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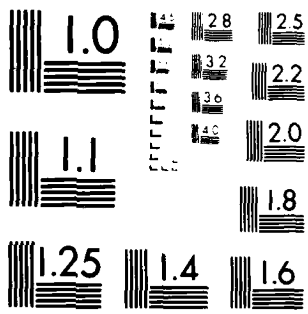

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VISUAL ACUITY WITH AND WITHOUT BINOCULARS THROUGH THICK OBSERVATION TOWER WINDOWS

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SEPTEMBER 1982

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AEROSPACE MEDICAL DIVISION
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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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Daytime visual acuity with and without hand-held M-19 7x50 binoculars was tested inside and outside of the cab of a Master Surveillance Control Facility (MSCF) Tower at Eglin AFB outfitted with thick laminated transparent armor windows. Three windows were tested, one with 13 observers and two with 5 observers. High, medium, and low contrast tri-bar resolution charts were used 400 feet from the base of the tower. Observers selected the smallest resolvable resolution pattern. The purpose was to determine if the windows were causing an appreciable loss in visual acuity.

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Differences between observers were large. Statistical tests found no significant loss in acuity, with or without binoculars, at any test chart contrast. The three windows were not significantly different in optical quality. Visual acuity with the binoculars averaged 4.5 to 6 times better than unaided eye acuity. It is concluded that the windows examined, and similar ones, cause negligible loss in visual acuity with or without hand-held binoculars. Optical quality of the windows is adequate for tower observers.

PREFACE

This report was prepared in the Human Engineering Division of the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed in support of the Base and Installation Security System (BISS) Special Project Office, Electronic Systems Division, Hanscom Air Force Base, MA. It was done under Project 7184, "Man-Machine Integration Technology," and Task 718412, "Human Engineering Application to Systems Design, Test and Evaluation."

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INTRODUCTION

The windows of security installations are frequently used for the inspection and surveillance ot ground areas and the fences that enclose them. Sometimes areas and objects that must be examined are hundreds of feet away, requiring the use of binoculars or other magnifying devices. Windows of high optical quality in the sizes required for adequate area surveillance can be very expensive. Windows that appear to the unaided eye to be of excellent quality may or may not severly degrade the ability to see fine details with binoculars or telescopes. Since looking through such windows with the eye alone may give no cue as to the optical quality when magnifying devices are used, a direct approach to quality evaluation is to use optically magnifying devices in testing.

STATEMENT OF THE PROBLEM

The windows in the Master Surveillance Control Facility (MSCF) are new and are quite thick to offer protection to the observer. They have an outer ply of ordinary window glass for weather protection and a quite thick inner ply of polycarbonate for impact resistance. The much thinner all glass windows that they replaced were tested in 1979 by AFAMRL* and found to be adequate, even for use with binoculars. The new windows, made of a laminate of plastic and glass, are much thicker than the original windows. Even if they are made to high quality standards, one might expect them to cause some loss in ability to discern fine details of intruders. How much loss in acuity or resolution is present, especially when using binoculars, is evaluated in this report.

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*Self, H. C. and Heckart, S. A. *Daytime Visual Acuity of Observers Through a Window with and without Binoculars*, AFAMRL-TR-79-23 (ADA-074727), Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio 45433, July 1979.

APPROACH, EQUIPMENT AND TESTING

VISUAL ACUITY TEST CHARTS

Visual acuity depends upon, among many other factors, the lightness or brightness contrast of the test patterns with their backgrounds. This is sometimes called achromatic contrast to distinguish it from color contrast which is attributable to differences in hue. This dependency of resolving power on contrast is true of all optical instruments, whether or not they are used directly by a human observer. Because of this, for decades the Air Force has used resolution test patterns with low, medium, and high contrast. Such patterns yield a single number, the limiting resolution, for each contrast, etc. test condition. Newer test methods, such as Modulation Transfer Function (MTF), Modulation Transfer Function Area (MTFA), and Optical Transfer Function (OTF), have supplemented, but not replaced, tests with tri-bar test patterns.

Observers were presented with a series of charts containing tri-bar resolution test patterns of the type widely used in the Air Force for testing optical devices for ability to resolve fine details. A "bar" is a stripe or rectangle on a uniform background. Each test pattern consists of three vertical and three horizontal bars. An example of a test pattern is shown in figure 1. Note that, in this standard Air Force pattern, the bars are five times as long as they are wide, and the spaces between bars are of the same width as the bars.

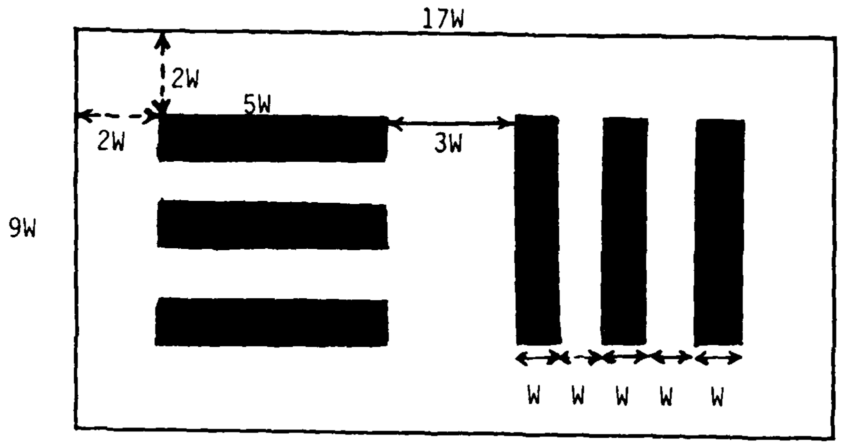
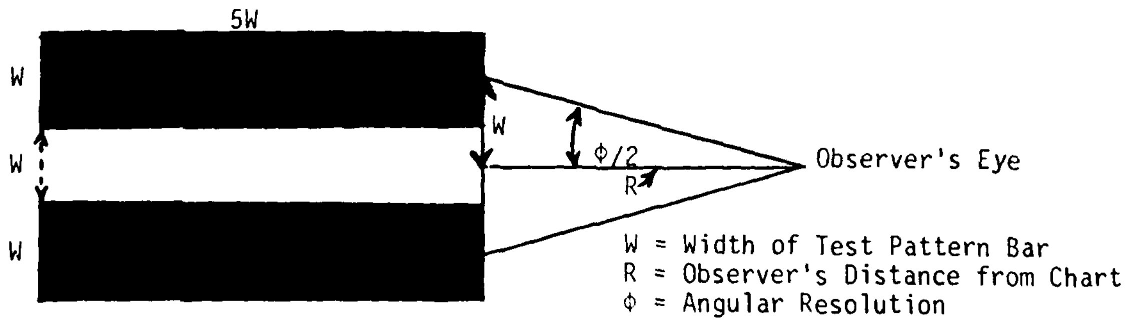


Figure 1. Resolution Test Target Configuration. The dashed lines and the W's do not appear on the test charts.



Tan $(\phi/2)=(\phi/2)$ in Radians $= (\phi/2)\ (57.296\text{x}60) = W/R = \phi/6875$.
Hence, ϕ in minutes of arc $= 6875\ W/R$. Note that optical scientists use the angle subtended at the eye by bar centers, 2W on the chart. Vision researchers use the width subtended by a bar, W, and regard $\phi/2$ as the angular resolution.

Figure 2. Angular Relationships of Test Target Resolution.

Resolving power test patterns may be made up with light bars on a darker background or with dark bars on a lighter background. Both types are commercially available. The optical tests conducted by the Air Force in its laboratories with optical collimators use white bars on a dark background. The test patterns used in the present study use light (white) bars on darker backgrounds. The point is important because, at daylight levels of illumination, white bars at higher levels of illumination are not expected to have better visibility than at somewhat lower levels of illumination. This is not the case when dark bars are used on a lighter background. With dark bars, visual acuity of a human observer is better at higher levels of illumination. The fact that the visibility of white bars varies in a way that is quite different from that of black bars as illumination changes has been known for a long time. A classical study using light bars published by Fry and Cobb* in 1935 found that acuity increased with illumination up to a point, then decreased at still higher levels of illumination.

The resolution test patterns used in the present study were constructed from paper at AFAMRL. The "bars" or stripes were made from thin white paper. There were three sets of test charts: a high contrast set, a medium contrast set, and a low contrast set. The high, medium, and low contrast test charts had, respectively, black, dark gray, and light gray backgrounds. Contrast, as used in the present report, is defined by the formula C = (Bar reflectivity minus background reflectivity)/(Background reflectivity). By this definition, contrast can range from a low of 0 to a high of 1. The three sets of charts used in the present study had contrasts of .91 (white-on-black), .59 (white-on-medium gray), and .34 (white-on-light gray). By the sometimes-used definition of (light-dark) (100)/(dark), the contrasts were, respectively, 1070, 144, and 52 percent. The contrasts of the charts and contrast computations are given in Appendix II. The size of the test patterns was selected to cover a range from 1/8 minute of arc to 2.5 minutes of arc of visual acuity (or angular subtense) when used at a slant range of 400 feet. Table 1 lists the dimensions of the resolution test patterns.

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*Fry, G. A. and Cobb, P. W. "A New Method of Determining the Blurredness of the Retinal Image" *Trans. Amer. Acad. Ophthal. Otolarng.*, 1935, 40, 423-428.

TABLE 1

TEST CHART DIMENSIONS

Visual Acuity, φ	Chart Number	Test Bars+		Test Charts			
		Width, W*	Length, 5W	Width = 17W		Height = 9W	
				M.M.	Inches	M.M.	Inches
3	1	53.2	266.0	904.2	35.6	478.7	18.8
2.5	2	44.3	221.6	753.5	29.7	398.9	15.7
2	3	35.5	177.3	602.8	23.7	319.1	12.6
1.5	4	26.6	133.0	452.1	17.8	239.4	9.43
1	5	17.7	88.6	301.4	11.9	159.6	6.28
3/4	6	13.3	66.5	226.1	8.90	119.7	4.71
1/2	7	8.9	44.3	150.7	5.93	79.8	3.14
1/3	8	5.91	29.6	100.5	3.96	53.2	2.09
1/4	9	4.43	22.2	75.4	2.97	39.9	1.57
1/5	10	3.54	17.7	60.3	2.37	31.9	1.26
1/6	11	3.0	14.8	50.2	1.98	26.6	1.05
1/7	12	2.5	12.7	43.1	1.69	22.8	.897
1/8	13	2.2	11.1	37.7	1.48	19.9	.785

* W = 17.73 ϕ m m at 400 feet slant range, where ϕ is visual acuity in minutes of arc.

+ Test bar dimensions are in millimeters.

Note: To convert to Snellen-equivalent acuity, which is conveniently used in vision research, divide the visual acuity, ϕ column values by 2.

Before presenting test results, it is worthwhile to make a few points about visual acuity and its measurement. Visual acuity is the ability to see very small objects, to distinguish separate details of objects, or to detect changes in contour. Actually, there are different types of visual acuity. Minimum perceptible visual acuity, or spot detection ability, describes ability to discern that a small object or spot is present. Vernier visual acuity is a measure of how well one can detect lateral displacement or misalignment in a broken line. Stereoscopic visual acuity is the ability to see depth, to see that one object is nearer than another. These types of visual acuity are important, but the type of visual acuity most relevant to discriminating enough detail in an intruder, to recognize him as an intruder is the type of visual acuity known as minimum separable visual acuity or gap resolution ability. It is the ability to discern that two objects separated by a small distance are really two objects rather than one—to see them as spatially separated. To measure this ability a variety of visual acuity targets are used: alternating dark and light lines (grids), black and white checkerboards, Landolt rings (a ring with a gap equal to the ring width and 1/5th its outer diameter), etc. Test results vary with target contrast, length-to-width ratio of lines, type of resolution target, illumination, etc.

Unfortunately, minimum separable visual acuity, hereafter referred to simply as visual acuity, is not measured in the same way by people in different disciplines. Astronomers, optical and photographic scientists and optical engineers measure resolution by the angle subtended by the centers of adjacent bars, stripes or discs. This is a 2W angular subtense at the observer's eye. As is clearly evident in figure 2, the USAF tri-bar resolution targets and the ones used in the present study have bar widths of W and edges that are separated by a distance of W. The centers of the bars are thus separated by 2W.

Optometrists and most vision researchers conventionally use the width, W, of one test bar, or the width of the space between bar edges, also W, as the angular measure of resolution. By using W instead of 2W, they report visual acuity values differing by a factor of two from the values reported by other workers. They follow the "one w" convention because Snellen letters on eye test charts, and similar letters on other eye test charts, have stroke widths that are 1/5th of letter height. Also, the Landolt "C," sometimes used as a visual acuity test target, has a gap width that is 1/5th of the height of the letter. Vision research reports, when a grid or bar pattern is used, usually do not tell the reader if they are reporting W or 2W angular subtenses. This difference in measurements leads to confusion and misuse of research data. Keep in mind that the data reported in the present study uses the 2W angular subtense used by optical engineers.

Another source of confusion comes from the fact that better resolution or acuity means a smaller resolved angle: as visual acuity increases, arc minutes of resolution decrease. Because of this, visual acuity is sometimes reported and plotted as the reciprocal of the resolved angle in minutes of arc. This procedure may cause other problems, but it has the advantage that the reported value of visual acuity numerically increases as visual ability increases.

TESTING OBSERVERS FOR VISUAL ACUITY

The visual acuity of an observer with and without hand-held binoculars was measured, both when standing inside the tower cab and when standing outside on the elevated platform surrounding the cab. The observers used M-19 7x50 binoculars, a compact model, light in weight and of very good optical quality. It is 152 mm wide in the open position and weighs 0.97 kg, about half of the size and weight of the standard issue M-17A1 that it is replacing, and uses individually focused eyepieces. It is being purchased in large numbers from the Bell and Howell Company for use by the Armed Forces. To date, thousands of M-19s have been used by the U.S. Army. The genesis, production, and implementation of the M-19 was described by Trsar et al.* in 1981.

Instructions for observers were handed to them on a typewritten sheet shown in Appendix I of this report. Also in the Appendix is a copy of the sheet given to them showing all of the test charts. They kept this latter sheet during testing to assist them in designating which test pattern was the smallest one that they could visually resolve. A pattern was resolved when both the horizontal and the vertical bars could be counted, even if the pattern was seen as somewhat blurred. Figure 2 shows how the distance between the centers of just-resolved bars is used to calculate visual resolution or visual acuity in minutes of arc.

During testing, the charts faced the sun and the observer faced the charts, hence facing away from the sun. The tower windows through which observations took place were thus not illuminated by direct sunlight. Had they been directly illuminated, contrast loss (due to scattering) and glare would have reduced visual activity by a small amount. This must be kept in mind, as well as the fact that data were not collected at low levels of illumination, such as is found very early or very late in the day or at night when artificial illumination is present.

The charts containing the resolution test patterns were fastened to a stand on the ground at a ground distance of 400 feet from the observer up in the tower. The height above the terrain of the eyes of an observer of average stature standing in the cab of the Master Surveillance Control Facility (MSCF) tower or outside on the platform surrounding the cab is estimated as about 49 feet 7 inches, which is 122,685 millimeters above ground. As noted earlier, the distance along the ground from the observer *in the tower to the resolution targets was* 400 feet. The slant range, S, from the observer's eyes to the test charts is, by the Pythagorean Theorem for a right triangle, $S = (400^2 + 49.583^2)^{1/2} = 403.1$ feet, which is about .77% or 3/4 of one percent greater than 400 feet. Figure 2 shows that, if $o = 6{,}875W/R$. From this, $o = 6{,}875W/122{,}685 = o = .0560W$ minutes of arc. For an R of 400 feet, instead of 403.1 feet, o would be .0556W.

Table 1 lists the visual acuity in minutes of arc for each test pattern when viewed at a slant range of 400 feet. Note that, at 400 feet, the test patterns yield simple whole numbers and fractions. Tables of test results in this report list these simple numbers. One may divide tabled values by 1.0077 to obtain correct values. These are negligibly different from the table values.

The first eight observers were tested under completely overcast conditions where the sun's disc was not discernable. However, the light level was high—it was far from dark. The last five observers were tested on a cloudless, very clear day. There was no trace of a cloud near the sun, nor was there any detectable haze. Test charts were in full bright sunlight. The observers tested during overcast days were tested on only one tower window, arbitrarily called window "A." The last five observers, those measured with bright sunlight, were tested with all three of the north-facing tower cab windows, A, B, and C. Measurements on any one observer were collected within about 20-30 minutes after briefing and study of test instructions, so that illumination on the test charts was essentially constant during the testing of any one person. Data were not collected earlier than 0930 or later than 1430.

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*Trsar, W. J., Benjamin, R. J., and Casper, J. F. "Production Engineering and Implementation of a Modular Military Binocular," *Optical Engineering* March April 1981 Vol 20 No. 2 201-17.

RESULTS

The test pattern resolution (or obtained visual acuity in minutes of arc) for all thirteen observers is listed in Tables 2-5. As noted previously, the first eight observers were tested under an overcast sky, but not under low light levels, on one of the three north-facing tower window panes. This window pane is abritrarily designated as window A. The last five observers were tested on a bright sunny day on all three of the north-facing tower window panes, designated in the data tables as windows A, B, and C, respectively. Tables 2-4 are for window A only, while Table 5 lists performance on all three windows. In addition to scores for individual observers, each column in the tables also presents the mean (or arithmetic average), the mode (the most frequent value) and the S.D. or standard deviation (a common measure of scatter or variability).

Tables 2-4 reveals some interesting facts. For example, the resolving power or visual acuity values for a large portion of the observers does not change from window to no window test conditions, both with and without the binoculars. Binocular data, of course, are quite different from data obtained without binoculars. The same lack of difference in averages, and also for individual observers with and without the window, is seen in the data of the overcast weather observers, S1-S8, when compared to the data for the sunny day observers, S9-S13. To statistically examine the differences between the averages of the overcast and the sunny day observers, "t" —tests were conducted on each of the eight columns in each of the three tables. Not one of the "t's" even approached statistical significance. It must be concluded that, for the various test conditions, the averages of the two groups of observers were not significantly different. The equivalence of overcast sky and sunny day performance permits combining the data to obtain an n of 13 observers for each test condition (or vertical column in the tables) for window A. For windows B and C, as noted, only five observers were used.

TABLE 2
HIGH CONTRAST VISUAL ACUITY *

CONDITION	OBSERVER	THE UNAIDED EYE			M-19 7x50 BINOCULARS			EYF- BINOCULAR	
		WINDOW		RATIO	WINDOW		RATIO	RATIOS	
		NO=A	YES=B	B/A +	NO=C	YES=D	D/C +	A/C +	B/D +
OVERCAST, S1-S8	1	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	2	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	3	1.5	1.0	.67	1/4	1/4	1.00	6.00	4.00
	4	1.5	1.0	.67	1/4	1/4	1.00	6.00	4.00
	5	1.5	1.5	1.00	1/4	1/3	1.33	6.00	4.00
	6	1.5	1.0	.67	1/4	1/4	1.00	6.00	4.00
	7	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	8	1.0	1.0	1.00	1/5	1/4	1.25	5.00	4.00
BRIGHT SUN S9-S13	9	1.5	1.5	1.00	1/3	1/3	1.00	4.50	4.50
	10	1.5	1.5	1.00	1/4	1/3	1.33	6.00	4.50
	11	1.0	1.5	1.50	1/5	1/5	1.00	5.00	7.50
	12	1.5	1.5	1.00	1/4	1/3	1.33	6.00	4.50
	13	1.5	2.0	1.33	1/2	1/2	1.00	3.00	4.00
S1-S13	MEAN	1.423	1.385	.988	.268	.291	1.095	5.500	4.846
	MODE	1.5	1.5	1.00	1/4	1/4	1.00	6.00	4.00
	S.D.	.188	.300	.239	.146	.0769	.150	.913	1.144
S1-S8	MEAN	1.437	1.250	.876	.244	.260	1.072	5.875	4.750
	MODE	1.5	1&1.5	1.00	1/4	1/4	1.00	6.00	4.00
	S.D.	.189	.267	.171	.0177	.0295	.136	.354	1.069
S9-S13	MEAN	1.400	1.600	1.166	.307	.340	1.132	4.900	5.000
	MODE	1.5	1.5	1.00	1/4	1/3	1.00	6.00	4.50
	S.D.	.224	.224	.235	.252	.106	.181	1.245	1.414

* TABLE VALUES ARE IN MINUTES OF ARC

\+ B/A : EYE ALONE, NO WINDOW VS WITH WINDOW

\+ D/C : BINOCULARS, NO WINDOW VS WITH WINDOW

\+ A/C : BINOCULARS VS EYE ALONE, NO WINDOWS WITH EITHER

\+ B/D : BINOCULARS VS EYE ALONE, BOTH WITH WINDOW

TABLE 3
MEDIUM CONTRAST VISUAL ACUITY *

CONDITION	OBSERVER	THE UNAIDED EYE			M-19 7x50 BINOCULARS			EYE-BINOCULAR	
		WINDOW		RATIO	WINDOW		RATIO	RATIOS	
		NO=A	YES=B	B/A +	NO=C	YES=D	D/C +	A/C +	B/D +
OVERCAST, S1-S8	1	1.5	1.5	1.00	1/4	1/3	1.33	6.00	4.00
	2	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	3	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	4	2.0	1.0	.50	1/3	1/4	.75	6.00	4.00
	5	1.5	1.0	.67	1/4	1/3	1.33	6.00	3.00
	6	1.5	1.0	.67	1/4	1/3	1.33	6.00	3.00
	7	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	8	1.0	1.5	1.50	1/5	1/4	1.25	5.00	6.00
BRIGHT SUN S9-S13	9	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	10	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	11	1.0	1.5	1.50	1/6	1/4	1.50	6.00	9.00
	12	1.5	1.5	1.00	1/2	1/3	.67	3.00	4.50
	13	2.0	2.0	1.00	1/2	1/2	1.00	4.00	4.00
S1-S13	MEAN	1.500	1.423	.988	.246	.295	1.089	5.538	5.192
	MODE	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	S.D	.289	.277	.284	.102	.0731	.243	.967	1.652
S1-S8	MEAN	1.500	1.312	.918	.254	.281	1.124	5.875	4.750
	MODE	1.5	1.5	1.00	1/4	1/4	1&1.33	6.00	6.00
	S.D	.327	.259	.308	.0365	.0431	.217	.354	1.389
S9-S13	MEAN	1.500	1.600	1.100	.233	.317	1.034	5.000	5.900
	MODE	1.5	1.5	1.00	1/4 & 1/2	1/4	1.00	6.00	6.00
	S.D	.354	.224	.224	.156	.109	.297	1.414	1.949

* TABLE VALUES ARE IN MINUTES OF ARC.
+ B/A = EYE ALONE, NO WINDOW VS WITH WINDOW
+ D/C = BINOCULARS, NO WINDOW VS WITH WINDOW
+ A/C = BINOCULARS VS EYE ALONE, NO WINDOWS WITH EITHER
+ B/D = BINOCULARS VS EYE ALONE, BOTH WITH WINDOW

TABLE 4
LOW CONTRAST VISUAL ACUITY*

CONDITION	OBSERVER	THE UNAIDED EYE: WINDOW NO=A	THE UNAIDED EYE: WINDOW YES=B	THE UNAIDED EYE: RATIO B/A+	M-19 7x50 BINOCULARS: WINDOW NO=C	M-19 7x50 BINOCULARS: WINDOW YES=D	M-19 7x50 BINOCULARS: RATIO D/C+	EYE-BINOCULAR RATIOS A/C+	EYE-BINOCULAR RATIOS B/D+
OVERCAST, S1-S8	1	1.5	2	1.33	1/4	1/3	1.33	6.00	6.00
	2	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	3	1.5	1.5	1.00	1/4	1/4	1.00	6.00	6.00
	4	2.5	1.5	.60	1/2	1/3	.67	5.00	4.50
	5	1.5	1.5	1.00	1/3	1/3	1.00	4.00	4.50
	6	1.5	1.5	1.00	1/3	1/3	1.00	4.50	4.50
	7	1.5	2	1.33	1/4	1/4	1.00	6.00	8.00
	8	1.0	1.5	1.50	1/4	1/3	1.33	4.00	4.50
BRIGHT SUN S9 S13	9	1.5	1.5	1.00	1/3	1/4	.75	4.50	6.00
	10	1.5	1.5	1.00	1/3	1/3	1.00	4.50	4.50
	11	1.0	1.5	1.50	1/6	1/6	1.00	6.00	9.00
	12	1.5	1.5	1.00	1/3	1/3	1.00	4.50	4.50
	13	1.5	2.0	1.33	1/2	1/3	.67	3.00	6.00
S1-S13	MEAN	1.500	1.615	1.122	.314	.295	.981	4.923	5.692
	MODE	1.5	1.5	1.00	1/4&1/3	1/3	1.00	6.00	4.50
	S.D.	.354	.219	.257	.271	.0550	.203	.997	1.451
S1-S8	MEAN	1.562	1.625	1.095	.302	.302	1.041	5.188	5.500
	MODE	1.5	1.5	1.00	1/4	1/3	1.00	6.00	4.50
	S.D.	.417	.231	.282	.0884	.0431	.211	.923	1.254
S9-S13	MEAN	1.400	1.600	1.166	.333	.283	.884	4.500	6.000
	MODE	1.5	1.5	1.00	1/3	1/3	1.00	4.5	4.5&6.00
	S.D.	.224	.224	.235	.118	.0745	.161	1.061	1.837

* TABLE VALUES ARE IN MINUTES OF ARC
+ B/A = EYE ALONE, NO WINDOW VS WITH WINDOW
+ D/C = BINOCULARS, NO WINDOW VS WITH WINDOW
+ A/C = BINOCULARS VS EYE ALONE NO WINDOWS WITH EITHER
+ B/D = BINOCULARS VS EYE ALONE, BOTH WITH WINDOW

TABLE 5
COMPARISONS OF THREE DIFFERENT WINDOWS

OBSERVER	THE UNAIDED EYE				M-19 7x50 BINOCULARS				EFFECTS, EYE ALONE			EFFECTS ON BINOCULARS		
	NO WINDOW	WINDOW TESTED			NO WINDOW	WINDOW TESTED			WINDOW			WINDOW		
		A	B	C		A	B	C	A	B	C	A	B	C
	KEY* P	Q	R	S	T	V	U	W	P/Q	P/R	P/S	T/U	T/V	T/W
(A) HIGH CONTRAST RESOLUTION TARGETS														
9	1.5	1.5	1.5	1.5	1/3	1/3	1/3	1/3	1.00	1.00	1.00	1.00	1.00	1.00
10	1.5	1.5	1.5	1.5	1/3	1/4	1/4	1/4	1.00	1.00	1.00	1.33	1.33	1.33
11	1.0	1.5	1.5	1.5	1/5	1/5	1/5	1/5	.67	.67	.67	1.00	1.00	1.00
12	1.5	1.5	1.5	1.5	1/4	1/3	1/3	1/3	1.00	1.00	1.00	.75	.75	.75
13	1.5	1.5	1.5	1.5	1/2	1/2	1/3	1/3	1.00	1.00	1.00	1.00	1.50	1.50
MEAN	1.400	1.500	1.500	1.500	323	323	290	.290	.934	.934	.934	1.02	1.12	1.12
MODE	1.5	1.5	1.5	1.5	1/3	1/3	1/3	1/3	1.00	1.00	1.00	1.00	1.00	1.02
S D	.224	0	0	0	.186	.114	.0619	.0619	.148	.148	.148	.206	.298	.298
(B) MEDIUM CONTRAST RESOLUTION TARGETS														
9	1.5	1.5	1.5	1.5	1/4	1/4	1/4	1/4	1.00	1.00	1.00	1.00	1.00	1.00
10	1.5	1.5	1.5	1.5	1/4	1/4	1/4	1/4	1.00	1.00	1.00	1.00	1.00	1.00
11	1.0	1.5	1.5	1.5	1/6	1/4	1/4	1/5	.67	.67	.67	.67	.67	83
12	1.5	1.5	1.5	1.5	1/3	1/2	1/2	1/2	1.00	1.00	1.00	.67	.67	.67
13	2	2	2	2	1/2	1/2	1/3	1/3	1.00	1.00	1.00	1.00	1.50	1.50
MEAN	1.500	1.600	1.600	1.600	.300	.350	.317	.307	.934	.934	.934	.868	.986	1.00
MODE	1.5	1.5	1.5	1.5	1/4	1/4	1/4	1/4	1.00	1.00	1.00	1.00	.67&1.00	1.00
S D	.354	.224	224	.224	.126	.137	.265	.265	.148	148	.148	.181	.340	.311
(C) LOW CONTRAST RESOLUTION TARGETS														
9	1.5	1.5	1.5	1.5	1/4	1/3	1/3	1/3	1.00	1.00	1.00	.75	.75	.75
10	1.5	1.5	1.5	1.5	1/3	1/3	1/3	1/3	1.00	1.00	1.00	1.00	1.00	1.00
11	1.0	1.5	1.5	1.5	1/6	1/6	1/5	1/5	.67	.67	.67	1.00	.83	.83
12	1.5	1.5	1.5	1.5	1/3	1/3	1/3	1/3	1.00	1.00	1.00	1.00	1.00	1.00
13	1.5	2	2	2	1/2	1/3	1/3	1/2	.75	.75	.75	1.50	1.50	1.00
MEAN	1.400	1.600	1.600	1.600	.317	.300	.307	.340	.884	.884	.884	1.05	1.106	.916
MODE	1.5	1.5	1.5	1.5	1/3	1/3	1/3	1/3	1.00	1.00	1.00	1.00	1.00	1.00
S D	224	224	224	.224	.124	.0745	.211	.106	.161	.161	.161	.274	.292	.118

*KEY AN ARBRITRARY LETTER IS ASSIGNED TO COLUMNS TO FACILITATE DESIGNATION OF RATIOS IN THE LAST 6 COLUMNS OF THE TABLE

S.D. = Standard Deviation = $[(N\Sigma x^2 - (\Sigma x)^2)/(N)(N-1)]^{1/2}$

In this study the primary problem was to examine the windows of the observation tower to determine if they caused a noticeable loss in visual acuity for either the unaided eye or the M-19 7x50 binoculars. Tables 2-4 permit this problem to be answered and also permit various comparisons of secondary interest to be made. Some of the comparisons, including those of primary interest, are listed in table 6.

The tests with the binoculars were of most interest because, if any appreciable loss in visual acuity were to occur, it would be expected with the binoculars. The data for observers with both binoculars and the unaided eye are plotted in figure 3. Note from the figure that for the binoculars at both high and medium contrast acuity is, as expected, better (lower resolution values) with no window, but the differences are quite small and are reversed at low contrast. Tables 7 and 8 list some statistical tests performed on the data of tables 2-4. Note from the tables that the differences just mentioned between means or averages do not attain statistical significance. It must be concluded that the tests did not demonstrate any significant loss in visual acuity for hand-held binoculars due to the tower window at any of the test chart contrast levels.

For the unaided eye, figure 3 shows a trend for both the window and no window cases for better acuity at higher contrast. This is what one would expect. Again, tables 7 and 8 show that the differences between the average ages are not statistically significant, except for the one between high and medium contrast with the eye alone (no window). Here $t_{12} = 2.18$ and P is less than .05. In view of repeated tests, this one significant difference is suspect, even though not unexpected. It must be concluded that, despite expectation, the data did not demonstrate any significantly greater loss in acuity at the lower contrast levels. In fact, for the unaided eye, it must be concluded that the data do not demonstrate a significant loss in visual acuity attributable to the window at any contrast level.

The results of the statistical analyses, discussed primarily, done on the data of tables 2-4 may be summarized as follows:

1. The average visual acuity of observers looking through the tower window was not significantly different from the average acuity with no window, both for the unaided eye and when using the binoculars, at any of the three levels of test pattern contrast. The window caused no significant loss in visual resolution or acuity.

2. Visual acuity through the window, for either the unaided eye or for hand-held binoculars, was not significantly different at different levels of test chart contrast.

The results discussed above are for window A. Table 5 lists the test data for windows A, B, and C. These data were obtained with five observers under overcast sky conditions. The data were statistically analysed, but in the numerous comparisons no statistical significance was attained between any of the obtained means at different contrasts, for different windows, or for between window and no window conditions. In view of the negative test results, the reader will not be subjected to an elaborate description of the data analysis. Instead, test results from table 5 are summarized as follows:

For both the unaided eye and the hand-held M-19 binoculars, statistical tests showed at all three levels of the test chart contrast:

1. The optical quality of the three north-facing observation tower window panes did not differ significantly from each other.

2. None of the three window panes caused a significant loss in visual acuity.

TABLE 6

VISUAL ACUITY COMPARISONS

1. Unaided Eye: Window vs No Window
   (Column B vs Column A at Each Contrast, i.e., in Each Table)

   Contrast:

   (a) High (T2)
   (b) Medium (T3)
   (c) Low (T4)

2. Binoculars: Window vs No Window
   (Column D vs Column C at Each Contrast, i.e., in Each Table)

   Contrast:

   (a) High (T2)
   (b) Medium (T3)
   (c) Low (T4)

3. Unaided Eye (No Window): Acuity at Different Contrasts
   (Column A at Different Contrasts, i.e., in Different Tables)

   Contrast:

   (a) High vs Medium (T2, T3)
   (b) High vs Low (T2, T4)
   (c) Medium vs Low (T3, T4)

4. Binoculars Alone (No Window): Acuity at Different Contrasts
   (Column C at Different Contrasts, i.e., in Different Tables)

   Contrast:

   (a) High vs Medium (T2, T3)
   (b) High vs Low (T2, T4)
   (c) Medium vs Low (T3, T4)

5. Eye with Window: Acuity at Different Contrasts
   (Column B at Different Contrasts, i.e., in Different Tables)

   Contrast:

   (a) High vs Medium (T2, T3)
   (b) High vs Low (T2, T4)
   (c) Medium vs Low (T3, T4)

6. Binoculars with Window: Acuity at Different Contrasts
   (Column D at Different Contrasts, i.e., in Different Tables)

   Contrast:

   (a) High vs Medium (T2, T3)
   (b) High vs Low (T2, T4)
   (c) Medium vs Low (T3, T4)

Note: T = Table, e.g., T2 = Table 2, Etc. "Column" refers to the columns of tables 2, 3, and 4, all of which are labeled.

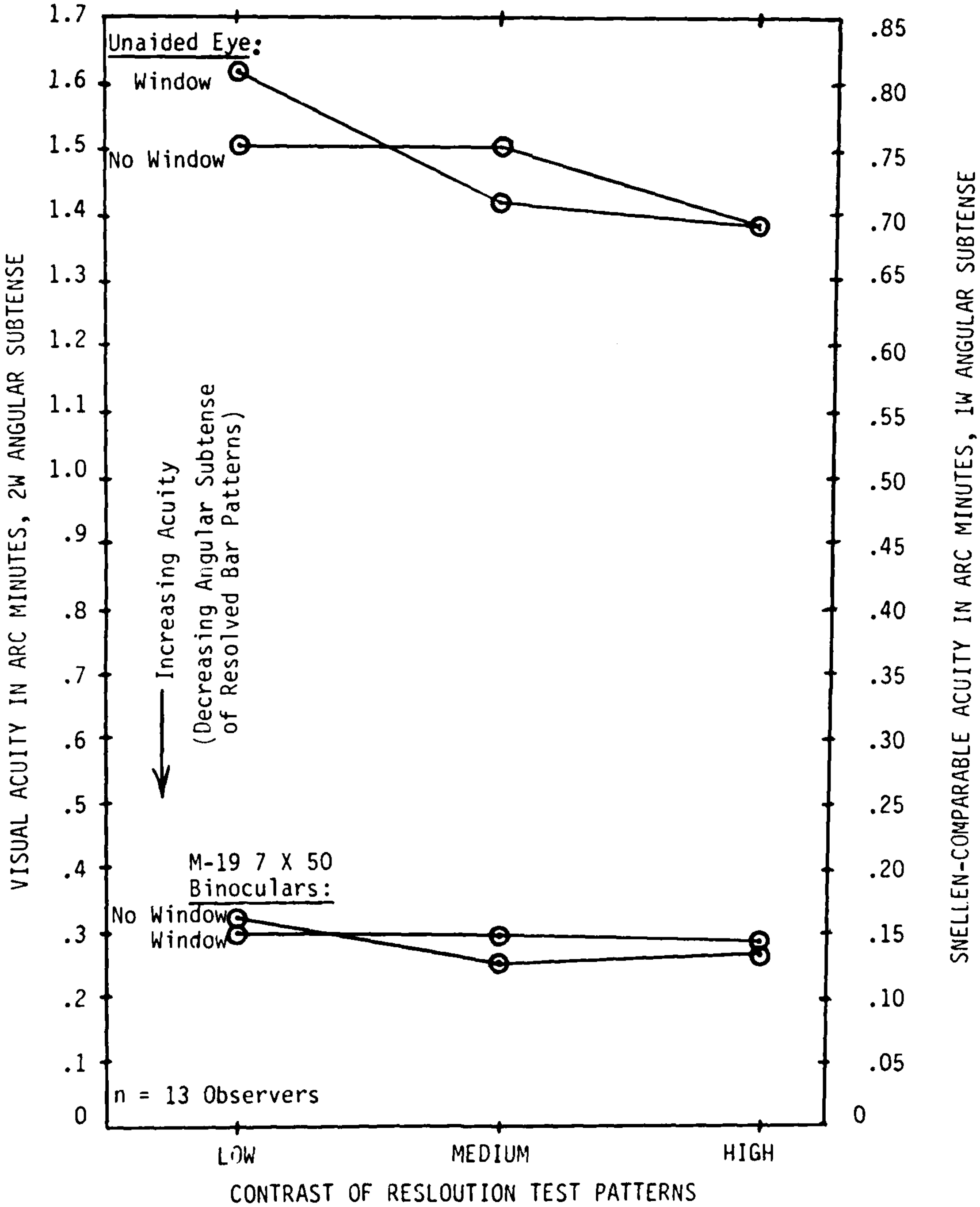


Figure 3. Comparison of Visual Acuity with and Without a Tower Window for the Unaided Eye and for Hand-held M-19 7x50 Binoculars

TABLE 7

VISUAL ACUITY WITH AND WITHOUT A WINDOW

(A) ALL 13 OBSERVERS

Target Contrast	Unaided Eye Averages			M-19 Binocular Averages		
	Window	No Window	t	Window	No Window	t
High	1.385	1.423	.12	.291	.268	.62
Medium	1.423	1.500	.19	.295	.246	.71
Low	1.615	1.500	.38	.295	.314	.25

(B) FIRST 8 OBSERVERS ONLY: OVERCAST SKY

Target Contrast	Unaided Eye Averages			M-19 Binocular Averages		
	Window	No Window	t	Window	No Window	t
High	1.250	1.437	.72	.260	.244	.50
Medium	1.312	1.500	.38	.281	.254	.54
Low	1.625	1.562	.19	.302	.302	0

TABLE 8

COMPARISON OF VISUAL ACUITIES AT DIFFERENT CONTRASTS

(A) ALL 13 OBSERVERS

Target Contrasts	Unaided Eye				M-19 Binoculars			
	Window		No Window		Window		No Window	
	Means	t	Means	t	Means	t	Means	t
High-Medium	1.385-1,423	.15	1.423-1.500	2.18*	.291-.295	.08	.268-.246	.26
High-Low	1.385-1.615	.87	1.423-1.500	.28	.291-.295	.08	.268-.314	.17
Medium-Low	1.423-1.615	.02	1.500-1.500	0	.295-.295	0	.246-.314	1.26

*Statistically Significant at the .05 Level.

(B) FIRST 8 OBSERVERS ONLY: OVERCAST SKY

Target Contrasts	Unaided Eye				M-19 Binoculars			
	Window		No Window		Window		No Window	
	Means	t	Means	t	Means	t	Means	t
High-Medium	1.250-1.312	.19	1.437-1.500	.36	.260-.281	.54	.244-.254	.34
High-Low	1.250-1.625	1.62	1.437-1.562	.35	.260-.302	.94	.244-.302	.25
Medium-Low	1.312-1.625	1.21	1.500-1.562	.35	.281-.302	1.09	.254-.302	.79

The advantage of using binoculars is in the higher visual resolution of fine details that they provide as compared to the resolution capability of the unaided eye. The last two columns of tables 2-4 are ratios of visual acuity of eye to binocular showing how many times better acuity with the binoculars is than acuity with the unaided eye. Column A C lists the ratio when no window is present and column B D lists it when looking through the window.

Figure 4 is a plot of the B D column data showing the resolution advantage of the binoculars when looking through the window. The numbers in the circles are numbers of observers and the vertical dashed lines indicate ±1 standard deviation about the means. From the figure it is apparent:

1. There is large variability in the data. At each contrast level, 6 of the 13 observers have the same acuity ratio: 4, 4.5, or 6, at low, medium, and high contrast, respectively. However, the remaining seven observers are widely scattered. Standard deviations are larger than differences between means.

2. The average or mean B D ratio, looking through the window decreases from low to medium to high contrast, indicating an increasing advantage for binoculars as contrast decreases. However, the average A C ratio (for no windows), shown by the "X's" connected by dashed lines, indicates an opposite trend.

3. Compared to the unaided eye, the average visual acuity or resolution through the window was 4.8, 5.2, and 5.7 times better at high, medium, and low contrasts, respectively. It is apparent that hand-held 7x50 binoculars provide an average advantage in resolution over the unaided eye of about 5 to 6 when looking through the tower window.

Because of the larger differences between observers and the small differences within observers from one test condition to the next, real differences in visual acuity through the window for test charts or different contrast may not be apparent in statistical tests performed on the sample of 13 observers. This turns out to be the case. The differences between the mean or average B D ratios at different contrasts are not statistically significant. The same is true for the A C ratios. It must be concluded that no real (or population) differences across contrast levels has been demonstrated for the visual acuity ratios. While binoculars were shown to permit much higher resolution of fine details, the data have neither established the existence of a trend with contrast, nor its direction, if it exists.

DISCUSSION OF RESULTS

The optical quality of the MSCF tower windows that were examined is clearly adequate for vision of intruders, either with or without binoculars. Only three window panes were examined, which is a small sample of window panes. However, if other MSCF window panes are of similar quality, the new thick transparent laminated composite windows do not pose a problem for observers.

The tests that were conducted were not intended to precisely measure acuity loss. Such tests would require many more test charts with smaller steps between adjacent steps of test patterns and repeated testing of selected observers using more complex psychophysical test procedures. Such tests would find visual acuity losses and differences between windows, but the tests reported herein show that both losses and differences would be too small to be of practical significance. It would not be worthwhile to the Air Force to measure them precisely. If, on the other hand, the tests had revealed appreciable loss in visual acuity and some windows optically unacceptable, then it would be necessary to develop precise test procedures for window inspection and acceptance purposes. We asked the question "Are the tower windows of good and acceptable optical quality?" and found that the answer was "yes."

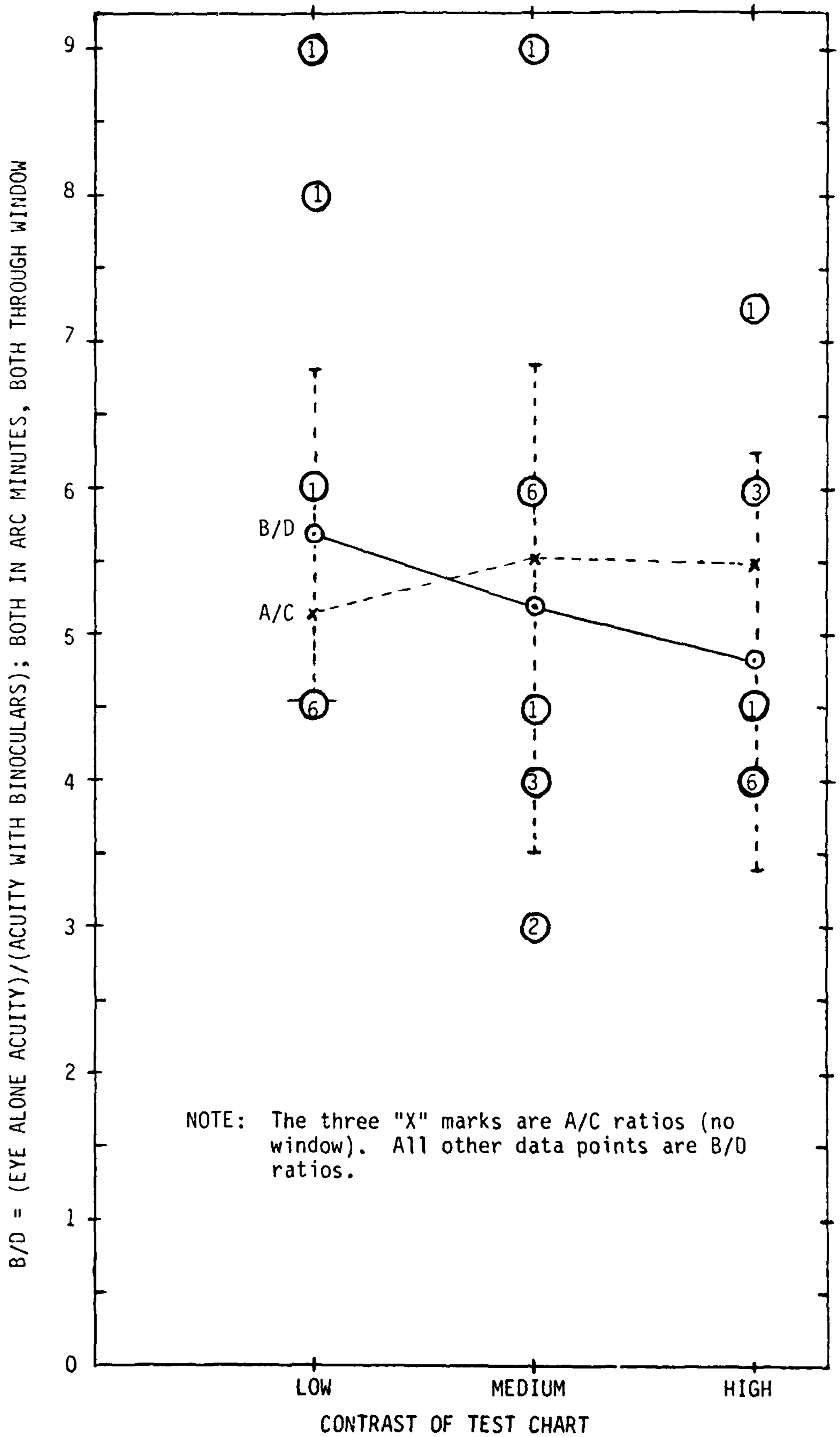


Figure 4. Eye-Binocular Acuity Ratios at Three Test Chart Contrasts.

APPENDIX I

INSTRUCTIONS FOR OBSERVERS

Your observations will be used in evaluating how well an observer can see things from the MSCF tower. You will look at a series of test charts on the ground several hundred feet away from the tower. These charts are known as "Resolution" charts. They contain patterns in the form of strips or "Bars." A pattern consists of three vertical bars and three horizontal bars.

With the largest strips or bars, there is only one pattern to a chart. The chart with the next-to-smallest bars contains three patterns, and the chart with the smallest bars contains seven patterns. There are three versions or "Sets" of each chart. They differ only in the contrast of the bars with the rest of the chart. The light gray chart yields low contrast: the medium gray chart yields medium contrast, and the black chart yields high contrast.

Examine each chart as it is presented to see if you can count both the vertical and horizontal bars in every pattern on the chart. If you can *see* three vertical and three horizontal bars, *even if they look somewhat blurred*, on a chart, say: "*I can resolve all of them.*" If you cannot resolve all of the patterns, select the pattern that you can just resolve and determine what number it is. To do this, *study* the attached sheet which shows what all of the charts look like. Note that for the 3-pattern chart the bar size decreases from left to right. However, for the 7-pattern chart, while the top row of three patterns decreases in size from left to right, *the bottom row of four patterns decreases in size from right to left*. During observations, you will be using the sheet with the pictures of the charts so that you do not have to memorize it. The numbers on the patterns on the instruction sheet do *not* appear on the actual charts. Chart "A" will not be used in the current series of observations: Chart "B" will have the coarsest pattern.

In some observations, you will use only your eyes, and in some, you will be using binoculars. When you use binoculars, you will be *assisted* in adjusting the separation of the eyepieces and focusing the binoculars. Focus will be adjusted while looking at the charts from the tower.

RESOLUTION CHARTS

There are four basic charts, each duplicated at three contrasts, for a total of 12 charts. Charts are labeled B, C, D, and E. The patterns of bars are numbered as shown below. Numbers do *not* appear on the charts! Each chart has only a *letter* designation. The figures below are *sketches* and are not drawn to scale.

Chart (B)

Only 1 pattern.

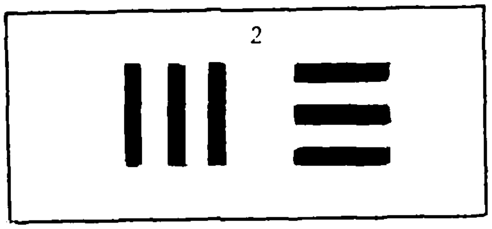


Chart (C)

Only 1 pattern.

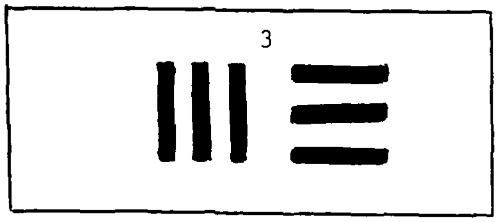


Chart (D): Three patterns

Size Decrease

Size Decrease

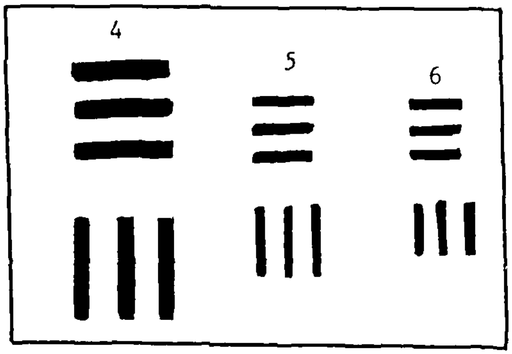


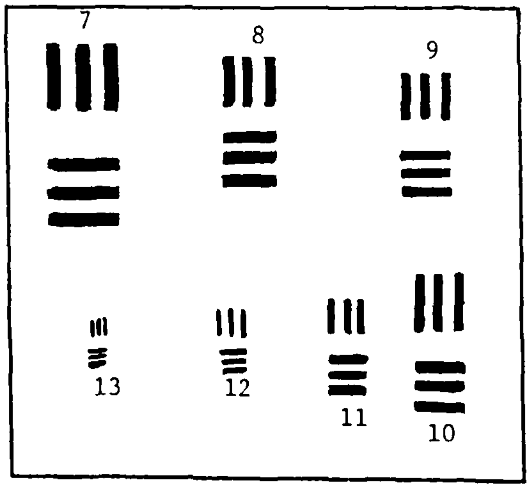
Chart (E): Seven patterns

Top Row

Size Decrease:

Bottom Row

Size Decrease



CONSENT FORM

I, (print name) ______________________, having full capacity to consent (or to decline without penalty or prejudice), do hereby volunteer to participate as an observer in a study entitled, "Visual Acuity With and Without Binoculars Through Thick Observation Tower Windows," under the direction of Dr. H. C. Self.

The nature and purpose of the study, how it was conducted (method and means), consequences of my voluntary participation, and any inconvenience or hazard have been explained to me by Dr. H. C. Self and are included at the bottom of this sheet, which I have initialed. I have been given the opportunity to ask questions about the study and any questions have been answered to my full satisfaction. I was under no pressure or coercion to participate and understand that at any time I may revoke my consent and withdraw without prejudice. If I withdraw, no reason is required, only my request.

I fully understand that I am making a decision on whether or not to participate. My signature indicates that, after reading the above paragraph, I have decided to participate.

VOLUNTEER: ______________________________
(Signature)

I was present while the above explanation was given, as well as when the volunteer was given an opportunity to ask questions, and I hereby witness his signature.

WITNESS: ______________________________
(Signature)

I briefed the volunteer and answered his questions about the study.

EXPERIMENTER: ______________________________
(Signature)

ADDENDUM TO THE CONSENT FORM

You are invited to be an observer in an experiment that measures how well observers can see through the windows of the BISS Tower. You will look at test patterns with and without binoculars to pick out the smallest pattern whose "Bars" you can see. Testing takes not more than about one-half hour.

The data taken will not be traceable to you as an individual: It will be identified only by a number. Your name as a participant and your performance will not be revealed to others. Your confidentiality as a participant will be protected.

No alternative way exists for obtaining the required data at the Eglin Test Site. Serving as a participant will not influence your future relations with the Air Force or with the Laboratory (AFAMRL). Participation is entirely voluntary and withdrawable without a stated reason at any time with no prejudice. Dr. Self will be happy to answer any questions at any time.

VOLUNTEER'S INITIALS: ____________________

APPENDIX II

CONTRAST OF TEST CHARTS

Samples of the material used in making the visual acuity tests charts were measured, one at a time, in diffuse constant room lighting with a calibrated Pritchard Digital Photometer. Readings were as follows:

Sample of Material	Reading in Foot-Lamberts
Black	2.10
Dark Gray	10.1
Light Gray	16.19
White	24.6

Contrast was defined as: $C = \frac{\text{High-Low}}{\text{High}} = \frac{\text{Target-Background}}{\text{Target}}$

This yielded contrasts as follows:

High Contrast = (24.6 - 2.1)/24.6 = .91

Medium Contrast = (24.6 - 10.0)/24.6 = .59

Low Contrast = (24.6 - 16.19)/24.6 = .34

Expressed as a percentage, these would be 91, 59, and 54 respectively.

By a second definition: Contrast $= \frac{\text{High-Low}}{\text{Low}} \times 100 = \frac{\text{Target-Background}}{\text{Background}} \times 100$

High Contrast = (24.6 - 2.1) (100)/2.1 = 1070

Medium Contrast = (24.6 - 10.1) (100)/10.1 = 144

Low Contrast = (24.6 - 16.19) (100)/16.19 = 51.9

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