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THE OPTICAL RESEARCH LABORATORY

of

THE UNIVERSITY OF TEXAS

Contract N6onr-266

Task Order IX

Project No. NR 015 702

1 December 1950

LITERATURE SURVEY OF MATERIAL PUBLISHED RELATING TO
SPECIFICATIONS OF HAND HELD BINOCULARS

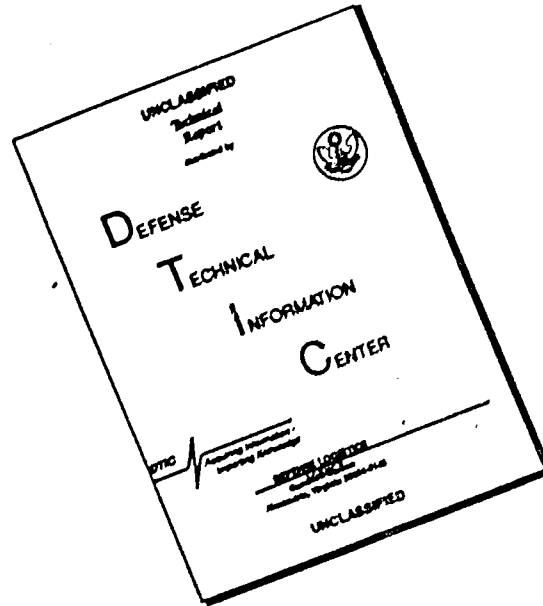
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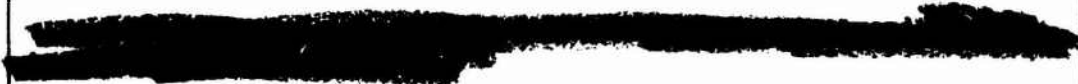
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LITERATURE SURVEY OF MATERIAL PUBLISHED RELATING TO
SPECIFICATIONS OF HAND HELD BINOCULARS

1. This report together with the five attached reprints, in the Field of Atmospheric Optics, constitute the Final Report in connection with Task IX of Contract N6onr-266 between the Office of Naval Research of the Navy Department and The Optical Research Laboratory of The University of Texas.

2. The work described in this report has been supported either directly or indirectly by the Office of Naval Research and the Bureau of Ordnance of the Navy Department, and the Ordnance Department of the Department of the Army.

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ACKNOWLEDGMENT

The work described in this report was performed by the Publications Division of The Optical Research Laboratory at The University of Texas and was under the supervision of Dr. Madeline F. Coleman. Other members of the Publications Division making material contributions to the report were Mrs. Rosemary B. Clowe, Mr. William A. De Savino, Mr. William B. Estes, Mr. David L. Fridge, Dr. Hans H. Neuberger, and Mr. Harold E. Rosenberger.

The Optical Research Laboratory wishes to acknowledge the special interest and assistance rendered by members and associates of the Armed Forces-NRC Vision Committee, and members of the Office of Naval Research. Of the latter particular cooperation was received from Captain R. P. Wadell, Commander J. T. Wulff, Dr. Urner Liddel, Dr. Elliott W. Montroll, Mr. Lawson M. Mc Kenzie, Mr. Frank B. Isakson Mrs. Elizabeth K. Kelly, Mr. Wilbert Annis, Mr. George F. Kucera, and Mr. John O. Richardson. In addition special mention should be made of the interest and assistance received from Mr. John E. Darr of the Ordnance Department of the Army.

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LITERATURE SURVEY OF MATERIAL PUBLISHED RELATING TO
SPECIFICATIONS OF HAND HELD BINOCULARS

ABSTRACT

A survey has been made of literature pertinent to the design of hand held binoculars (hereafter simply referred to as binoculars) intended to be used visually. This survey covered over 5,000 open and classified literature items published during the past one hundred and sixteen years, the majority of the more important works of which were completed during the World War II years.

The results of the literature survey clearly indicate that the design of binoculars has not been based on visual tasks intended to be performed using such devices. It has largely been governed by preceding designs and the limitations imposed by technological skill in producing instruments at a rate said to be necessary to meet military requirements. This procedure may have resulted in the design of binoculars of higher quality (and hence more costly) than is required for many military purposes. Accordingly it has been concluded that the procedure of designing binoculars should be changed by making allowances for the end use to which such devices are to be put. Such allowances would include the limitations imposed by the characteristics of the target, the properties of medium between the target and the binocular, and the response of the human observer.

In order to pursue the above proposed approach to the design of a binocular, a considerable amount of further study would be required. For the most part this study involves the collection of specific data

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dealing with the responses of the human eye used in connection with the binocular. At the present time our state of knowledge in this field is largely limited to the detection of stationary simple geometrical targets viewed under more or less uniform brightness conditions. The problems associated with the recognition of targets, targets in motion, heterogeneous brightness conditions, and the realistic military targets have been scarcely explored. Until visual response data have been collected for these factors, a logical approach to design of binoculars cannot be made.

In spite of the fact that much additional information is required before the optimum design characteristics can be specified, it has been possible to reach the conclusion that of the present conventional designs of binoculars it is clear that our best overall design would have a magnification of 10x, an exit pupil of 5 mm, and a field of not less than 7°.

INTRODUCTION

In accordance with the terms of Task IX of Contract N6onr-266 between the Office of Naval Research of the Navy Department and the University of Texas, a survey was made of literature that could be related to the design specifications of hand held binoculars to be used visually. The survey was made on the basis of a resolution formulated by the Sub-committee on Binoculars of the Army-Navy-NRC Vision Committee and adopted by that Committee 26 June 1946 in Washington, D. C. The following excerpt is from the resolution:

"It is the opinion of this Sub-committee that the studies already made provide a basis for the determination

of the optimum characteristics of telescopic optical instruments, provided that this information is properly collated.

(1) It seems appropriate to us that Dr. Coleman be invited to undertake this collation. - - - - -"

The individuals present at the Sub-committee meeting during the writing of the above resolution were:

Dr. H. K. Hartline, Chairman
Dr. F. S. Brackett
Dr. George M. Byram
Dr. Howard S. Coleman
Dr. Theodore Dunham, Jr.
Dr. Irvine C. Gardner
Dr. A. C. Hardy
Dr. Selig Hecht
Dr. Carl W. Miller
LCDR Nathan H. Pulling
Dr. Richard Tousey
Dr. William S. Verplank

The procedure used in conducting the literature survey consisted of five steps. The first step involved the collection of a little over 5,000 literature items of possible pertinence to the specification of binoculars. The primary sources of the literature were Vision Committee files, Penn State Optical Inspection Laboratory files, The University of Texas Optical Research Laboratory files, NDRC Reports, Science Abstracts in Physics, and miscellaneous Optical text and reference books. The second step consisted in the cataloging and listing of these literature items into 25 different categories, somewhat similar to the categories of instrumental properties covered in Government specifications for the procurement of binoculars during World War II. The third step consisted of the elimination of those literature items not primarily applicable to the material to be used in this report. The fourth step consisted of abstracting a little over 300 of the literature items believed to be most nearly applicable

to the specifications of binoculars, and the fifth step consisted of summarizing the material abstracted. This process consequently resulted in a highly condensed collection of specific facts which bear on the present report. Accordingly this report presents the only conclusions reached as a result of the survey. In this connection, an effort was made to reference many of the wartime reports directly rather than condensed versions of the same material which often were later published in the open scientific literature. This plan was adopted only after it was found that much of the detail upon which binocular specifications might be based was to be found in the original article and had been omitted in the open publications (since in many cases such publications were not intended primarily to bear on binocular specifications).

When possible, the analysis of the literature pertaining to the specifications of binoculars was based on the adoption of a performance criterion against which the importance of specific factors relating to the specifications of binoculars could be based. On the basis of the most reliable published material available, this performance criterion was taken to be the influence of such instrumental characteristics on the range at which objects were visible. This limits the scope of the report since the present knowledge of the manner in which the human eye responds to performing different visual tasks has been largely limited to the case of the detection of stationary objects of more or less regular shape and viewed under practically uniform illumination conditions.

The conclusions and discussion of the literature items are

presented according to the following categories in which the literature was eventually divided:

1. Target and Brightness Factors
2. Binocular Size, Shape and Weight
3. Magnification
4. Exit Pupil
5. Angular Field
6. Light Transmission and Reflection Reducing Films
7. Contrast Rendition and Stray Light
8. KDC Efficiency - Tolerances for Aberrations
9. Monocular vs. Binocular Designs
10. The Use of Aspherical Surfaces
11. The Use of Reflection Optics
12. Eye Relief
13. The Human Eye as a Part of the Binocular
14. The Atmosphere as a Part of the Binocular
15. Fixed vs. Adjustable Focus
16. The Use of Plastics
17. Anti-Oscillation Mounts
18. Collimation of Mechanical and Optical Components
19. Weather Proofing
20. Slings and Head Rests
21. Diopter Setting and Orientation of Reticles
22. Filters
23. Resistance to Shock
24. Mechanical Requirements
25. Resistance to Changes caused by Changes in Temperature

ANALYSIS OF THE DATA

Since for the most part this report covers the influence of the design properties of binoculars on detection problems, the method used in making allowances for variations in such factors on the performance of binoculars is briefly presented. This method can be thought of as consisting of the determination of the loss in range caused by a given change in one of the design characteristics of binoculars. For example, using the method described, the loss in detection range could be determined, for a wide range of weather and brightness conditions, that would result if the exit pupil were reduced from 7 mm to 5 mm. Similarly losses in range that would be caused by imperfect light

transmission, stray light, and aberrations, could be computed in terms of the magnitudes of the imperfection.

The Method of Computing the Detection Range

The following description of the method used to compute the range at which an object is visible using a binocular is taken from Reference (12). This method was largely based on work described in References (9) and (10) which involve work performed during and immediately following World War II.

In order to compute the range at which objects are detectable it is necessary to have a knowledge of the contrast threshold of the human eye at all of the various brightness conditions which may be encountered in situations of interest and for objects of various shapes and brightness structures. In addition the apparent reduction in contrast of objects by the atmosphere at various distances between the object and the observer must be known for the variety of weather and brightness conditions of interest. The thresholds of the human eye and the influence of the atmosphere on visibility have been incorporated in a set of visibility charts which have been described in detail in Reference (10). These visibility charts, a sample of which is shown in Figure 1, make it possible to compute the detection range for the unaided eye provided the following quantities are known:

1. The inherent target area (A_0)
2. The inherent target contrast (C_0)
3. The brightness of the background against which the target is viewed (B_0)
4. The meteorological range (R_m)
5. The shape of the target

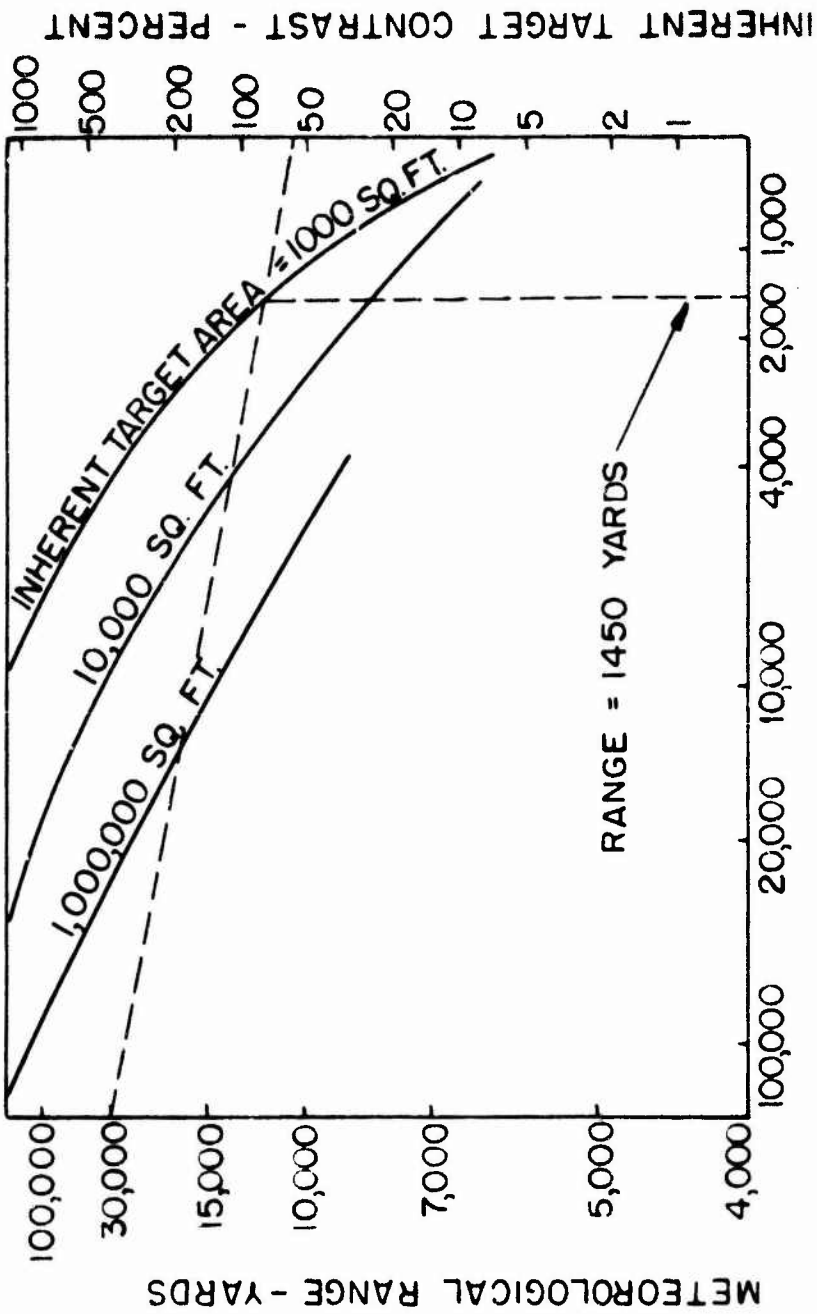
Visibility charts have been prepared for objects of a number of different shapes for brightness conditions ranging from overcast starlight (i.e. at a sky brightness of 10^{-5} foot lamberts) to bright sunlight conditions (i.e. sky brightness equal to or greater than 10^3 foot lamberts).

The use of the visibility charts for the unaided eye is illustrated by the solution of a definite problem. Suppose that the range is to be determined at which a circular target of 1000 sq. ft. inherent area and 60 percent inherent contrast would just be visible to the unaided eye on a night when the brightness level is 10^{-4} foot lamberts and the meteorological range were 30,000 yds. The procedure of determining the range at which such an object is visible consists of the following steps:

1. Locate the 60 percent position of the inherent target contrast scale and the 30,000 yd. position on the meteorological range scale and connect them with a line as shown in Figure 1.
2. Select the curve which represents an inherent area of 1,000 sq. ft. and note the point at which it intersects the straight line connecting the meteorological range position and the inherent target contrast position. The detection range corresponding to this intersection is given directly by the scale at the bottom of the chart as indicated by the vertical broken line. It is seen in this case that the detection range would be 1450 yds.

The procedure for using the visibility charts to determine detection ranges of objects viewed with the aid of a binocular is similar to the procedure sketched above for the unaided eye except that allowances must be made for certain characteristics of the binocular being used. These characteristics are:

EXAMPLE SHOWING THE USE OF THE VISIBILITY CHARTS TO PREDICT THE RANGE AT WHICH A TARGET WOULD BE DETECTABLE IN STARLIGHT WITH THE UNAIDED EYE



DETECTION RANGE - YARDS

KNOWN DATA :

- SHAPE OF TARGET - CIRCULAR
- SKY BRIGHTNESS - 10^{-4} FOOT LAMBERTS
- INHERENT TARGET AREA - 1000 SQ. FT.
- INHERENT TARGET CONTRAST - 60 %
- METEOROLOGICAL RANGE - 30,000 YDS

FIGURE 1

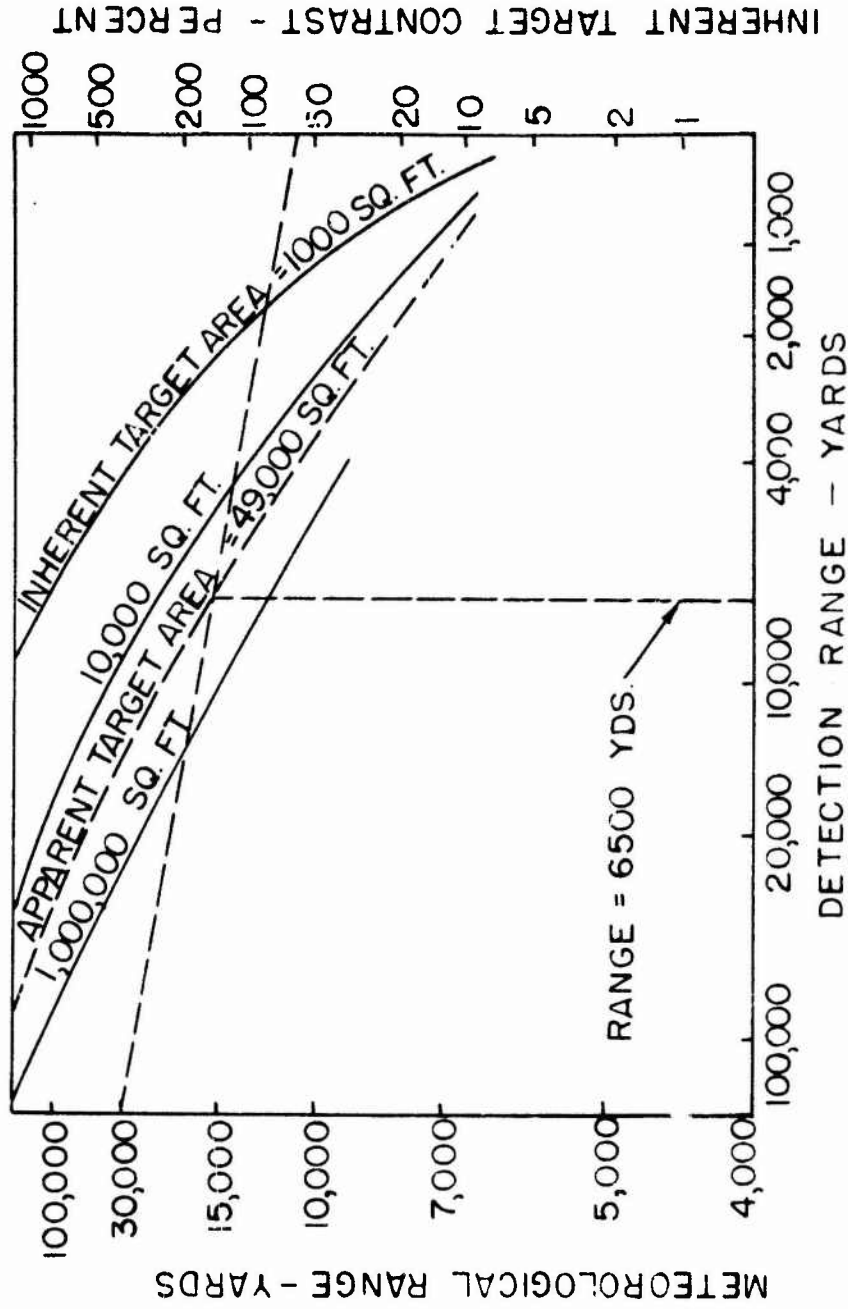
1. The magnification (M)
2. The contrast rendition (CR)
3. The light transmission (T₀)
4. The exit pupil (XP)

The influence of the magnification of a binocular is to make the target appear to have a greater area than with the unaided eye. Since the magnification increases the apparent magnification of each dimension linearly, the area of the target will appear through the binocular to be the square of the magnification times its inherent area. Therefore in using the visibility charts, the inherent area, A₀, is replaced by the apparent area A_a, as computed using the following equation:

$$(1) \quad A_a = A_0 M^2$$

The manner in which allowances are made for the magnification of the binocular is illustrated using the simplified visibility chart shown in Figure 2. In this case, suppose the detection range is to be determined in starlight using a 7 x 50 x 7° binocular for a circular target having an inherent area of 1000 sq. ft., an inherent contrast of 60 percent, and a meteorological range of 30,000 yds. For simplicity the binocular is assumed to have no faults and that its only property is to produce an apparent increase in the size of the target. The procedure of computing the detection range is then the same as described for the case of the unaided eye with the exception that an apparent area equal to 49 times that of the inherent area is assumed for using the visibility chart. The detection range is seen to be 6500 yds., as shown in Figure 2.

EXAMPLE SHOWING THE CORRECTION IN VISIBILITY CHART
 DATA FOR MAGNIFICATION USING A 7 X 50 X 7° BINOCULAR



KNOWN DATA :

- SHAPE OF TARGET - CIRCULAR
- SKY BRIGHTNESS - 10^{-4} FOOT LAMBERTS
- INHERENT TARGET AREA - 1000 SQ. FT.
- INHERENT TARGET CONTRAST - 60%
- METEOROLOGICAL RANGE - 30,000 YDS.
- CONTRAST RENDITION - 100%
- LIGHT TRANSMISSION - 100%

The fidelity, with respect to brightness contrast, of an image having a certain amount of stray light in it is referred to as contrast rendition and is defined by the following equation:

(2)

$$\text{Contrast Rendition in Percent} = \frac{\text{Contrast of the Image}}{\text{Contrast of the Object}} \times 100$$

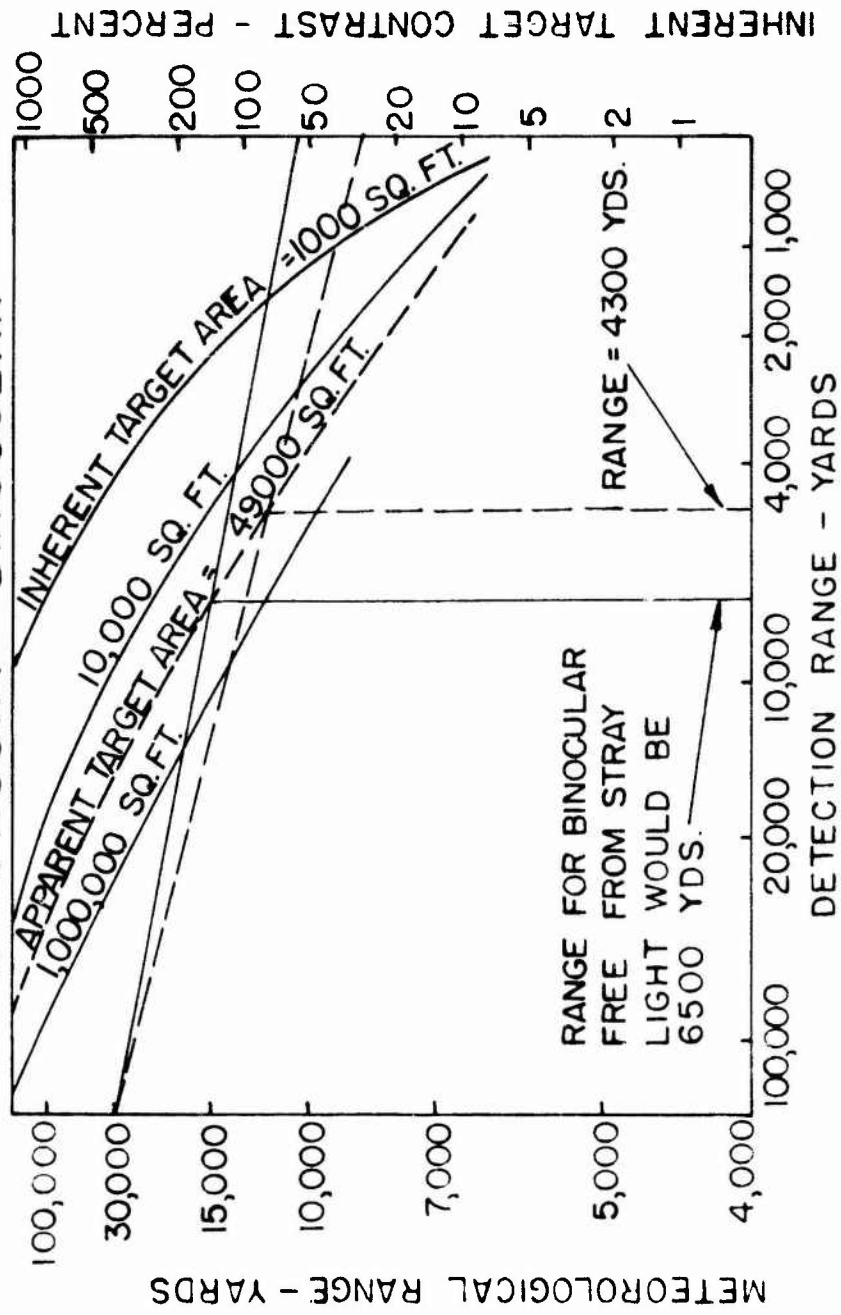
In predicting the detection range, allowances must be made for the presence of stray light, the magnitude of which is indicated by a contrast rendition of less than 100 percent. The factor by which the contrast of an otherwise perfect image has been reduced by the stray light in a binocular is equal to the contrast rendition, giving rise to a quantity referred to as the apparent contrast, C_a , which is the product of the inherent contrast, C_o , and the contrast rendition as given by the following equation:

$$(3) \quad C_a = CR \times C_o$$

The influence of imperfect contrast rendition is illustrated in Figure 3, using the problem solved previously by adding the complication of imperfect contrast rendition of 50 percent. Accordingly, the only change in the procedure is to use a value of 50 percent of inherent contrast instead of the inherent target contrast. It is seen from Figure 3 that the detection range now becomes 4300 yds., whereas for a binocular free from stray light the detection range would have been 6500 yds.

As used in this report, light transmission is defined to be the ratio of the retinal brightness of image of an object formed using

EXAMPLE SHOWING THE CORRECTION IN VISIBILITY CHART DATA FOR THE CASE OF IMPERFECT CONTRAST RENDITION USING A 7 X 50 X 7° BINOCULAR



KNOWN DATA:

- SHAPE OF TARGET - CIRCULAR
- SKY BRIGHTNESS - 10^{-4} FOOT LAMBERTS
- INHERENT TARGET AREA - 1000 SQ. FT.
- INHERENT TARGET CONTRAST - 60%
- METEOROLOGICAL RANGE - 30,000 YDS.
- CONTRAST RENDITION - 50%
- LIGHT TRANSMISSION - 100%

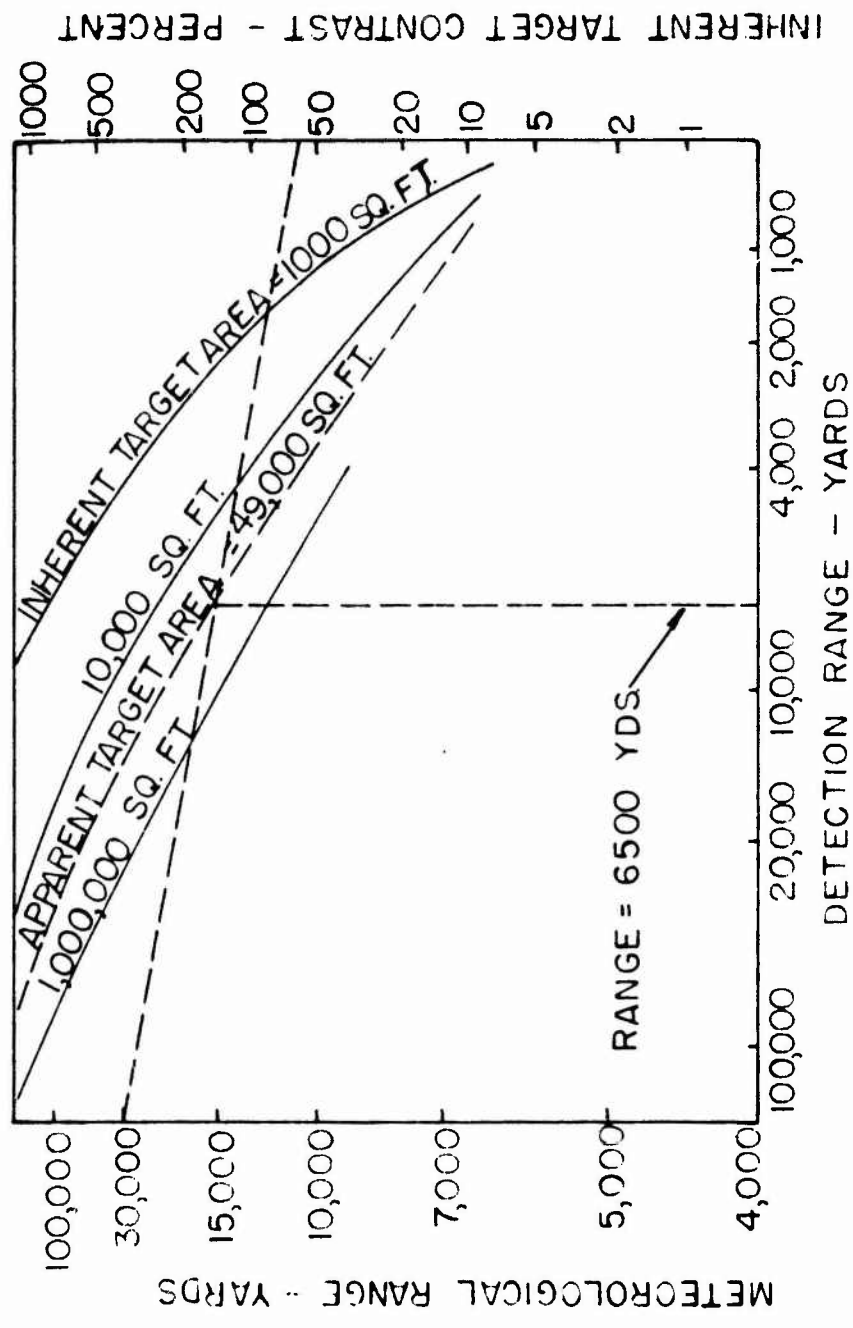
FIGURE 3

the binocular under consideration to the retinal brightness of the image of that object using the unaided eye. From this definition, it is seen that if the light transmission of a binocular is less than unity, the effect will be to reduce the apparent brightness of the field viewed through the instrument. Since the detection range depends upon the brightness of the field presented to the eye, this must be taken into account in using the visibility charts. In as much as visibility charts of the type mentioned in this report are generally constructed for a sequence of brightness levels differing by a factor of 10, it is necessary to obtain detection ranges by interpolation for intermediate brightness levels. For practical purposes, a linear interpolation may be used as a result of the nature of the response function of the human eye to changes in brightness.

The manner of making allowances for imperfect light transmission is illustrated by the solution of another problem using the same conditions otherwise as in the second example. Suppose the detection range is to be computed for a 7-power binocular having a light transmission of 50 percent but free from stray light. The detection ranges at brightness levels of 10^{-4} and 10^{-5} foot lamberts are determined using Figures 4 and 5. It is seen that these ranges are 6500 and 3450 yds. respectively. The interpolated range for an effective brightness level of 5×10^{-5} foot lamberts is given by the following equation.

$$\begin{aligned} (4) \quad R_{5 \times 10^{-5}} &= R_{10^{-5}} + \frac{T_0}{100} (R_{10^{-4}} - R_{10^{-5}}) \\ &= 3450 + \frac{50}{100} (6500 - 3450) \\ &= 4775 \text{ yds.} \end{aligned}$$

EXAMPLE SHOWING THE CORRECTION IN VISIBILITY CHART DATA FOR THE CASE OF IMPERFECT LIGHT TRANSMISSION USING A 7X50X7° BINOCULAR

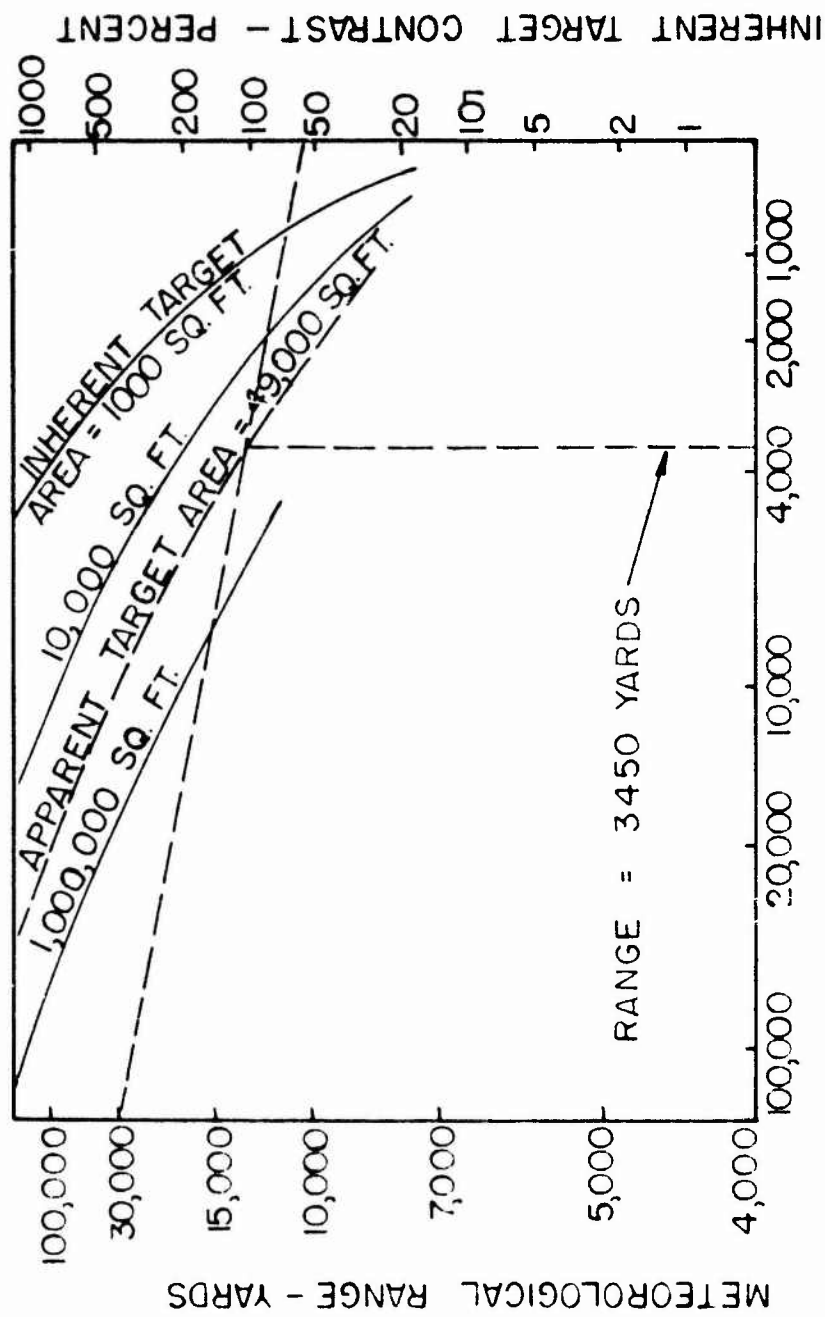


KNOWN DATA:

- SHAPE OF TARGET - CIRCULAR
- SKY BRIGHTNESS - 10^{-4} FOOT LAMBERTS
- INHERENT TARGET AREA - 1000 SQ. FT.
- INHERENT TARGET CONTRAST - 60%
- METEOROLOGICAL RANGE - 30,000 YDS.
- CONTRAST RENDITION - 100%
- LIGHT TRANSMISSION - 50%

FIGURE 4

EXAMPLE SHOWING THE CORRECTION IN VISIBILITY CHART DATA FOR THE CASE OF IMPERFECT LIGHT TRANSMISSION USING A 7X50X7° BINOCULAR



DETECTION RANGE - YARDS

KNOWN DATA:

SHAPE OF TARGET - CIRCULAR
 SKY BRIGHTNESS - 10^{-5} FOOT LAMBERTS
 INHERENT TARGET AREA - 1000 SQ. FT.
 INHERENT TARGET CONTRAST - 60 %
 METEOROLOGICAL RANGE - 30,000 YDS.
 CONTRAST RENDITION - 100 %
 LIGHT TRANSMISSION - 50 %

FIGURE 5

The size of the exit pupil of an instrument influences the range at which a target is detectable through that instrument by its control over the apparent brightness of the field in which the target is viewed. If the exit pupil is larger or equal to the pupil of the eye, no correction for exit pupil size is required. If there is no loss in light caused by imperfect light transmission, the retinal brightness of the field with the instrument is the same as for the unaided eye. However, if the exit pupil is smaller than the pupil of the eye, the apparent brightness is reduced by the ratio of the square of the diameter of the exit pupil to the square of the diameter of the pupil of the eye. This is taken into account in the same manner as an imperfect light transmission factor and for that reason is generally combined with it in making a calculation. This is done by computing an apparent light transmission factor as shown in the following equation:

$$(b) T_a = T_o \left(\frac{K_i}{P} \right)^2$$

where P is the size of the pupil of the eye, at the particular brightness level to which it is adapted, and K_i is the effective pupil of the optical system and T_o is the light transmission factor.

The value of P varies with the brightness level. In bright daylight, it may be less than 3 mm in which case most exit pupil sizes would not have to be taken into account. However, at night the pupil may be 7 or 8 mm in diameter, and hence larger than the exit pupils of many instruments. In this latter case, a correction would have to be made. The corrections required for an exit pupil smaller than the pupil of the eye are illustrated in the next section.

The general problem of computing the range at which an object may be detected with a real binocular is illustrated by a fifth example. Suppose that the detection range of the target discussed in previous problems were to be determined for a 10 x 50 x 7° binocular having a contrast rendition of 50 percent, a light transmission of .70, and an exit pupil of 5 mm, on a starlit night (brightness level of 10^{-4} foot lamberts) when the natural pupil of the observer's eye were 8 mm in diameter.

In as much as the magnification of the binocular is 10x, the area of the target appears to be one hundred times as large as it would appear to the unaided eye. Therefore, the value of the area to be used in the visibility charts would be 100,000 sq. ft. instead of 1,000 sq. ft.

Since the contrast rendition of the binocular is 50 percent, the contrast of the target appears to be only 50 percent of its inherent value. Therefore, in using the visibility charts, a value of 30 percent would be used as the target contrast rather than its inherent value of 60 percent.

Because the exit pupil of the binocular is smaller than the natural pupil of the eye, and since the binocular has an imperfect light transmission, the brightness of the field viewed through the binocular is less than the brightness of the same field if it were viewed with the unaided eye. As has been indicated, the visibility charts are constructed for brightness levels differing by a factor of 10. For this reason it is necessary to determine the detection range for an intermediate brightness level by interpolating between

the final apparent brightness level and the two adjacent brightness levels for which visibility charts have been constructed. This interpolation is made between the two detection ranges (5200 and 2450 yds. from Figures 6 and 7), for brightness levels of 10^{-4} and 10^{-5} foot lamberts by taking into account the apparent light transmission factor as defined by Equation (5).

$$(6) T_a = T_o \frac{K^2}{F^2} = 70 \times \frac{2^2}{8^2} = 0.27$$

The detection range may then be computed by means of Equation (6).

$$(7) R_{2.7 \times 10^{-5}} = R_{10^{-5}} + \frac{T_a}{100} (R_{10^{-4}} - R_{10^{-5}})$$

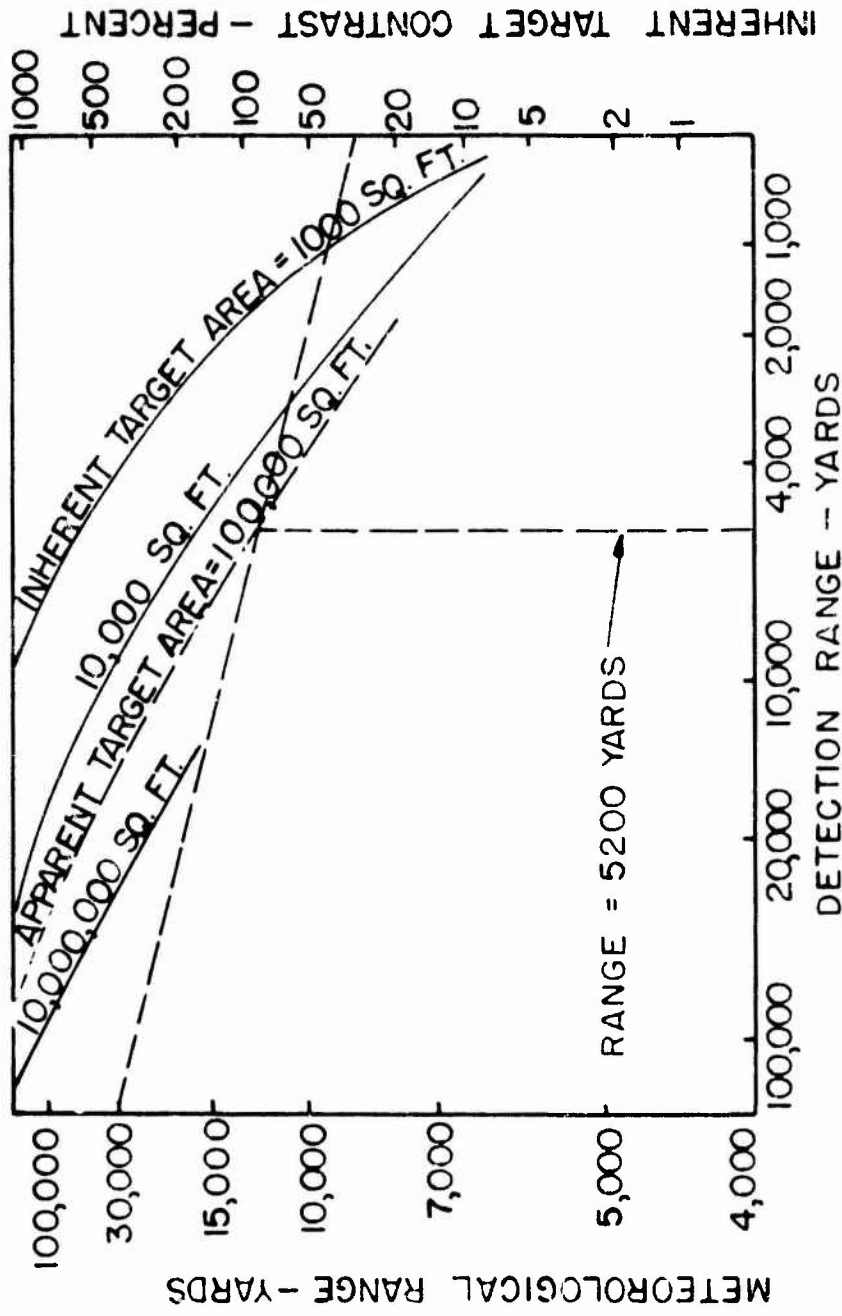
$$R_{2.7 \times 10^{-5}} = 5200 + \frac{.27}{100} (5200 - 2450) = 3193$$

In the case of this binocular, it is seen that the final detection range computed is 3193 yards.

In a fashion similar to that outlined above, a wide variety of questions can be answered rather simply concerning the general design features of binoculars, such as what would the effect on performance be if the magnification were reduced from 7x to 5x, if the exit pupil were reduced from 7 mm to 5 mm, should binoculars have coated optics, etc.

The above somewhat abbreviated presentation of the basic method used in analyzing the various claims and experiments reviewed in making the literature survey described in this report gives some idea as to the objectivity which can be claimed when the method is applicable, and by means of which conclusions in this report have been reached. However, it is necessary to emphasize that many factors

VISIBILITY CHART NO.1 SHOWING THE METHOD OF PREDICTING THE
DETECTION RANGE FOR AN OBJECT IN STARLIGHT USING A 10X50X7°
BINOCULAR

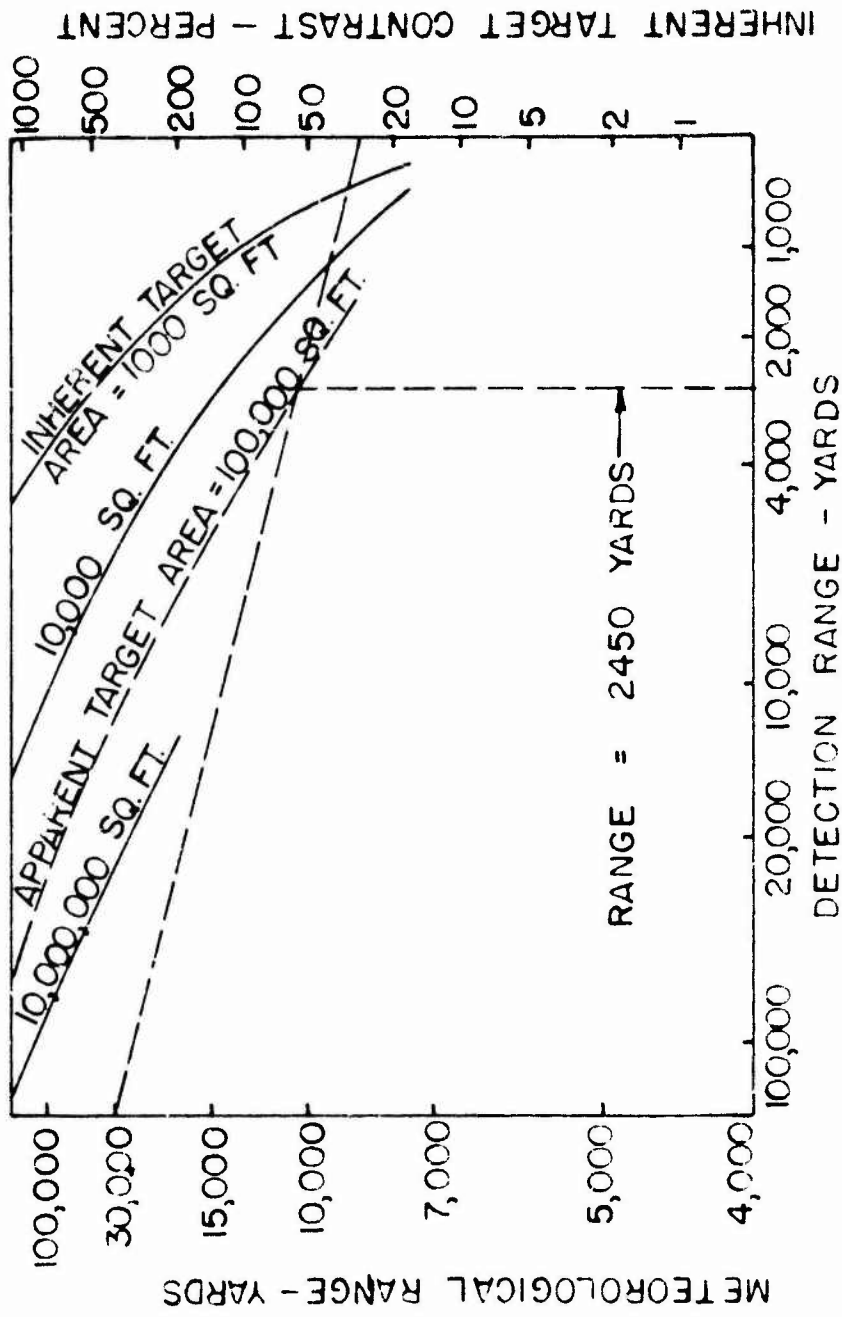


KNOWN DATA:

- SHAPE OF TARGET - CIRCULAR
- SKY BRIGHTNESS - 10^{-4} FOOT LAMBERTS
- INHERENT TARGET AREA - 1000 SQ. FT.
- INHERENT TARGET CONTRAST - 60%
- METEOROLOGICAL RANGE - 30,000 YDS.
- CONTRAST RENDITION - 50%
- LIGHT TRANSMISSION - 70%

FIGURE 6

VISIBILITY CHART NO.2 SHOWING THE METHOD OF PREDICTING THE
DETECTION RANGE FOR AN OBJECT IN STARLIGHT USING A 10X50X7°
BINOCULAR



KNOWN DATA :

SHAPE OF TARGET - CIRCULAR
 SKY BRIGHTNESS - 10.5 FOOT LAMBERTS
 INHERENT TARGET AREA - 1000 SQ. FT.
 INHERENT TARGET CONTRAST - 60 %

METEOROLOGICAL RANGE - 30,000 YDS.
 CONTRAST RENDITION - 50 %
 LIGHT TRANSMISSION - 70 %

exist for which allowances cannot be made at the present time in attempting to fix the design of binoculars. In particular there is a notable lack of information available concerning the recognition type of task. Specifically, knowledge of the perceptual capacity of the eye under recognition types of situations is particularly needed. Others of particular importance involve a need for methods of making allowances for vibrations and inherent target motion. It is felt that until such additional information is available, the visibility problem through binoculars cannot be said to have been solved. However, it should be emphasized that the major factors upon which the detection of targets depends, have evidently been isolated, and can be allowed for. This is evidenced by the rather remarkable agreement between the computed and actual performance determined in the field by a considerable number of instruments of different design (Reference 12) as shown in Figure 8. It is believed that the results presented in the above table adequately demonstrate that the problem of detection of fixed targets can be said to have been satisfactorily solved at least for conditions of night time observation from aboard ship.

PRINCIPAL SOURCES OF INFORMATION

The general survey of the literature included studies of reports dealing with investigations conducted in Germany, France, Great Britain, and the United States. To a considerable extent the work performed by these various nations in the field of binocular studies was quite similar, and the conclusions reached are generally in accord. In general the most extensive work (and likely the most reliable work) was performed in the United States. For this reason

PREDICTED VS. FIELD PERFORMANCE (RELATIVE TO MOUNTED 7X50X7.1°
BINOCULARS) OF MOUNTED BINOCULARS AT NIGHT*

DESCRIPTION OF INSTRUMENT	PREDICTED PERFORMANCE	FIELD PERFORMANCE
6 X 33 X 7°	76 %	73 %
6 X 42 X 7°	88	76
6 X 50 X 7°	102	80
10 X 70 X 7°	116	104
7 X 50 X 7.1°	100	100
10 X 50 X 7°	106	106
10 X 80 X 7°	118	115
25 X 100 X 3.6°	159	156
20 X 120 X 3°	163	163

* FIELD TEST RANGE FOR MOUNTED 7X50 X 7.1° BINOCULARS - 2630 YDS.
PREDICTED DETECTION RANGE FOR 7X50X7.1° BINOCULAR — 2,180 YDS.

the studies outside the United States will be mentioned only briefly in this report even though they have been studied closely.

Some of the more important ideas associated with the work dealing with the design specifications of binoculars in Germany have been summarized in Reference 5. This reference is an unpublished manuscript dated 30 March 1945, translated by Dr. I. C. Gardner of the Bureau of Standards which presumably represents the opinion of the members of the staff at the Zeiss Works at least. In this connection, two general conclusions were reached by the Germans regarding the optimum design characteristics of binoculars. The first is that the exit pupil size need not exceed 6 mm in diameter and should not be less than 4 mm in diameter. The second is that the magnification is twice as effective as the diameter of the exit pupil in controlling the performance in those cases in which the exit pupil is at least 4 mm.

During the War the French were very active in studying the properties of optical instruments. Most of this work dealt with the development of testing methods, particularly with respect to measuring the resolving power for Foucault test objects of different inherent contrast and considerations by means of which the ill effects of stray light in optical systems could be evaluated. This work appears to have first been announced publicly by Charles Fabry (Reference 114) and is primarily directed toward the establishing of a sound philosophy upon which design of visual telescopic systems can be based. With the exception of the work dealing with the stray light in optical instruments, the French research is not applicable

to the problems of detection with which this report deals.

Of the various British reports reviewed, perhaps the most complete summary of their studies is described in Reference 2. This report covers experimental studies touching upon many of the factors controlling the design of binoculars for use in night time search problems. For example the following items are included in the British report:

1. The effect of using reflection reducing films on the detection of targets
2. The influence of magnification on detection
3. The effect of target contrast
4. The effect of the shape of the target
5. Visibility of camouflaged ships through binoculars
6. Visibility of point sources through binoculars
7. The effect of the speed of scanning on visibility of point sources
8. The effect of stray light on the detection of targets
9. The effect of exit pupil size on the detection of objects
10. The relative advantages of binocular vs. monocular
11. The effect of illuminated reticles on the detection of objects with binoculars
12. The comparison of detection factors of 7 x 30 and 10 x 50 binoculars
13. The relative performance of Galilean type binoculars used for the detection of objects
14. The establishment of probability curves for the detection of objects
15. The limitations imposed by the atmosphere upon the visibility of objects viewed through binoculars

16. The effect of the brightness adaptation level on the contrast threshold of the human eye

In the United States, for the most part the studies related to the design features of binoculars were pursued under the sponsorship of the Ordnance Department of the Army, the Bureau of Ordnance, the Bureau of Ships, Bureau of Medicine, the Office of Naval Research of the Navy Department, and the National Defense Research Council. Most of the work performed in this field either by or under the sponsorship of Army Ordnance was directed toward the development of methods by means of which the physical characteristics of binoculars could be objectively measured. This work led to the development of quantitative quality control inspection fixtures such as the ABC Apparatus, the Dioptrimeter, and the use of the Interferometer in evaluating optical systems. In addition analyses were made of many of the mechanical requirements of binoculars such as the alignment of the optical and mechanical parts and changes in alignment caused by shock believed to be comparable with that received by binoculars during their use in the field.

During and since the War, the Navy has been particularly active in pursuing studies dealing with the visibility of objects through binoculars and hence has been concerned either directly or indirectly with their design characteristics. Many of these studies were started during World War II and cover three general areas. The first of these deals primarily with the perceptual capacity of the human observer under the wide variety of conditions of brightness, weather, and surround conditions under which search operations may be made

using binoculars as aids to vision. The second area involves consideration of the limitations imposed by the medium between the binocular and the target on the design characteristics of the binocular. The third type of study involved specific considerations of various instrumental characteristics of binoculars such as limitations imposed upon performance by exit pupil size, magnification, light transmission, contrast rendition, size and shape of the binocular, and the relation of these factors to the quantity and cost of binoculars from the point of view of mass production.

Since most of the data used to form the conclusions mentioned in this report are highly condensed, it is recognized that the reader may care to consult some of the references for further details. Fortunately the more important of these are summarized in references (9), (10), (11), and (12). Reference (9) presents a summary of our state of knowledge concerning the instrumental characteristics mentioned. Reference (10) summarizes our present state of knowledge with respect to the perceptual capacity of the human observer and the limitations imposed by the atmosphere on the visibility of objects and hence the design of binoculars. Reference (11) presents the results of an extensive field test in which a number of different designs of binoculars were graded in terms of their performance in detecting objects at night from a warship. Reference (12) describes the methodology means of which all values can be made for the perceptual capacity of the observer, the various observation conditions, and the instrumental characteristics necessary to predict the range at which the presence of specific objects can be detected using binoculars.

TARGET AND BRIGHTNESS FACTORS

Discussion

The allowances that must be made in the design of binoculars for variations in the target and brightness conditions are in effect really allowances that must be made for the perceptual capacity of the human observer when using the binocular as an optical aid. This, on the basis of our present knowledge, limits our considerations to the influence of these factors on design to the case of detection types of tasks.

As is more or less common knowledge, the visibility of a target viewed through a binocular depends upon the brightness of the field presented to the observer, the shape of the image of the target, the magnification and size of the image, and the brightness and color contrast of the image.

Generally, the higher the brightness level of the target, and the larger the area of the target, the easier it is for him to see it. The important brightness of the image formed by a binocular depends upon the light transmission. The higher the light transmission the brighter the image. From a design point of view, this indicates that the number of reflecting surfaces and imperfect total reflectors should be kept to a minimum.

From the point of view of the shape of the image of a target, the point of interest of design is indicated. It is of interest to determine whether the visibility of a uniform target, regardless of its shape, is ever greater than that of a circular target having the same contrast.

From the point of view of the target subtense, it is the solid angular subtense of the image presented to the observer's eye that is important. In general, the greater the subtense, the greater is the visibility of the target. This suggests using the highest magnification possible in the design of the binocular.

Perhaps the most important factor of the target controlling its visibility is its effective contrast with respect to the background against which it is viewed. The higher the contrast the easier it is in general for a target to be detected. This suggests from a design point of view that the binoculars should be practically free from stray light (which reduces the contrast of the image) and free from appreciable residual chromatic aberrations, since in effect the contrast of the image formed by a binocular has two components. The first is known as the brightness contrast, C_b , and the second as color contrast, C_c . The effective contrast, C_o , is given by Equation (7).

$$(7) \quad C_o = (C_b^2 + C_c^2)^{1/2}$$

However in this connection, it should be indicated that the visibility of most military targets is primarily controlled by the brightness contrast since the color contrast rarely exceeds 0.5 whereas the brightness contrast can range from 0 to infinity.

Recommendation

It is recommended that a study be made of the influence on the design of binoculars of targets having realistic military shapes from both the points of view of detection and recognition and that target

motion be considered.

BINOCULAR SIZE, SHAPE, AND WEIGHT

Discussion

The problem of selecting the size, shape, and weight of a hand held binocular depends to a large degree upon its end use. For example, if one were to consider three types of search problems for which binoculars might be used, likely three different compromises of the three factors mentioned would be made. In the case of using binoculars on foot, likely the weight factor would be the most important. This would lead to a binocular of the smallest possible size and hence likely would have smaller exit pupils and magnifications than those of the present design. In the case of using the binocular from aboard an aircraft, perhaps a wide field (not necessarily of the highest optical quality) would be particularly desired. Hence large eyepieces and prisms would be needed and some alteration in the shape from the present conventional binocular, shown in Figures 9 and 10, would be made. In the case of the use of a binocular aboard ship, likely, since the targets of interest would generally subtend very small angles, the field of view could be sacrificed in order to gain an image quality with the result that relatively little changes from the conventional design would be needed. In this regard, it has been helpful to summarize some of the shape, size, and weight data reported for existing designs of binoculars. For comparison purposes these are presented here in Tables 1 and 2.

SCHEMATIC DIAGRAM OF BINOCULAR MARK 28 MOD 0

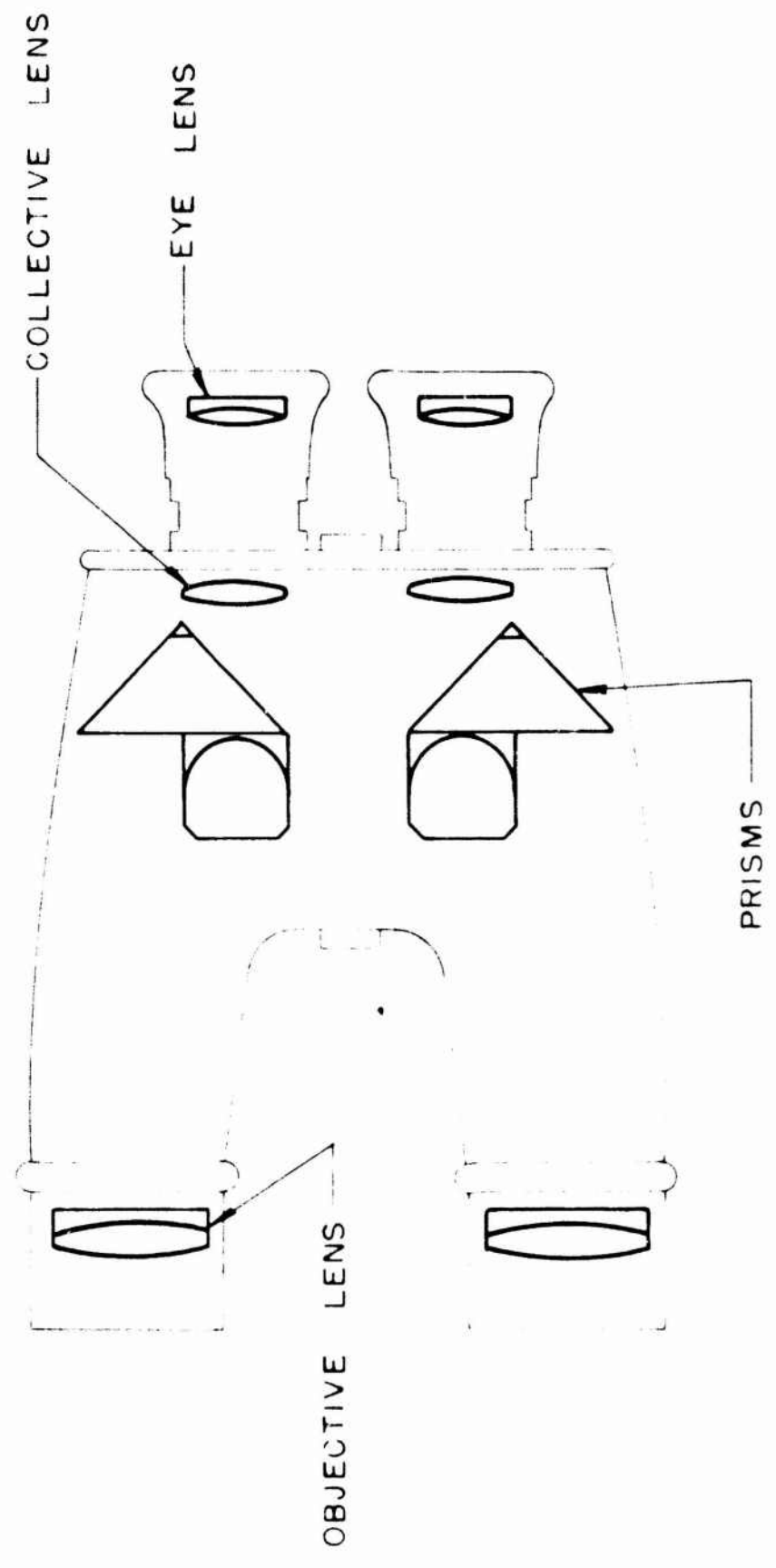
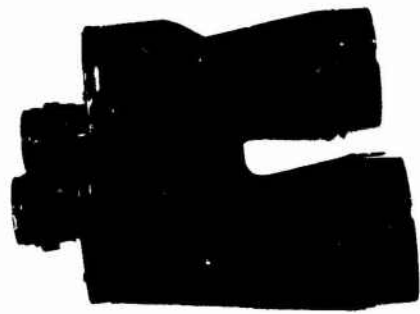


FIGURE 9

BINOCULAR MARK 28, MOD 0



CHARACTERISTICS OF INSTRUMENT

ENTRANCE PUPIL	50.0 MM
EXIT PUPIL	7.1 MM
MAGNIFICATION	6.94
TRUE FIELD	2.3°
EYE RELIEF	14.6 MM
WEIGHT	1360
LENGTH	186

FIGURE 10

SIZE, SHAPE, AND WEIGHT DATA FOR EXISTING BINOCULARS

Binocular M-13 (6 x 30 x 9°)

Entrance Pupil 30 mm
Weight 720 gm
Length 12.3 cm

Binocular Mark 43 Mod 0 (6 x 42 x 12°)

Entrance Pupil 42 mm
Weight 1720 gm
Length 14.5 cm

Zeiss Deltarem Binocular (8 x 40 x 11°)

Entrance Pupil 40 mm
Weight 1000 gm
Length 12.2 cm

Binocular Mark 1 Mod 2 (7 x 50 x 7.1°)

Entrance Pupil 50 mm
Weight 1165 gm
Length 18.2 cm

Binocular Mark 28 Mod 0 (7 x 50 x 7.1°)

Entrance Pupil 50 mm
Weight 1360 gm
Length 18.6 cm

Marine Corps Binocular Mark 28 (7 x 50 x 7.1°)

Entrance Pupil 50 mm
Weight 1360 gm
Length 18.5 cm

Binocular Mark 32 Mod 2 (7 x 50 x 7.1°)

Entrance Pupil 50 mm
Weight 1420 gm
Length 18.5 cm

TABLE 1

SIZE, SHAPE, AND WEIGHT DATA FOR EXISTING BINOCULARS

Binocular Mark 41 (7 x 50 x 10°)

Entrance Pupil	48.8 mm
Weight	1700 gm
Length	17.3 cm

Bausch and Lomb Wide Field Binocular (7 x 50 x 10°)

Entrance Pupil	50 mm
Weight	2100 gm
Length	15.8 cm

Binocular Mark 36 (10 x 50 x 7°)

Entrance Pupil	50 mm
Weight	1290 gm
Length	18.1 cm

German Binocular (8 x 60 x 8.9°)

Entrance Pupil	60 mm
Weight	2615 gm
Length	21.2 cm

Binocular Mark 37 (9 x 63 x 6°)

Entrance Pupil	63 mm
Weight	1700 gm
Length	24.8 cm

Bausch and Lomb Wide Field Binocular (10 x 70 x 7°)

Entrance Pupil	70 mm
Weight	3170 gm
Length	23.7 cm

Johnson Foundation Folded Binocular (10 x 70 x 5.2°)

Entrance Pupil	70 mm
Weight	2300 gm
Length	17.0 cm

From the data presented in References (14) through (20), it has been concluded that the 10 x 50 x 7" binocular yields the overall best performance. Therefore its size, shape, and weight appear to be acceptable. However these same references suggest two possible modifications that need to be considered. The first is in the shape of the binocular. For the most part, only binoculars of the conventional shape have been compared in detail. It would therefore appear reasonable to expect some improvement by the use of a radically different shaped binocular, such as the Johnson Foundation design, shown in Figures 11 and 12. Also, the possibility of developing a binocular that could be worn somewhat like a pair of spectacles, as shown in Figures 13 and 14, should be considered. The second possibility lies in the drastic reduction of the weight of the binocular. It appears that the use of such modifications in design as tapering the erecting prisms, the use of mirrors, changing the methods of mounting the erecting prisms such as using non-adjustable plastic mountings, and the elimination of such adjustable features as hinges and focusable eyepieces, might possibly reduce the weight of the present type of binocular by as much as a factor of 2. Unusual as some of these suggested modifications might seem from the point of view of the conventional designs, there are no objective data that would rule them out or that would indicate that it would not be feasible to mass produce binoculars having such features.

Recommendations

On the basis of References (14) through (20), two general

SCHEMATIC DIAGRAM OF THE 10X70X5.2° JOHNSON FOUNDATION
FOLDED BINOCULARS

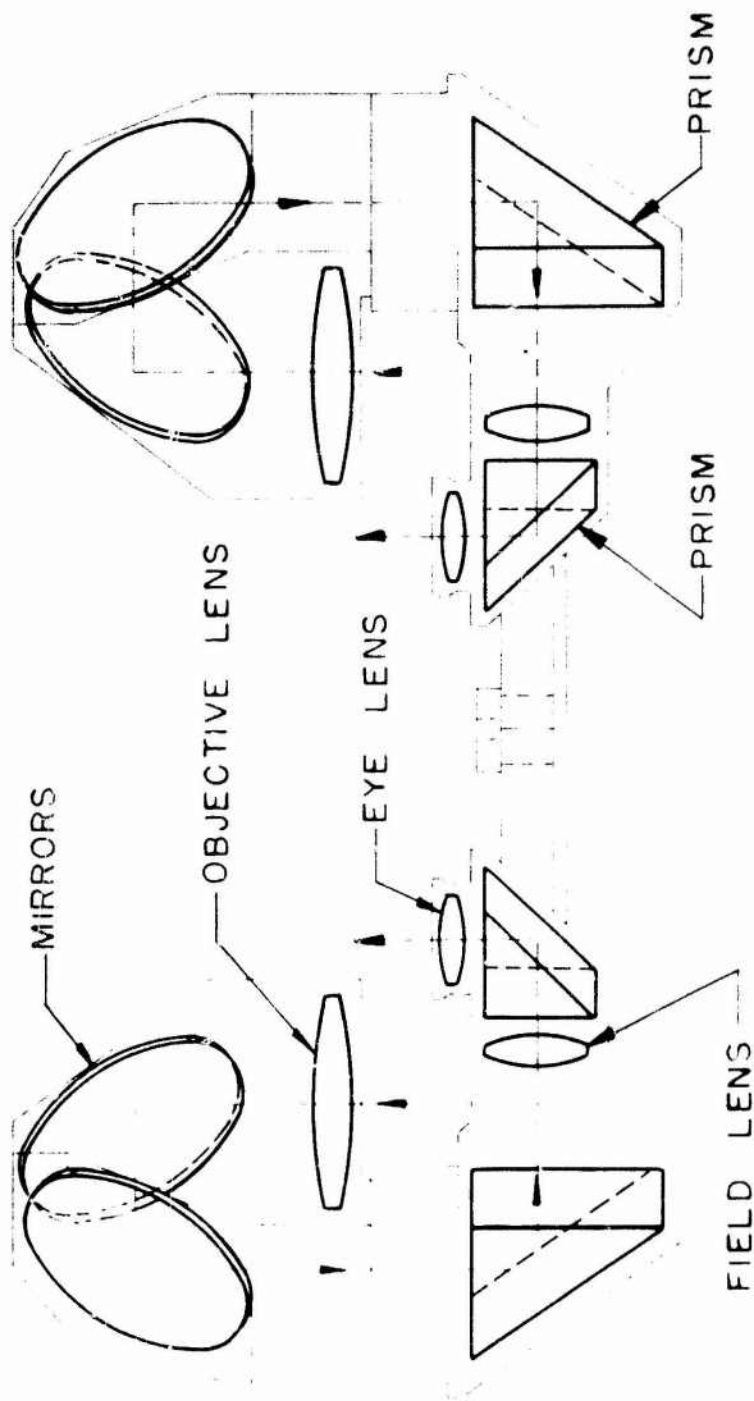


FIGURE 11

10X70 JOHNSON FOUNDATION
FOLDED BINOCULAR

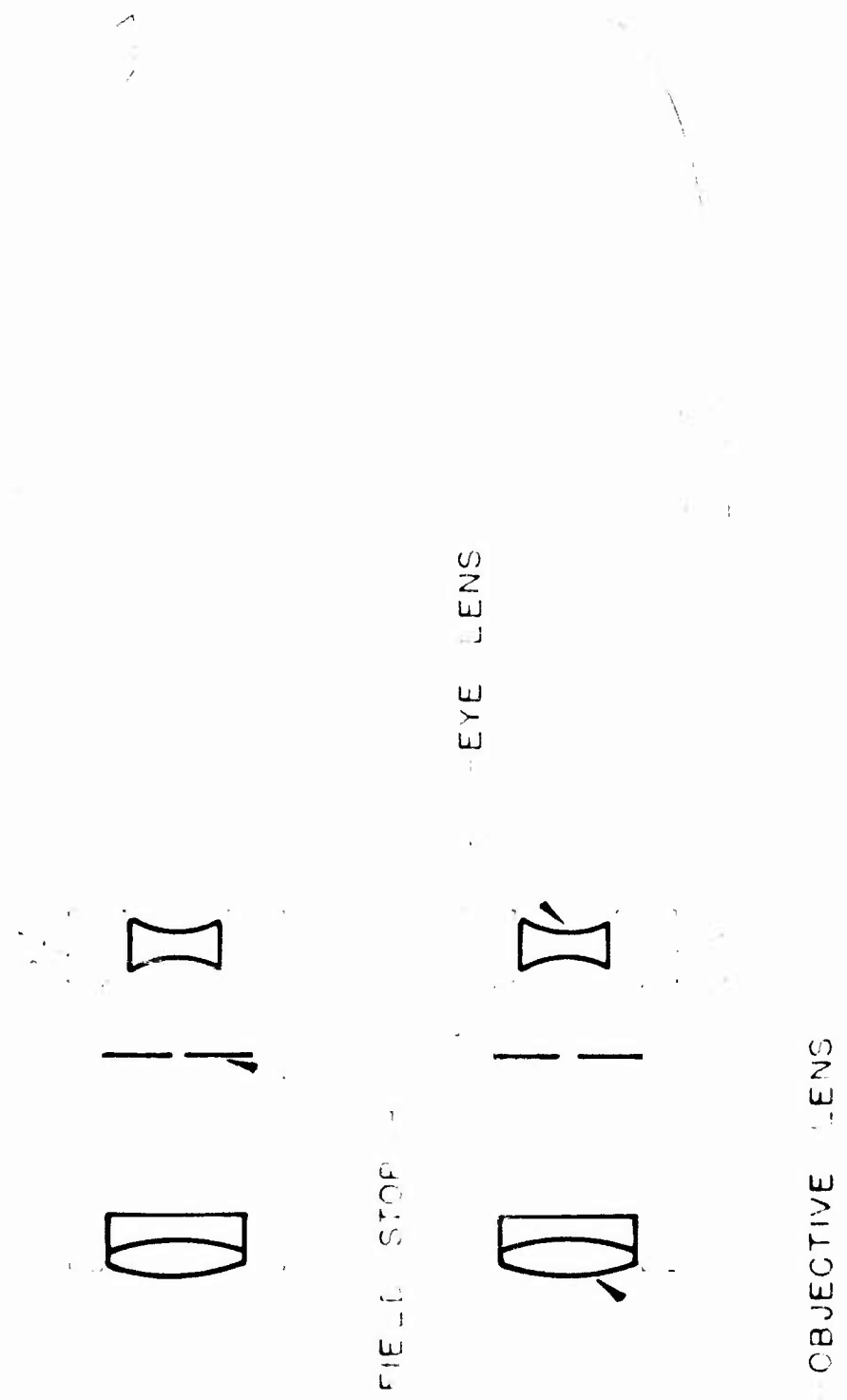


CHARACTERISTICS OF INSTRUMENT

ENTRANCE PUPIL	70 MM
EXIT PUPIL	7.0 MM
MAGNIFICATION	9.5X
TRUE FIELD	5.17°
EYE RELIEF	12.0 MM
WEIGHT	2300 G
LENGTH	110 CM

FIGURE 12

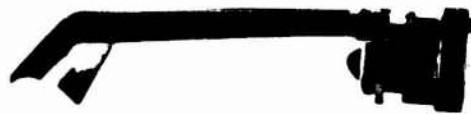
SCHMATIC DIAGRAM OF SPECTACLE BINOCULAR



ORL/UT
10 NOVEMBER 1950
D-7284

FIGURE 13

X16X19° SPECTACLE BINOCULAR



CHARACTERISTICS OF INSTRUMENT

ENTRANCE PUPIL	-----	16 MM
EXIT PUPIL	-----	8 MM
MAGNIFICATION	-----	2
TRUE FIELD	-----	19°
WEIGHT	-----	100GM.
LENGTH	-----	174CM

FIGURE 14

ORL/UT
28 AUGUST 1950
1-5470

conclusions as to size, shape, and weight have been reached.

These are:

- (1) If it is necessary to select a binocular of the conventional design, then the specifications as to size, shape, and weight that are recommended are as follows:

entrance pupil - 50 mm
weight - 1300 gm
length - 180 mm
true field - 7°
magnification - 10x

- (2) It is recommended that studies be made of the possibility of producing a radically different design of binocular which would be lighter in weight, less costly to produce, and yield equal or better field performance than the present conventional design.

MAGNIFICATION

Discussion

There is a vast amount of published data dealing with the importance of magnification on the performance of binoculars. Some of the more important publications are listed in references (21) through (45). These references touch upon a variety of aspects of the influence of magnification on performance of binoculars. For example, considerations of the influence of magnification are given to both detection and recognition types of tasks. There is information presented dealing with fixed and moving targets, and fixed and moving observers. These latter range from observation on foot to observation from aboard ship, aboard aircraft, and from aboard tanks. In addition there are data relating to the optimum values of magnification under different conditions of the weather, different target characteristics, such as size, contrast, and shape.

In spite of the heterogeneous types of information published concerning the magnification of binoculars, it is possible to arrive at a number of specific conclusions about which there is general agreement. These conclusions are somewhat easier to accept if the proper perspective regarding the basic function of the magnification is taken. Magnification causes an object to appear larger and nothing more. Accordingly, when one makes proper allowances for such factors as the medium between the observer and the target, the effect of vibration, and the effect of imperfect alignment of the binocular with the observer's eyes, it becomes evident that the increase in range at which the target was just detectable with the unaided eye is not an exact multiple of the magnification of the binocular. The degree to which the magnification of a "perfect" binocular increases the detection range over that for the unaided eye is shown in Figure 15. It is seen that diminishing gains over that of the performance of the eye are quickly reached as the magnification is increased. Since the cost, size, and weight increase rapidly with increasing magnification, if the exit pupil is held constant, it is evident that care in judgement must be exercised in fixing the magnification of a binocular in terms of the visual task for which the instrument is to be used as an optical aid.

Recommendations

Based on a study of References (21) through (45), the following two conclusions have been reached:

- (1) The general overall best value for the magnification of a hand held binocular is 10x and should be used in a

C

RELATIVE DETECTION RANGE VS. MAGNIFICATION OF "PERFECT" BINOCULARS FOR A CIRCULAR TARGET HAVING AN AREA OF 100 SQUARE FEET AT VARIOUS METEOROLOGICAL RANGES

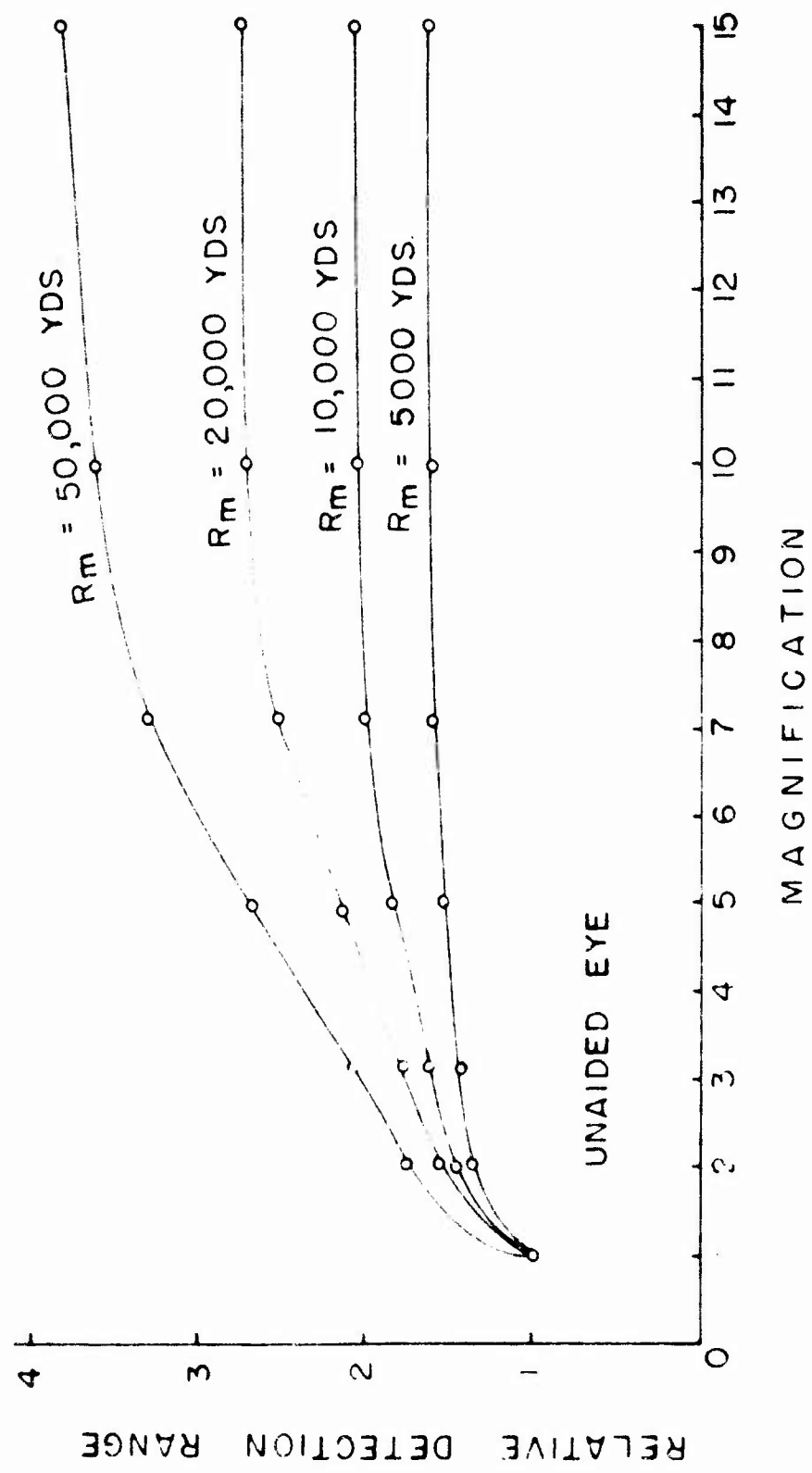


FIGURE 15

design that has an exit pupil of 5 mm and a field of 7°.

(2) There are a number of specific uses for binoculars in which a magnification of 10x is not tolerable. This is particularly true in the case of observations made under conditions of vibration, and observers performing tasks in which excess magnification may cause serious errors in judgment, (such as pilots performing reconnaissance operations).

EXIT PUPIL

Discussion

Other design factors being fixed, the exit pupil size is one of the most important quantities controlling the range at which objects are detectable using binoculars. References (46 through (64) set forth in detail many facts which must be considered in specifying the exit pupil size of a binocular. From a broad point of view, these references contain two types of information. The first deals with the actual size of the pupil of the human eye at various brightness levels to which it is adapted. The second deals with considerations, usually based on experimental tests, which form the basis of making the final compromise with respect to the optimum exit pupil size for binoculars to be used for military purposes.

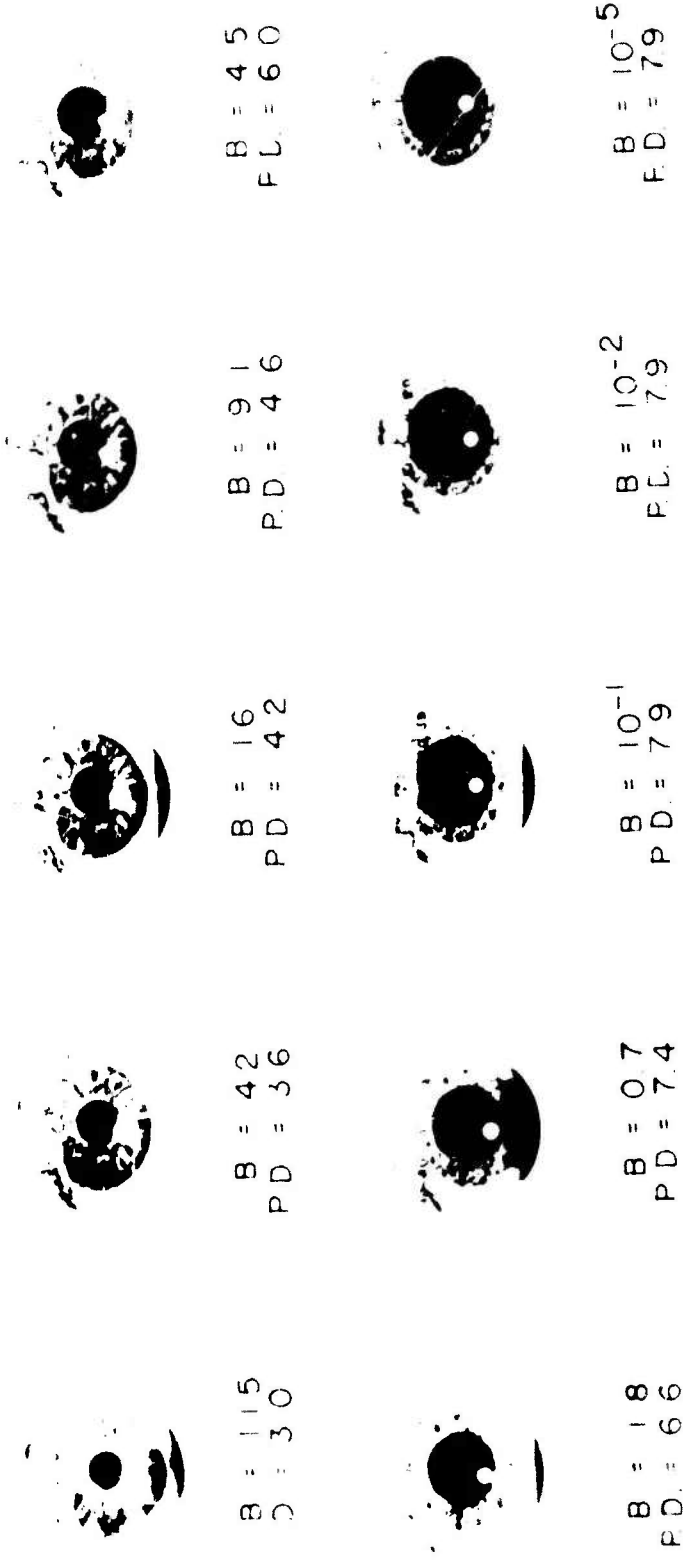
For the most part studies made of the pupil sizes attained by the human eye at different brightness levels involved photographic techniques. Some of these used infrared radiation and others used "flash bulb" photography. In general the results reported are in agreement. It has been shown that on the average, individuals in the age group between 30 to 40 years have pupils that are approximately 10 percent less in diameter, at all brightness levels, than

those in the age group from 16 to 30 years. The range in pupil size, for all brightness levels of interest, is approximately from 2.00 to 8.00 mm. A sample of the summary of data from one laboratory is shown in Figures 16 and 17. Figure 16 shows photographs of the pupil of the human eye taken at different brightness levels and Figure 17 shows the dependence of pupil diameter on the brightness level to which it is adapted.

If one attempts to make allowances for the fact that the retinal brightness of the image of an object viewed through a binocular is never greater than the retinal brightness of the object viewed with the unaided eye, for the Stiles-Crawford Effect (which generally is negligible in detection tasks at low brightness levels and is practically absent at higher levels), and for the problem of "clipped" exit pupils (caused when the pupil of the eye is not properly aligned with the exit pupil), it becomes evident that the most expeditious way to determine the optimum exit pupil size of a binocular is by actual experiment. Two types of such experiments have been reported. The first involves indoor studies simulating field conditions and the second involves tests under actual field conditions. Fortunately the two types of tests have led to the same conclusions (although the exact reasons for this agreement is not clear). This agreement leads to the conclusion that the optimum value of the exit pupil should be 5 mm.

In spite of the agreement mentioned above, there are two radically different conclusions that could be reached by further considering the material presented in the references. These are related

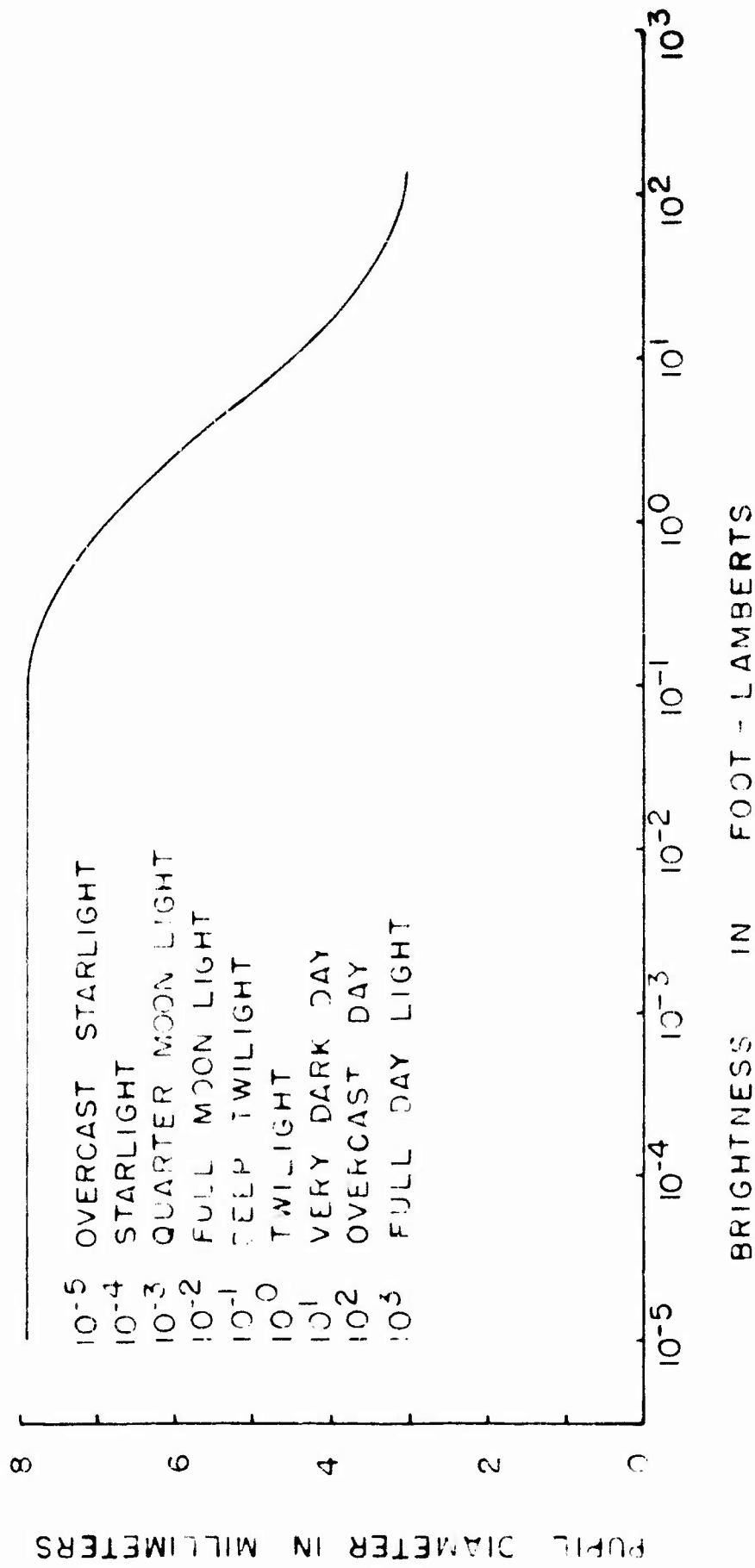
FLASH PHOTOGRAPHS OF THE PUPIL OF THE HUMAN EYE
ADAPTED TO VARIOUS BRIGHTNESS LEVELS



B = BRIGHTNESS IN FOOT LAMBERTS
P.D. = PUPIL DIAMETER IN MILLIMETERS

FIGURE 16

PUPIL DIAMETER OF THE HUMAN EYE VS. THE ADAPTATION BRIGHTNESS



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FIGURE 17

to the fact that in order to utilize, to the fullest extent, the exit pupil designed in a binocular, the pupil of the eye must be aligned such that whatever decentering exists between it and the exit pupil, the effect is not equivalent to reducing the exit pupil in size. This premise suggests two different procedures that might be followed. The first is to have the exit pupil sufficiently smaller than the pupil of the eye so that any slight decentering would not result in "clipping". The second would be to make the exit pupil of the instrument sufficiently larger than the pupil of the eye as to make certain that the pupil of the eye was always the limiting stop in the system. In the former case, perhaps an exit pupil of 5mm would be satisfactory, and in the second case, perhaps an exit pupil of approximately 10 mm would meet the requirements.

In reaching a conclusion as to the optimum size of the exit pupil for binoculars, it should be indicated that until more studies can be made of the matter, the best basis for choosing the exit pupil would be on the basis of the conclusions reached as a result of the field tests described in Reference (61).

Recommendations

- (1) It is recommended that the exit pupil of a hand held binocular be set at 5 mm provided the magnification is not less than 7x.
- (2) It is recommended that a study be made of the possible advantage of using exit pupils greater than 7 mm in diameter. In this connection, exit pupils up to at least 12 mm in diameter should be considered.

ANGULAR FIELD

Discussion

Although practically no studies have been reported which deal explicitly with the relation of angular field of a binocular and its limitation on the range at which objects are visible, a number of suggestions concerning this matter are to be found in References (65) through (75). In general the feeling is that the field should be as large as possible and specifically that it should not be less than 7°.

From a design point of view, two general observations can be drawn from the references mentioned. The first is that if the present optical quality over the entire field of view is to be maintained, the product of the field by the magnification likely cannot exceed much more than 70. To achieve a higher value may require the use of aspheric surfaces and possibly the use of special glasses which could lead to increases in manufacturing costs and lower production rates than would be possible using conventional designs. From a practical point of view however, the premise that it is necessary to maintain the present standards of optical quality over the field of view is at least subject to review. Specifically, if the optical quality were sacrificed near the edge of the field, where it is poor anyway, in order to gain a greater field of view, there are no objective tests that can be cited which would show that the field performance would be impaired. This suggests the possibility of the design of a binocular having excellent optical quality at the center of the field

and poorer optical quality toward the edge of the field than would have been regarded as acceptable in the past. If this were done, quite likely a binocular having a magnification of 10x could be designed such that it would have a true field of approximately 9°. On the same basis, a binocular having a magnification of 7x likely could be designed having a true field of nearly 13°, and a 5x binocular might be designed having an 18° field. Such increases in true field would be expected to result in material gains in performing search tasks using binoculars as optical aids.

Recommendations

It is recommended that an attempt be made to design binoculars having a product of the true field by the magnification of approximately 90 and that studies be conducted to determine the possible gains in performance that would result in increasing the field of view above that presently existing in military designs.

LIGHT TRANSMISSION AND REFLECTION REDUCING FILMS

Discussion

There is little doubt as to the desirability of using reflection reducing films on the air-glass surfaces of binoculars. There is a definite gain in light transmission and some gain in reducing the stray light in binoculars that can be attributed to the use of such films.

From the point of view of increasing the light transmission, a gain of approximately 23 percent (55 to 78 percent) can be expected by the use of magnesium fluoride films in the present design of binoculars. The gain in performance that would be expected for the

case of a target viewed against a uniform surround under three brightness conditions is shown in Figure 18 (for the present design of a 10 x 50 x 7° binocular). It is seen that an increase in range of one half of one percent may be expected in daylight, a gain of 10 percent in twilight, and a gain of 17 percent in starlight might be expected by the use of the present type of reflection reducing films.

From the point of view of new designs of binoculars, it would seem reasonable to attempt to improve the reflection reducing efficiency of the films to be used. In considering this, it is convenient to introduce a definition of the efficiency of a reflection reducing film. This definition is given by Equation (8) and involves the reflectance r_g , of the non-coated air-glass surface under consideration, the reflectance r_f , of the same surface after the reflection reducing film has been applied, and the reflection reducing efficiency RRE.

$$(8) \text{ RRE} = 100 \times \left(1 - \frac{r_f}{r_g}\right)$$

On the basis of the above definition, a film that would reduce the reflectance to 0 would have 100 percent efficiency. The magnesium fluoride films used at present have efficiencies of approximately 50 percent.

In connection with the value of reflection reducing films, apparently special attention needs to be given to the possible gains that could be achieved from the point of view of reducing the type of stray light that is caused by multiple reflections (Fresnel) among

RELATIVE DETECTION RANGE OF A CIRCULAR TARGET HAVING AN AREA OF 100 SQUARE FEET AND AN INHERENT CONTRAST OF 20 PERCENT VS. THE TRANSMISSION OF A 10 X 50 X 7° BINOCULAR USED AT VARIOUS BRIGHTNESS LEVELS

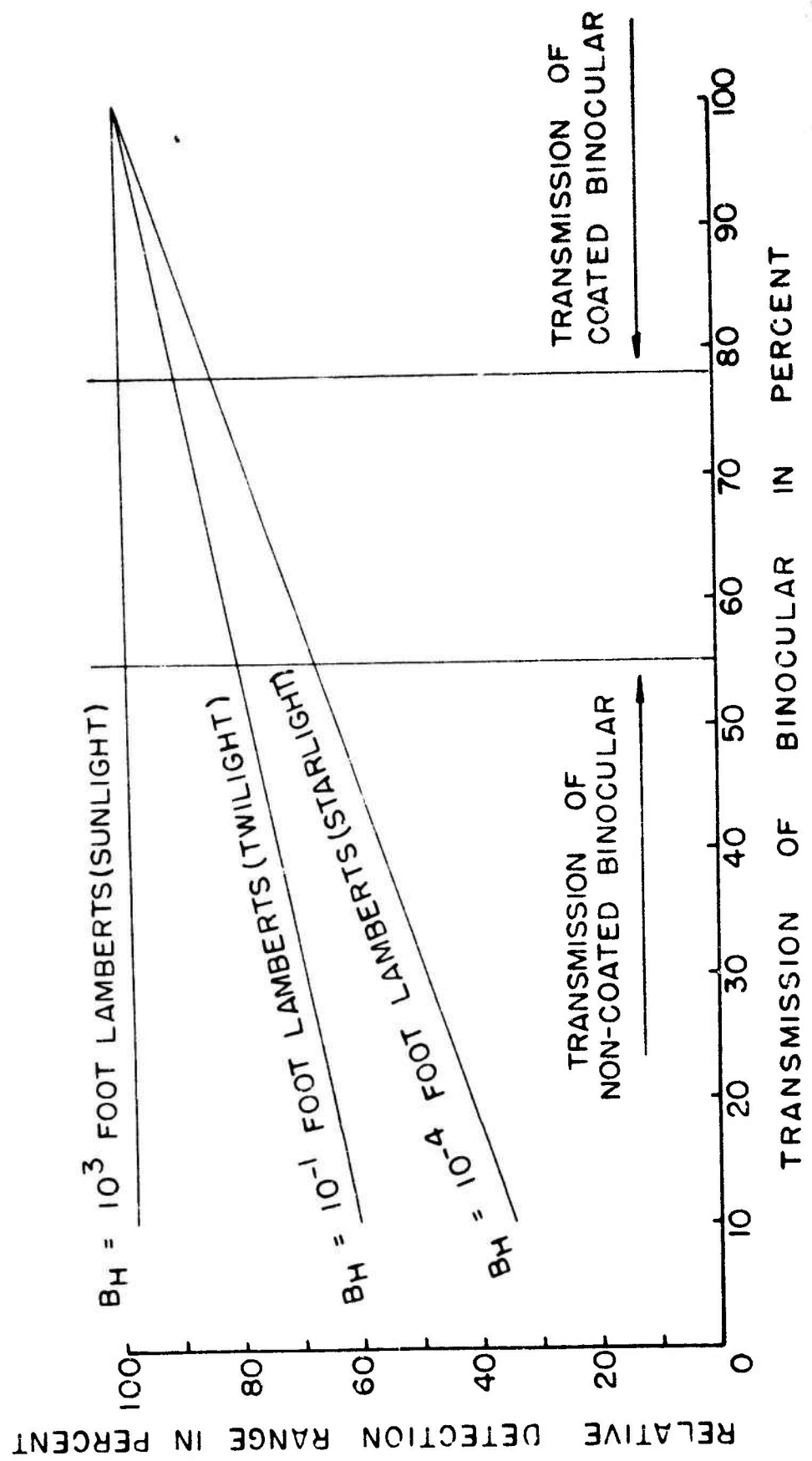


FIGURE 18

the optical surfaces. In the case of viewing a target which may either appear to be near to a relatively bright object (such as the Sun or its reflection) or to lie in a field of non-uniform brightness (such as observing an object illuminated by a search light), a more efficient reflection reducing film would be of great value. Unfortunately, at the present time, the more efficient films are not only less durable but also scatter more light than magnesium fluoride films. It would seem reasonable however, that better films could be produced.

Recommendations

It is recommended that the use of reflection reducing films be continued and that more efficient films be developed.

CONTRAST RENDITION AND STRAY LIGHT

Discussion

The contrast rendition (CR) of a binocular is a measure of the fidelity of an image of an object viewed through the binocular with respect to the apparent brightness contrast the object has (from the point of view of the observer) without the use of the binocular. It is defined in terms of the contrast of the image, C_1 , and the contrast C_0 , the object appears to have without the binocular as shown in Equation (9).

$$(9) \quad CR = \frac{C_1}{C_0} \times 100$$

The contrast rendition of the best military optical instruments that have been produced has been found to range from 95 percent to

practically 0, depending upon the degree of uniformity of the brightness conditions involved in observations. An example of such a variation is shown in Figure 19, for the recently developed Navy binocular Mark 39. The scene simulated was that of the observation of an aircraft viewed against the sky as it approached the condition of "coming out of the Sun". The reduction in contrast rendition in this case was largely caused by stray light reflected back and forth among the optical surfaces along or near the axis of the optical system. The result of this reflection was to cast a veiling glare over the image formed on the retina of the observer's eye. At the point when the contrast of the image of the object is reduced (by imperfect contrast rendition) to something less than the contrast threshold of the observer's eye, the object becomes invisible. In the case of camouflaged targets, which are purposely made as close to the threshold of the human eye as possible, even the slightest imperfection in contrast rendition may cause an object to become invisible. In fact, in both these cases, it frequently occurs that objects are more visible with the unaided eye than they are with a binocular because of the imperfect contrast rendition.

From the point of view of design, every effort should be made to produce binoculars having contrast renditions of practically 100 percent. Progress could be made toward this end by the use of more efficient reflection reducing films, the development of better methods of using stray light stops, and possibly by the re-design of the shapes of the mechanical and optical parts of a binocular. A practical limit to which the improvement to be set as a goal likely

AXIAL CONTRAST RENDITION VS. ANGLE BETWEEN ARTIFICIAL SUN AND TARGET FOR THE RIGHT BARREL OF BINOCULAR MARK 39 MOD I SERIAL NO. 2655

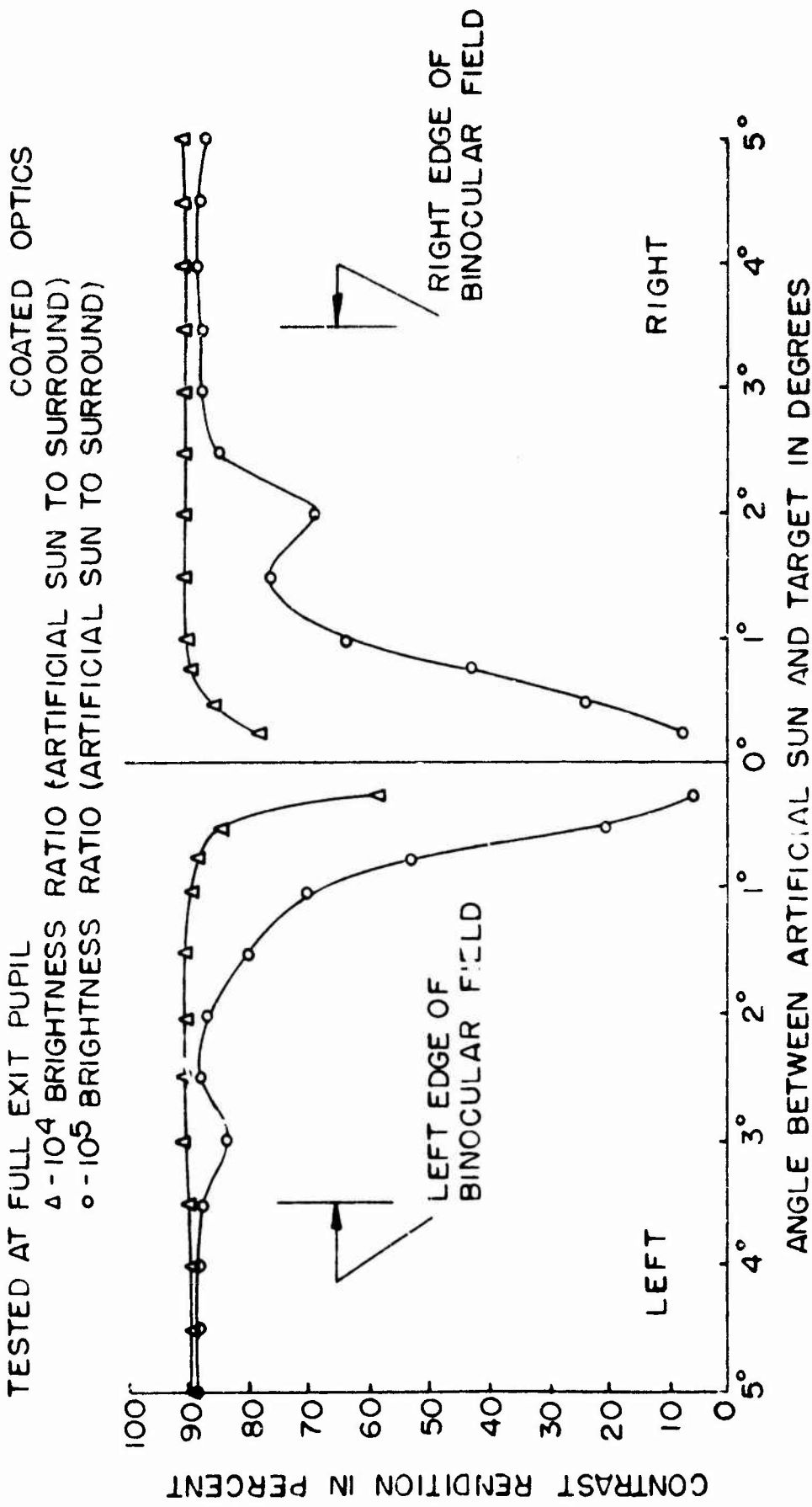


FIGURE 19

should be to produce a binocular having a contrast rendition of at least 90 percent for all the conditions of interest.

Recommendations

It is recommended that the lower limit for the contrast rendition of a binocular be set at 95 percent for the case of the uniform surround and that studies be made of possible modifications in the design of binoculars such as changes in shape, use of stray light stops, and rearrangement of the optical mechanical parts, whereby the contrast rendition would not become less than 90 percent for any of the brightness conditions in which the binocular is to be used.

KDC EFFICIENCY AND TOLERANCES FOR ABERRATIONS

Discussion

One of the most controversial issues concerning the design of binoculars is the allowable amount of the so-called optical aberrations. This controversy is associated with the practice of the Government of inspecting in detail those optical instruments being procured for its use. Once the individual or overall tolerances of aberrations of the optical parts of a binocular have been fixed by a procurement contract, the process of inspection requires that the binoculars be judged to either meet or not to meet the specifications governing the procurement and that acceptance or rejection be made on this basis regardless of whether or not a particular binocular rejected might be serviceable. Since this is really a contractual matter in which the price of the binocular supposedly reflects the cost of complying

with the Government specifications, the procedure followed is not only legal but reasonable. However, when a binocular manufacturer finds an appreciable percentage of his products being rejected, he generally raises the question (improperly from a contract point of view) as to whether or not the instruments that were rejected might not have been at least serviceable, and perhaps just as serviceable as those judged to be acceptable. It is at this point that the Government procurement agency is in a real dilemma. On one hand if it calls its legal advisors for assistance, the legal staff naturally would hold that specifications must be met, otherwise revision downward in price should be demanded. If the procurement agency calls upon its technical advisors for help, frequently it becomes evident that the rejection in question could not be validly defended on the basis of serviceability of the instruments. Often this leaves the procurement agency in the peculiar position of making "sub rosa" modifications in the specifications by liberalizing the tolerances in the case at one production center which cannot meet the specifications and not in another which can meet the specifications in order that the procurement agency may meet its delivery quotas which have been set by still another agency. All of this gives rise to lack of harmony among those involved and is something that largely can be eliminated. This can be done by having a defensible basis for specifying the tolerances of aberrations. Such a basis should be established objectively so that the results would be accepted by all concerned. Tests are needed to show the ill effects in service uses of binoculars caused by various amounts of specific aberrations

and mixtures of such aberrations. Having thus established the ill effects caused by the imperfections in optical quality, realistic tolerances could then be assigned, and the inspection processes associated with the procurement of such equipment could be defended without question. In this connection, it appears that it would not be expedient to attempt to assign numerical values to the tolerable amounts of individual aberrations. It would be better to assign some overall figure of merit such as either the KDC efficiency or the interferometer quality of the binocular at various field angles, as described in Reference (178).

Until some such procedure as that outlined above can be pursued to conclusion, the specific information in References (112) through (180) form the best available basis for fixing the tolerances of optical aberrations in binoculars since much of the data given indicate what actually has been achieved and what the variation in quality has been for binoculars produced under wartime conditions. For example, it has been found that the actual KDC efficiency (or interferometer quality) of binoculars averaged about 85 percent and that the range in KDC efficiency was from 70 to 95 percent. Accordingly, it would seem reasonable to set the limit of acceptability at approximately 80 percent for the actual KDC efficiency of a binocular. In doing so however, it should be kept in mind that a difference of 2 percent in KDC efficiency is detectable (using the human eye without auxiliary magnifying aids) for two binoculars of the same design and having efficiencies of approximately 90 percent. The KDC efficiency has been found to average about 20 percent at the

edge of the field for a large number of binoculars that have been tested. This suggests that the KDC efficiency across the field could be permitted to decrease continuously to 20 percent at one twentieth of the true field from the edge of the field.

Recommendations

It is recommended that a study be made of the ill effects caused by optical aberrations, singly and in combination, on the field visibility of objects through binoculars and that the results of such a study be used to form the basis upon which tolerances of optical aberrations are set in procurement specifications. Until such studies have been completed, it is recommended that the KDC efficiency be used to specify the optical quality of binoculars. It is further recommended that the lower limit of the KDC efficiency be set at 80 percent at the center of the field and at 20 percent near the edge of the field (defined to be one twentieth of the true field from the edge).

MONOCULAR VS. BINOCULAR DESIGNS

Discussion

There is ample evidence presented in References (181) through (185) to show that the range at which objects are detectable through binoculars is approximately 10 percent greater than using a monocular of substantially the same optical design. Accordingly there seems little doubt but what the extra cost in making the binocular over that of a monocular could be justified.

Recommendation

It is recommended that binoculars be used rather than monoculars as optical aids for detection and recognition tasks.

THE USE OF ASPHERIC SURFACES

Discussion

An evaluation of the desirability of using aspheric surfaces in binoculars is not possible on the basis of existing reports. In general, it appears that the optical industry is somewhat resistant to the idea even though moderately satisfactory use has been made of aspheric surfaces in Germany during World War II. This reluctance is based on the assumption that the government procurement agencies will insist on the same overall image quality of the present conventional designs and not the knowledge of possible gains in field performance of the binoculars. Consequently it is evident that experimental studies are needed to determine the value (from the use in the field) of increasing the field of view by a few degrees (which is largely what could be expected from the use of aspheric surfaces). From the results of such a study, it should be possible to determine whether or not the use of aspheric surfaces could be justified.

Recommendation

It is recommended that the usefulness of aspheric surfaces in binoculars be evaluated from the point of view of performance.

THE USE OF REFLECTION OPTICS

Discussion

From time to time, interest is created in the possible use of reflection type optics for binoculars. Aside from their use as total reflecting plane mirrors (used to replace prisms or change the present shape of binoculars) there seems to be no particular gain in using such objects in binoculars. This seems particularly true in the case of using concave and convex mirrors in place of refraction optics used in the present designs. The basis for this conclusion is the fact that of the designs proposed there is always a hollow exit pupil (or some impractical ingenious device proposed to eliminate it) and optics that are more sensitive to alignment than refracting optics.

Recommendation

It is recommended that reflection optics not be used in binoculars except as plane reflectors.

EYE RELIEF

Discussion

Although the eye relief of a binocular is an important quantity, no reports were found that show how it influences the range at which objects are detectable. There are the obvious data that show that the eye relief must be great enough to permit the eye to utilize the full apparent field of the instrument and the fact that if it were too great it would not be easy to steady the binocular against

the forehead. However, aside from these facts, which are not directly translatable into loss in range if certain optimum values are not met, little has been said about the matter. This absence of data suggests one of two things. Either the present average of approximately 15 mm for eye relief is satisfactory or it is a factor which has been neglected. Because of the tendency toward designs that are smaller and yet have higher magnifications than the present designs, both of which might tend to reduce the eye relief, it is felt that this matter needs further consideration. In particular it is felt that experimental tests are needed to determine any obvious influence of eye relief on performance.

Recommendation

It is recommended that no change be made in the eye reliefs of the present designs of binoculars until studies show that such changes are warranted.

THE HUMAN EYE AS A PART OF THE BINOCULAR

Discussion

It is a somewhat surprising conclusion to reach, but it appears that the limitations imposed by the human eye have had little influence on the design of binoculars to the present. This appears to be a result of a lack of information pertaining to the eye in a form which is interpretable to the optical designer. This lack continues although some progress recently has been made such as is set forth in Reference (222). This lack is also associated with the

fact that the present design of binoculars was essentially fixed about 1900, while most of the reports upon which a proper approach to the design could be based, were not published until about 1940.

At the time of writing this report (1950), it is evident that we still lack sufficient information concerning the role of the human eye as a part of the binocular to make all the allowances necessary for its limitations in designing a binocular. In particular about the only information we have concerning the limitations imposed by the human eye apply to the case of the uniform, stationary, regularly shaped, targets viewed in more or less uniform brightness conditions. Since most of the military targets of interest are not uniform in shape, are rarely stationary, and generally are viewed under non-uniform brightness conditions, it is evident that a considerable amount of additional research is required before the information needed can be made available to the designer. Specifically, basic laboratory determinations are needed of the contrast thresholds of the human eye under these various conditions of interest mentioned. In particular both general recognition and detection tasks should be considered and thresholds obtained for each. With such data, it likely would be possible to eliminate many of the highly specific experiments which now appear necessary from a tactical point of view. Once such basic data have been collected, likely some type of nomographic charts could be constructed, such as those mentioned in Reference (222) which, together with physical analyses of the type described in Reference (233), could result in basic guidance to the lens designer in a form which would be intelligible to him.

Recommendations

It is recommended that in future designs of binoculars, proper allowances be discovered and made for the limitations imposed by the human eye by considering it as a part of the optical observing system.

THE ATMOSPHERE AS A PART OF THE BINOCULAR

Discussion

Although it has not yet done so, the limitations imposed by the atmosphere on the visibility of objects viewed through binoculars, should have a profound effect on their design. The manner in which the atmosphere limits vision through it, is to scatter light along the line of sight thereby reducing the contrast objects appear to have with respect to the background against which they are viewed. This reduction in contrast increases as the distance between the observer and the target is increased and hence is referred to as an attenuation process. The dependence of the attenuation upon the state of the atmosphere is fairly well established for observations along a horizontal path. The attenuation appears to be an exponential function of the distance between the object and the observer. This exponential dependence upon distance has been found to hold for a wide variety of conditions of the weather and for targets ranging from black to white. As a result of knowledge of this dependence, it is possible to construct such visibility charts as those mentioned in Reference (237). These visibility charts appear to represent the first realistic approach toward the providing of the optical designer with atmospheric and observer data in a form which he can use in

pursuing designs of binoculars. The big gap in our present state of knowledge lies in the fact that similar charts are not available for recognition tasks and for slant range observations.

The manner in which the atmosphere influences the design of binoculars is shown in Figures 20, 21, and 22. These figures show the detection range at various binocular magnifications as a function of the clarity of the atmosphere (expressed in terms of meteorological range) for three different brightness levels of interest and for a circular target having an inherent area of 100 ft.², having a 20 percent inherent contrast. It is seen that even on the clearest of days, diminishing returns would quickly be reached if an attempt were made to increase the range at which objects are visible by increasing the magnification of the binocular. Or from another point of view, it indicates that enormous increases in magnification are required to produce even moderate gains in detection ranges. This type of consideration also could be applied to the range at which targets of different contrasts can be detected as a function of the state of the atmosphere. This is illustrated in the example shown in Figure 23 in which it is assumed that a 10 x 50 x 7° binocular is used to view targets of three different inherent contrasts at different meteorological ranges. It is seen that the detection range rapidly decreases in the case of each of the targets as the meteorological range decreases.

The above examples are presented to support the fact that in designing a binocular, the atmosphere must be regarded as a part of the optical system. If such a procedure were followed, it frequently

DETECTION RANGE VS. MAGNIFICATION FOR A CIRCULAR TARGET
 HAVING AN AREA OF 100 SQUARE FEET AND AN INHERENT
 CONTRAST OF 20 PERCENT AT A BRIGHTNESS LEVEL OF 10^3
 FOOT LAMBERTS FOR VARIOUS METEOROLOGICAL RANGES

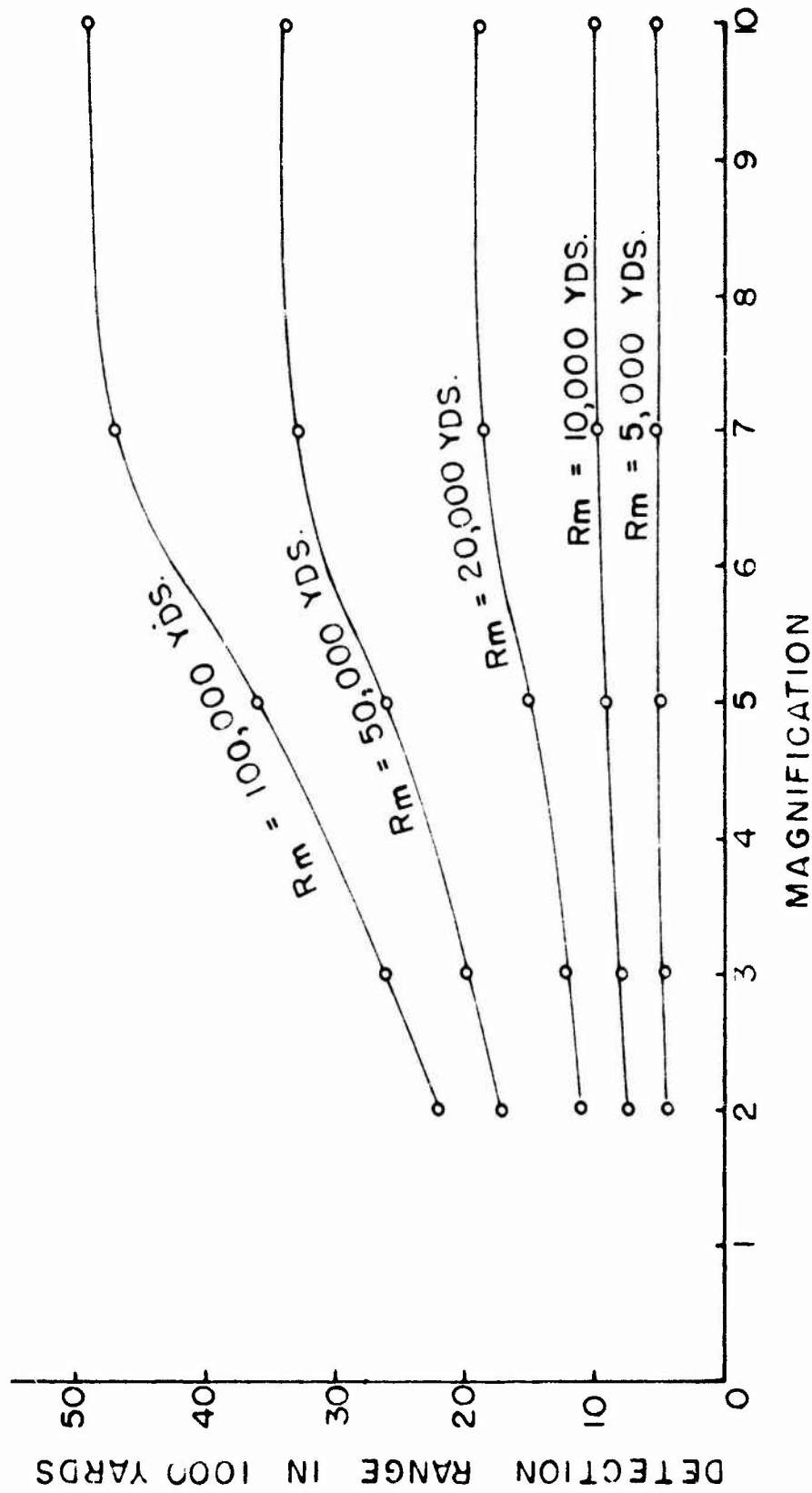


FIGURE 20

DETECTION RANGE VS. MAGNIFICATION FOR A CIRCULAR TARGET HAVING AN AREA OF 100 SQUARE FEET AND AN INHERENT CONTRAST OF 20 PERCENT AT A BRIGHTNESS LEVEL OF 10^{-1} FOOT LAMBERTS FOR VARIOUS METEOROLOGICAL RANGES

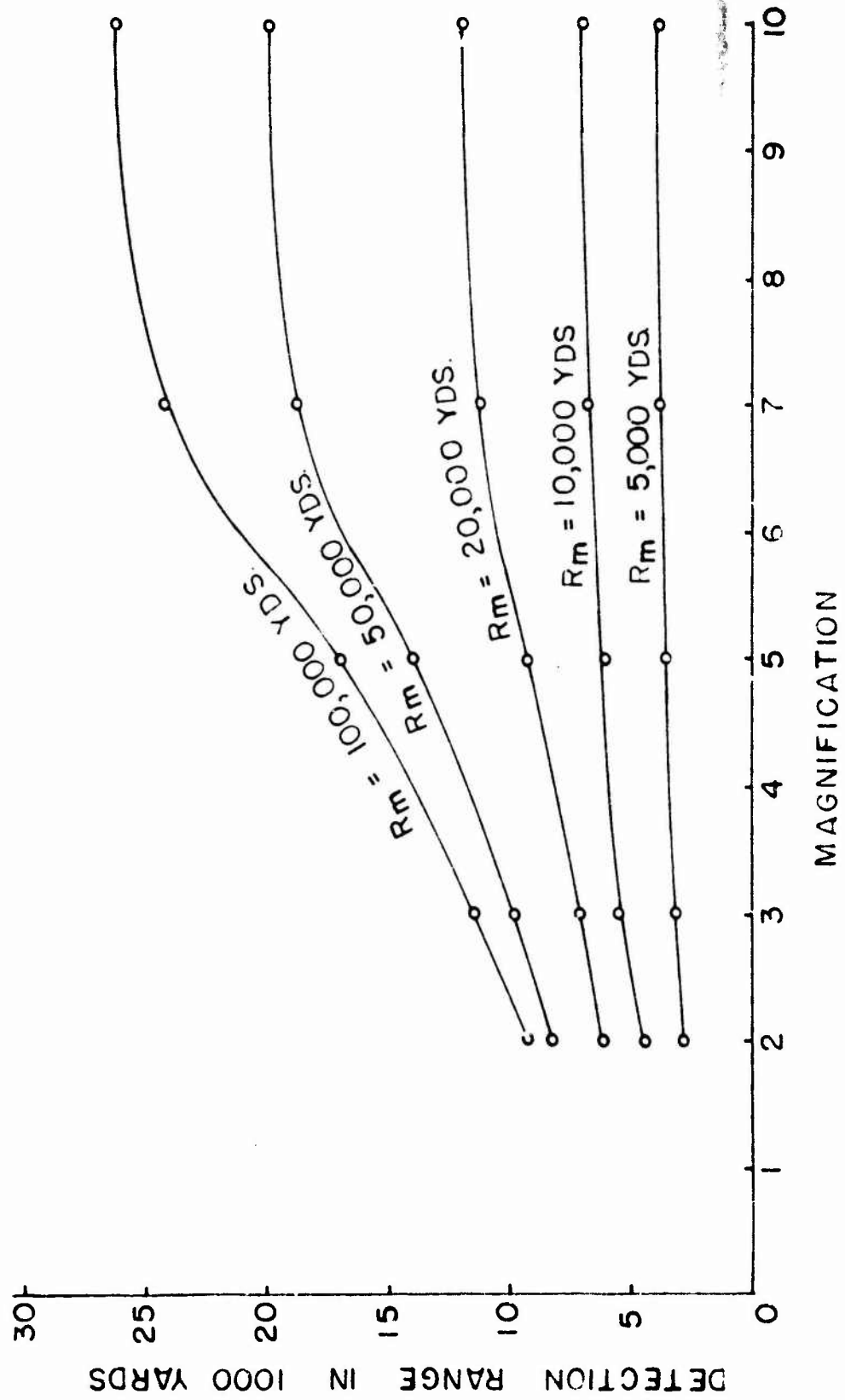


FIGURE 21

DETECTION RANGE VS. MAGNIFICATION FOR A CIRCULAR TARGET HAVING AN AREA OF 100 SQUARE FEET AND AN INHERENT CONTRAST OF 20 PERCENT AT A BRIGHTNESS LEVEL OF 10^{-4} FOOT LAMBERTS FOR VARIOUS METEOROLOGICAL RANGES

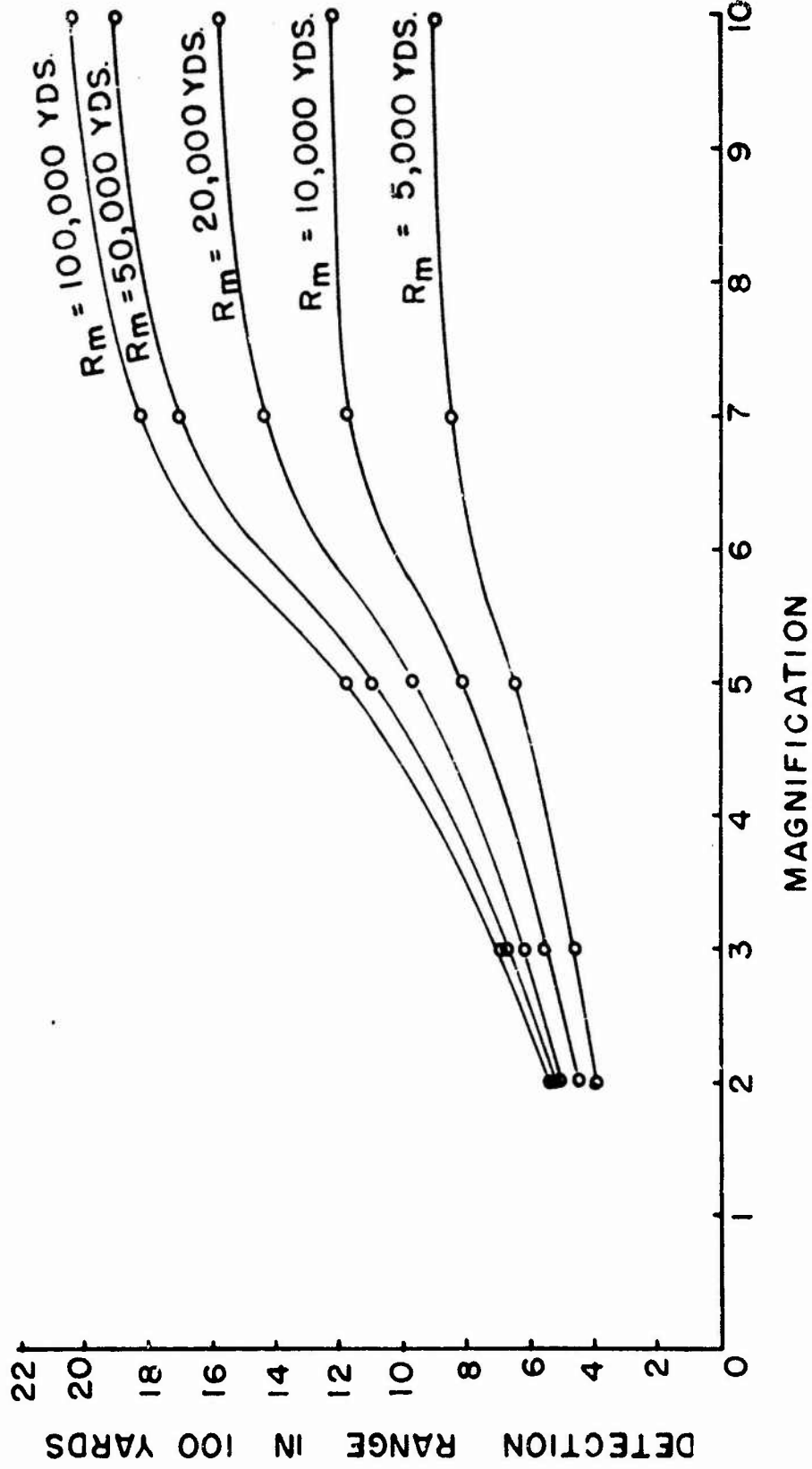


FIGURE 22

DETECTION RANGE VS. METEOROLOGICAL RANGE OF CIRCULAR TARGETS HAVING AREAS OF 100 SQUARE FEET AND VARIOUS INHERENT CONTRASTS VIEWED THROUGH A 10X50X7° BINOCULAR AT A BRIGHTNESS LEVEL OF 10^{-4} FOOT LAMBERTS

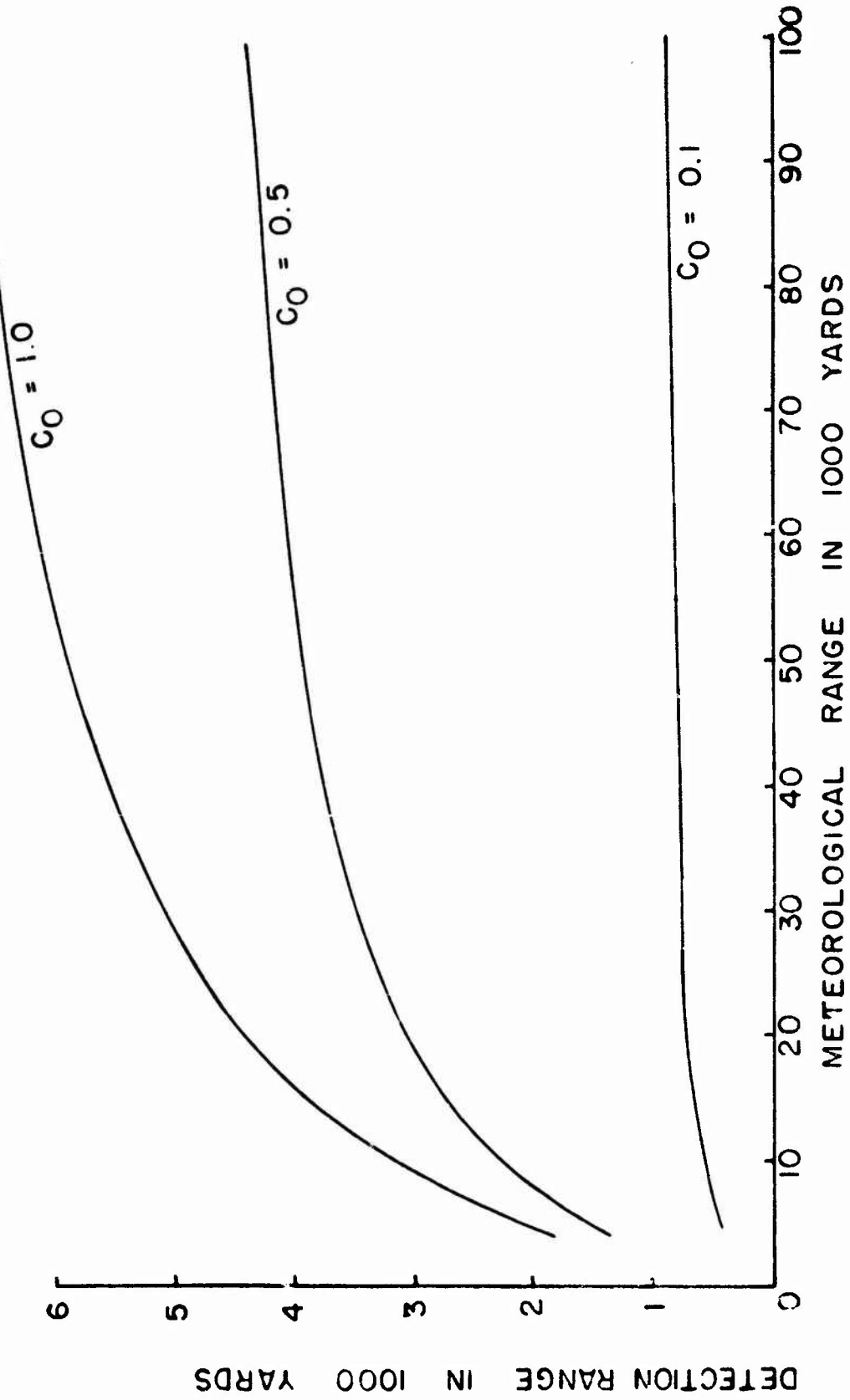


FIGURE 23

would be possible to avoid obvious mistakes in attempting to select such instrumental characteristics as the magnification, which would be woefully inadequate or otherwise unreasonable to develop a binocular capable of yielding satisfactory performance in the field.

Recommendations

It is recommended that in the design of binoculars, the atmosphere be considered as a part of the optical system and that procedures for making allowances for its limitations be developed and extended to recognition types of tasks and to slant range observations.

FIXED VS. ADJUSTABLE FOCUS

Discussion

The problem of deciding just how many adjustments should be included on a given design of binoculars has not yet been solved. This problem still exists because no realistic tests have been made to demonstrate the possible gains, under critical conditions, in eliminating the usual adjustments. There are two general misadjustments that are made in binoculars. The first is in the focal setting of the eyepieces and the second is in the interpupillary setting. The former is uncommon in daytime use of binoculars while both are common errors at night.

A number of possible gains might result from the use of non-adjustable binoculars. The first would be in the direction of eliminating improper adjustments of the instruments and the second would be in the direction of producing lighter weight binoculars with "sealed in" optics which likely would be procured at a considerable

saving to the Government should they prove satisfactory. Although a number of objections have been offered toward the use of such non-adjustable binoculars, no reports were reviewed in which objective tests showed clearly that such binoculars would be inferior to the present adjustable designs.

Recommendation

It is recommended that realistic tests be made in which a comparison is made between adjustable and non-adjustable binoculars from the point of view of field performance.

THE USE OF PLASTICS (BODY AND/OR OPTICS)

Discussion

The attempts made during and immediately following World War II to use plastics in connection with the production of binoculars has been disappointing. From the point of view of using plastics in the body of the binoculars, the objections generally centered around two points. The first concerned the fact that plastic bodies were breakable, and the second was associated with the fact that generally it was proposed to render the binocular non-adjustable, presumably on the basis of lack of resistance to wear (particularly in the binocular hinge and eyepiece focusing adjustments).

From the point of view of using plastics as optical elements, there are a number of reasons such a possibility should be considered. In particular, during wartime conditions, it would be desirable to supplement the supply of optical glass with optical plastics. It

also would be presumably possible to fabricate optical parts using unskilled or semi-skilled labor, or at least individuals who would not have to be drawn from the optical industry, which is particularly hard pressed in wartime. A third value in the use of plastics would be to provide optical materials, radically different from available optical glasses, which could lead to an improvement in the design of binoculars. In particular this possibility could lead to binocular designs of wider angular fields than possible at present. This is likely since it is possible to produce plastics having fairly high optical quality with indices of refraction approximately that of the glasses available at the present time but with unusually low values of reciprocal dispersion. From a design point of view, this makes it possible to reduce the steepness of the curves of the spherical surfaces required in wide angle eyepieces. In addition, the use of plastics would likely simplify the production of aspheric surfaces.

Unfortunately, the development of the possible use of plastics for binoculars seems to have ceased. There are a number of causes for this. Perhaps the first is that the optical glass production centers have expanded their capacities so that the country is at least no longer dependent on imports for its optical glass. A second reason for the lack of pursuit of development of plastics for optical purposes centers around the several undesirable properties, from an optical and mechanical point of view, of the plastics presently available. For example, polycyclohexylmethacrylate (CHM) and polystyrene (styrene) have a lack of optical homogeneity, a lack of freedom from haze, a lack of reproducibility with respect to refractive

index and reciprocal dispersion, a lack of freedom from color, they change in shape with changes in temperature, they have relatively low abrasion resistances, and they have relatively high water absorptivity. There is little doubt that these two plastics have too many objectionable features to be considered much further from the point of view of developing new types of binoculars. However, the fact that it has been possible to develop optical systems of "fair" optical quality, seems to be at least encouraging from the point of view of the possibility of using such materials. This matter is of particular importance from the point of view of the conclusions to be drawn in this report which effectively imply that the optical quality of the present type of binoculars may be far greater than can be utilized in view of the limitations imposed by the human eye, the atmosphere, and the observation conditions.

Recommendations

It is recommended that studies be made of the possibilities of developing plastics for bodies of binoculars and for the optical elements both from the point of view of economy and the possibility that the high optical quality demanded of present designs may not be justifiable on a performance basis.

ANTI-OSCILLATION MOUNTS

Discussion

Although the subject of anti-oscillation mounts is not directly a part of this report (since it deals largely with hand held binoculars), such mounts do have an effect on the design of binoculars.

For this reason some brief comments are included. Specifically, the use of anti-oscillation mounts would permit an increase in the magnification of binoculars, particularly when used from aboard aircraft or aboard ship in which the vibrations transmitted to the binocular may be relatively great. The ill effects caused by vibrations are largely describable in terms of the angular displacements of the images formed by binoculars as presented to the observer's eye. In the case of an ordinary binocular, the apparent angular motion of a distant object will be $(m - 1)$ times the angular motion of the optical axis, where m is the magnification. On the basis of experimental evidence, it has been found that if the vibrations transmitted to the binocular do not exceed more than two or three times that of the apparent angular displacements of an object viewed with the unaided eye, no particular ill effects are found. From a design point of view this would tend to suggest that the upper limit of magnification for a hand held binocular, used under vibration conditions ordinarily found in aircraft, moving tanks, and from aboard ship, ought not to exceed 4x. Likely it would be better to limit the magnification to from 2x to 3x. Or from another point of view, it might be concluded that if a higher magnification is required to perform a particular task, an anti-oscillation mount is required. This then would lead to the conclusion that in general binoculars mounted in anti-oscillation fixtures should be used where possible.

Recommendations

It is recommended that binoculars having a magnification greater

than 4x be mounted in anti-oscillation fixtures when observations are made under conditions in which appreciable vibrations are transmitted to that binocular in its normal course of use.

COLLIMATION OF MECHANICAL AND OPTICAL PARTS

Discussion

The alignment of the optical and mechanical parts of a binocular should be such that if two parallel pencils or bundles of rays enter the two objectives of the binoculars, the rays emerging from the eyepieces would be practically parallel. However, the degree to which the emerging beams shall be parallel must be assigned a tolerance from a practical point of view. In general it is held that this parallelism must be maintained for all states of adjustment of the inter-ocular settings of the binocular and focal settings of the eye pieces within the following limits:

- (1) They must not emerge at an angle greater than 14 minutes of arc in the direction perpendicular to the plane determined by the two entrant pencils.
- (2) They must not diverge by more than 28 minutes of arc and must not converge more than 14 minutes of arc in the direction parallel to the plane of the two entrant pencils.

Although the above collimation requirement is fairly easily achieved, from a production point of view, it does not seem to be founded upon a firm basis. Accordingly, it is felt that some psychophysical experimentation should be pursued which would show any possible dependence of imperfect collimation on the range at which objects are visible through binoculars. Such experiments might

become of a subjective nature in that perhaps fatigue or other ill effects might eventually have to be used to form the basis of the specification.

Recommendations

It is recommended that the present specifications on the collimation of binoculars be used until such time as objective experiments have been performed to indicate a need for a change.

WEATHER PROOFING

Discussion

It has generally been held that binoculars must be resistant to penetration by moisture even to the extent of being able to resist such penetration when completely immersed in water for as long as five minutes. This specification is a particularly rigid one and frequently results in the rejection of as many specimens of binoculars as are inspected. It is also highly doubtful if an examination immediately following the removal of the binoculars from the immersion is adequate to determine whether or not moisture actually has penetrated the binocular. In particular it appears that water does penetrate the binoculars through the eyepiece focusing unit and may not be evident for several days or weeks after the immersion test. Although no objective data have been reported on this matter, it appears that the specification requiring binoculars to be moisture proof, in the sense mentioned, is unnecessarily strict, and it also appears to be impractical from the point of view of the conventional design of binoculars. However, if such a specification is justified,

it seems that special consideration should be given to the use of non-adjustable plastic binoculars which presumably could be sealed satisfactorily.

Recommendation

It is recommended that an investigation be made as to the necessity of requiring that binoculars be weather proofed to the extent of withstanding penetration of moisture upon immersion of the binocular in water.

SLINGS AND HEAD RESTS

Discussion

The subject of slings and head rests for binoculars has been highly controversial. This controversy arises largely because of the reluctance of the Services to change from the conventional type of binocular to something radically different on one hand, and on the other because some of the proposed designs of slings and head rests have been utterly impractical. On the basis of the assumptions that for many military purposes, the present design of binoculars is optically better than necessary, and that it has such characteristics as magnification and optical quality improperly specified, it would seem desirable to consider the possibility of developing new shapes of binoculars in which slings and head rests likely would play an important part. In this connection, it should be indicated that of the field tests that have been conducted in which slings and head rests of binoculars of the conventional design were used, it appears that the use of such equipment has not been shown to be objectionable.

However, no great claims for improvement in performance have been reported by the use of slings and head rests in the field tests. Consequently it can be assumed that likely no great gains can be expected from such auxiliary equipment as long as the conventional binocular is involved. For this reason it is concluded that slings and head rests would be of value only if utilized in connection with new designs of binoculars, particularly in which changes of shape, size, and weight, have been made from that of the conventional design.

Recommendations

It is recommended that slings and head rests not be used in general for the conventional design of binoculars, and that a study be made of the possibility of utilizing slings and head rests for binoculars of non-conventional shapes, sizes, and weights.

DIOPTER SETTING AND ORIENTATION OF RETICLES

Discussion

In the case of binoculars in which reticles are required, it is important to specify that the reticle always be in focus to the observer. This requires that the reticle markings be located somewhat nearer the field lens of the eyepiece of the binocular than the principal focus of the eyepiece. Also it is necessary to specify that the reticle be attached to the eyepiece, in the case of a focusable eyepiece, so that the distance between it and the field lens does not vary.

One problem associated with the use of reticles in binoculars is the fact that the image appears to tilt as the inter-pupillary

adjustment is changed. It generally is specified that this image tilt must not exceed a half a degree for all inter-pupillary settings from 63 mm to 72 mm. So far as can be determined from reviewing literature in this connection, no firm basis can be found for this particular specification. However, since it does not appear to be a difficult specification to meet from the point of view of the production of binoculars, no objection can be seen for continuing its use.

Recommendations

It is recommended that reticles used in binoculars be so located with respect to the eyepiece that light from the reticle markings is diverging by at least one half of one diopter and that the image tilt not exceed $1/2^\circ$ for inter-pupillary settings ranging from 63 to 72 mm.

FILTERS

Discussion

The question of the desirability of including filters in binoculars is still unresolved. There seem to be two valid reasons why the filters might be used. The first is to decrease the overall brightness of the field viewed for the comfort of the observer and the second is in the possibility of penetrating haze, thereby increasing the range at which objects are visible. Unfortunately however, there seems to be ample evidence to indicate that the range at which objects are visible through binoculars cannot be increased by the use of filters. This conclusion has been largely based on field tests, but for that reason has been subject at least to some

doubt. In any event it seems that the use of filters in binoculars for anything other than reduction in field brightness is subject to further review. In this connection, there does seem to be a possibility of increasing the range at which objects are visible by the use of both polarization type filters and by colored filters under conditions in which losses in light transmission caused by such filters can be neglected. Whether or not such filters actually would be practical to include in the design of a binocular is a matter for further study.

Recommendation

It is recommended that a study be made of the advisability of including filters in binoculars from the point of view of increasing the range at which objects are visible.

RESISTANCE TO SHOCK

It is obvious that any optical instrument, such as a binocular, that is to be used in the field must have certain resistance to shock both from a point of view of breaking and from the point of view of maintaining alignment of its optical and mechanical parts. The present general specifications for binoculars dealing with shock resistance requires that binoculars remain in collimation after having been dropped a distance of 6 ft. onto fine white sand 6 inches deep, covered with thin cloth with the binocular eyepieces held upward. If the instrument passes such a test, a strong cord, practically free from stretch, such as a sash cord, and of sufficient length is tied around the hinge fin or sleeve and the binocular dropped 6 ft. without striking any object in such a manner that the fall is arrested

by the cord. It is required that the binocular not have changed in collimation by an amount greater than is allowed by the specification covering the procurement.

So far as can be determined, the above specification is satisfactory and is something that can be achieved in mass production of binoculars of the conventional design.

Recommendation

It is recommended that no change be made in the specifications set forth above for shock resistance for binoculars.

MECHANICAL REQUIREMENTS

Discussion

Although it is not the purpose of this report to discuss the mechanical requirements of hand held binoculars, there are a number of aspects of the mechanical requirements which bear on the performance of such instruments. In particular, the focusing adjustment of the eyepieces and the inter-pupillary distance adjustments must be serviceable. In particular the adjustment of the eyepiece must not be either too loose or too tight. The same applied to the action of the hinge used in changing the inter-pupillary distance. In this regard, it appears that the present specifications covering binoculars are adequate.

Recommendation

No change in the present mechanical requirements for binoculars is recommended.

RESISTANCE TO CHANGES IN TEMPERATURE

Discussion

Because of the relatively wide range of temperatures in the field in which binoculars are to be used, it is essential that they perform properly, not only from an optical point of view but from a mechanical point of view for the range of temperatures of interest. In particular it is necessary that the binoculars satisfactorily perform under low temperature uses. Accordingly it is common practice to specify that the binoculars must remain serviceable under cold temperature conditions which are set by the various agencies procuring the binoculars for the Services. Generally the specifications indicate that the binoculars shall be exposed to an ambient temperature of - 60°F for five hours and subsequently at - 45°F for two hours and then tested for possible failures. After the cold temperature test, it is frequently specified that the binoculars be exposed to an ambient temperature of + 160°F for five hours and subsequently + 150°F for two hours and then retested for possible failure. This latter requirement generally is supplemented by the fact that such binoculars that have been subjected to the temperature ranges mentioned are to be retested completely after they have reached normal room temperature for about two hours. Naturally only samples of binoculars being procured are subjected to this rather involved temperature test, however it should be indicated that if a sample fails, generally the entire shipment of binoculars is regarded as unacceptable by the Government until such time as an investigation into the

matter shows the cause of the trouble and it can be rectified.

Recommendation

It is recommended that the present specifications of binoculars dealing with resistance to changes in temperature continue to be used.

GENERAL SUMMARY

The literature relating to the design of binoculars has been collated. As a result of this collation seven general conclusions have been reached, the basis of which, as a result of present world conditions, should be digested by the optical design and procurement agencies of the Armed-Forces at an early date. The final form of the conclusions can be considered as consisting of the following parts:

- (1) The present (1950) designs of hand held binoculars are not based on their intended end use, and it appears that they may have been over designed from the point of view of many possible uses.
- (2) It is not possible at the present time (1950) to arrive at the optimum design of binoculars based on their intended end use largely because of a lack of knowledge of the response of the human observer and the limitations imposed by the atmosphere under the observation situations of military interest.
- (3) In order to design binoculars logically, it will be necessary to determine the contrast thresholds of the human observer, in particular, for recognition types of tasks, for moving targets, and moving observers (making proper allowances for vibrations) in the case of both detection and recognition types of tasks, and to develop methods of making proper allowances for targets of realistic shapes viewed under conditions of non-uniform brightness.
- (4) In order to design binoculars logically, it will be necessary to develop methods of making allowances, during field operations, for the limitations imposed on observations by the atmosphere. Specifically the atmospheric attenuation of brightness and color contrasts must be determined for both horizontal and slant observations.

In addition a practical device is needed which is capable of describing the state of the atmosphere and indicating the brightness level to which the unaided eye is adapted under observation conditions of interest.

- (5) A set of practical visibility charts is needed by means of which the detection range and recognition range, (for stationary and moving targets), can be determined for the general conditions of military interest and which would make it possible to make allowances quickly and simply for the instrumental, atmospheric, brightness, and observer factors.
- (6) If the above information were available an entirely new but valid philosophy of designing binoculars could be developed. This could start with the end use of the binoculars and be pursued by considering the allowances that must be made for the target, the medium between the target and the binocular, the binocular, and the human observer, by regarding these as one complete optical system.
- (7) Until the above mentioned data required have been collected, the guidance in the design of binoculars must be limited to the case of detecting the presence of stationary objects by stationary observers. This guidance can be simply summarized by indicating that of the present designs, the 10 x 50 x 7° binocular may be expected to yield the best general performance.

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REFERENCES PERTINENT TO BINOCULAR SPECIFICATIONS

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