxygen mask combinations (mean +6.62 mm, range +2.20 to +10.33mm) but was consistently downward (Figure 4b) when the five fullface devices were worn (mean −7.66 mm, range −5.09 to −12.18 mm).

TABLE 4. Bifocal Displacement

Test Item	Mean Displacement (mm)	Standard Deviation (mm)
01	+5.86*	3.63
02	+8.79	3.80
03	+9.17	1.60
04	+3.16	6.73
05	+2.78	3.29
06	+8.40	1.82
07	+2.20	3.18
08	+5.94	5.73
09	+10.33	3.64
10	+3.16	4.13
11	+8.02	4.56
12	+7.86	5.02
13	+8.94	4.32
14	+8.56	3.08
15	+3.08	4.85
16	+7.40	1.20
17	+7.09	5.48
18	+8.79	3.38
19	+7.25	3.24
20	+6.71	4.52
21	+5.47	5.28
22	-6.25	1.17
23	-5.47	3.00
24	-9.33	5.62
25	-12.18	8.51
26	-5.09	2.12

*With reference to the center of the pupil (+) indicates an upward displacement and (-) indicates a downward displacement.

IV. Discussion.

The near-vision portion of an opthalmic lens should correct visual acuity in the 40.6- to 50.8-cm (16- to 20-in) range. Bifocal elevations greater than 2 to 3 mm above the centers of the pupils (about half the diameter of the normal pupil) would create a loss of visual acuity in the distant range (6.0 m) and perhaps also in the intermediate range (0.5 to 1.0 m). To avoid bifocal interference, the individual must drop his chin or lean forward and look upward to retain vision in the distant portion of the lens. However, this maneuver may not be effective because the supraorbital ridges limit the superior field of vision when the head is depressed. The supportive structure surrounding the facepiece of the test item may limit vision in the same way. When the tops of the bifocals are elevated about 6 to 8 mm above the center of the pupils, any head manuever to see at a distance would be difficult, if not impossible to perform successfully.

FIGURE 4a. Photograph of test subject wearing goggles/oxygen mask combination with spectacles displaced upward.

FIGURE 4b. Photograph of test subject wearing fullface device with spectacles displaced downward.

Experiments with pilots have demonstrated that binocular vision is not necessary for proficient landing performance. Lewis *et al.*[2] reported that monocular occlusion of low-time pilots during the approach phase has no effect on landing performance. Landing performance was measured by the proximity of the touchdown point to a fixed target on the runway. The authors confirmed similar results compiled by Lewis and Krier,[3] who studied NASA pilots and reported no impairment of landing performance following the sudden loss of binocular vision. Whether monocular occlusion can be equated to the alteration in stereopsis caused by the characteristics of the facepiece of a smoke-protective device is not known.

The data from this evaluation suggest that an acceptable smoke-protective device should:

1. Create no impairment in distant or near visual acuity when worn by a normal-sighted presbyopic individual wearing bifocal lenses.
2. Allow minimal reduction in the wearer's peripheral field of vision. The device should provide a peripheral vision envelope of at least 120° (60° on each side of the central point) in the horizontal meridian, and 80° (40° above and below the central point) in the vertical meridian.
3. Create no significant stress and/or change in the integrity of the binocular system. Significant alterations include diplopia, suppression of vision in one eye, or a marked degradation of stereoscopic depth perception.
4. Cause no changes in color perception, including the addition of color to a neutral surface (white or gray) by a tinted facepiece or the reduction in normal color perception by selective absorption.
5. Be designed and constructed to fit snugly but also allow adequate space for corrective lenses to be worn without being displaced upward or downward when used in combination with an oxygen mask.

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