UNITED STATES DEPARTMENT OF COMMERCE
JESSE H JONES, *Secretary*
CIVIL AERONAUTICS ADMINISTRATION
CHARLES I STANTON, *Administrator*

Technical Development Report No 30

INCIDENCE AND EFFECT OF ANISEIKONIA ON AIRCRAFT PILOTAGE

By

THE RESEARCH DIVISION
DARTMOUTH EYE INSTITUTE
HANOVER, NEW HAMPSHIRE

MARCH 1943

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON 1943

CONTENTS

ILLUSTRATIONS

FOREWORD

This investigation was undertaken to determine the extent to which aniseikonia[1] exists among pilots and student pilots and whether or not it may be considered a factor in flying ability. It was very desirable to learn, for instance, whether its presence is responsible for poor flying technique, and whether it can be induced through fatigue, and if so, to what extent.

Some student pilots learn to fly readily and with an apparently natural aptitude, while others, who qualify equally well physically under present standards of measurement, have considerable difficulty during instruction. This fact, of course, applies to the military services as well as to civilian training. In some cases those having difficulty turn out reasonably well, while others never develop into safe pilots.

Important researches are being conducted by a number of institutions for the determination of better physiological and psychological standards by which to measure pilot aptitude and ability. Indications point rather strongly to the possibility that the prevalence of aniseikonia may be one of the causes of flying faults, such as leveling off too high or too low above the ground or consistently landing with one wing low, etc.

In considering the results of this investigation, the following facts should be kept in mind:

(1) The subject material studied at Pensacola constituted a particularly selected group in which cadets with deficient flying capacities had been eliminated in earlier stages of training.

(2) Data available on the flying performance of the cadets studied did not disclose the nature of the pilots' faults or provide a basis for correlation with the nature of the aniseikonia found.

(3) The precision of binocular spatial localization needed by cadets in training is not of a high order since they fly over well-known fields where there are a preponderance of uniocular clues. The uniocular spatial localization clues from such environments might enable a cadet to successfully perform even though he had anomalous or poor stereoscopic vision. In other environments where such clues are few or do not exist, and where binocular localization has to be relied upon the presence of aniseikonia might act to the disadvantage of the pilot.

Studies of many clinical patients of the Dartmouth Eye Institute show a high correlation between aniseikonia and anomalous (faulty) binocular spatial localization in environments where there are few monocular spatial localization clues, such as perspective and known forms.

The lack of correlation therefore, found between the amount of aniseikonia measured in the pilots studied in this investigation and their flying performance should not lead one to the conclusion that there exists no correlation between aniseikonia and flying performance.

The attached preliminary report of an investigation of the incidence and effect of aniseikonia on aircraft pilotage was prepared under certain restrictions caused by the war situation.

It is regretted, for instance, that a more complete scientifically documented statement, including correlations with performance data and the data relating to physiological and psychological conditions obtained by members of other institutional research staffs with which this study subsequently became associated, was not possible due to other assignments caused by the war.

The report was prepared by the Dartmouth Eye Institute from data gathered by Dr. Robert H. Peckham who carried the field supervision responsibilities of the study both at Kansas City and at Pensacola.

[1] A defect of the binocular visual processes in which differences exist in the size or shape of the ocular images from the two eyes.

INCIDENCE AND EFFECT OF ANISEIKONIA ON AIRCRAFT PILOTAGE

INTRODUCTION

Aniseikonia[1] is defined as a defect of the binocular visual processes in which differences exist in the size or shape of the ocular images in the two eyes. The term "ocular image" is used to designate the image which finally reaches consciousness through the vision of one eye. Significant differences in size between the two ocular images, ½ percent to 4 percent, are usually too small to be observed by the individual and hence can be measured only with special instruments.

In the clinical division of the Dartmouth Eye Clinic where patients with aniseikonia have been measured, and in the laboratory where artificial aniseikonia can be introduced by special lenses, experience has shown that a marked false space localization generally occurs when the individual with a size difference of even a small amount, is placed in an environment where strong perspective monocular clues do not exist.

Specific types of spatial distortions associated with different ocular incongruities include: The apparent sloping of the ground—the "sidehill" effect or the "uphill" or "downhill" effect; the apparent change in the distance of objects, the apparent enlargement or diminution of objects, the distortion of the forms of extended figures, etc. These false space localizations would be important to the aviator flying near the ground, in landing or taking off, so as to avoid flying with one wing low, or with nose of the plane too high or too low, in estimating the height of the plane from the ground, in the avoidance of obstacles, and in flying in formation or in acrobatics.

Because of the association between image size differences and faulty binocular spatial localization, the incidence of aniseikonia appears to be important in the selection and training of pilot candidates. In the summer of 1939, the Civil Aeronautics Authority made arrangements with the Dartmouth Eye Institute to obtain data on the problem. It was provided that 100 or more subjects (later specified as pilots) were to be tested to determine the percentage having aniseikonia.

The Dartmouth Eye Institute began making the visual examination for the incidence of aniseikonia (and the faulty binocular space perception associated with it) upon first-line commercial pilots at the Civil Aeronautics Authority Medical Science Station at Kansas City, Mo., in January 1940. The project was continued in September 1940 at the U. S. Naval Air Station at Pensacola, Fla. Up to January 1, 1941, the following subjects were tested:

36 Civil air carrier pilots (Kansas City)
188 Cadets entering Pensacola for training
55 "Washouts" or cadets whose flying progress was in question or whose limited flying ability warranted their dismissal from the Station
37 Ensign instructor-pilots

This report is based upon the data collected from the tests made on these subjects.

At Pensacola, because of service conditions, the time allowed for the testing of each cadet was limited to half an hour so that the tests had to be abbreviated and confined to the following instruments:[2]

(1) The Eikonometer — a nonstereoscopic type of instrument in which the relative size of the ocular images of the two eyes is compared directly by the subject (10 minutes).

(2) The so-called "Leaf Room"—a strictly functional test for ascertaining whether or not a subject sees binocularly a three-dimensional form where it actually is. This is a subjective test in which the observer describes the appearance of a rectilinear room under different test conditions. The extent to which the subject fails to see the room in its true form or fails to see it distorted when "size lenses" are put

[1] A bibliography on the subject will be found in Appendix I.

[2] Brief descriptions of these instruments and of their operation are given in Appendix II. Greater detail may be found in the three manuals prepared for the Kansas City and Pensacola projects.

before the eyes gives a measure of the ocular image incongruities present

(3) The so-called "Frontal Plane Apparatus"[3]—a semifunctional test using binocular space perception as criteria of the presence of ocular image incongruities The subject sets a series of rods for an apparent frontal plane under different test conditions[4] (10 minutes)

DISCUSSION

THE EIKONOMETER DATA

From the Eikonometer data obtained, the subjects were placed in separate groups according to the image size difference (aniseikonia) measured for distant vision in the vertical and horizontal meridian The percentages of the Pensacola and Kansas City subjects which fall into the various groups are given in table I Also included for comparison are the data obtained on a class of college students and on a large number of clinical patients from the Dartmouth Eye Clinic[5]

The decreasing cumulative distributions of these data are shown graphically in figure 1

It is clear that the incidence of aniseikonia as measured on the Eikonometer is strikingly less in the Pensacola cadets than in the other population groups—even less than that in the civil airline pilots The table and graphs show, for example, that approximately 8 percent of the Pensacola subjects have image size differences greater than ½ percent, while approximately 40 percent of the airline pilots, more than 40 percent of the college group, and approximately 80 percent of aniseikonic clinical patients have differences greater than ½ percent

To be considered also with the low incidence of aniseikonia in the Pensacola subjects is the much higher sensitivity[6] to the recognition of small image size differences in the Eikonometer as compared with other population groups[7] In view of this higher sensitivity, the smaller

[3] This instrument was added to the tests when the project was moved from Kansas City to Pensacola Data from this test were therefore not obtained on the Kansas City subjects

[4] At the Kansas City Station more time was available for the testing of each subject hence there were in addition to the first and third instruments listed above (1) the induced effect S curve apparatus (2) the horizontal tilting board, and (3) an instrument for testing 'cycle' image incongruities Because the subjects tested at Pensacola were not given these additional tests no data on these instruments for the Pensacola group can be included in this report

[5] All of the college students were from the class of 1940 at Dartmouth College The clinical patients were those referred to the eye clinic primarily for aniseikonic examinations

[6] For the Kansas City and Pensacola subjects see Appendix III for distribution of so-called "size amplitudes" which are measures of the sensitivity

[7] The difference in the degree of aniseikonia found in the civil pilots and in the Pensacola cadets cannot be accounted for entirely See Appendix IV

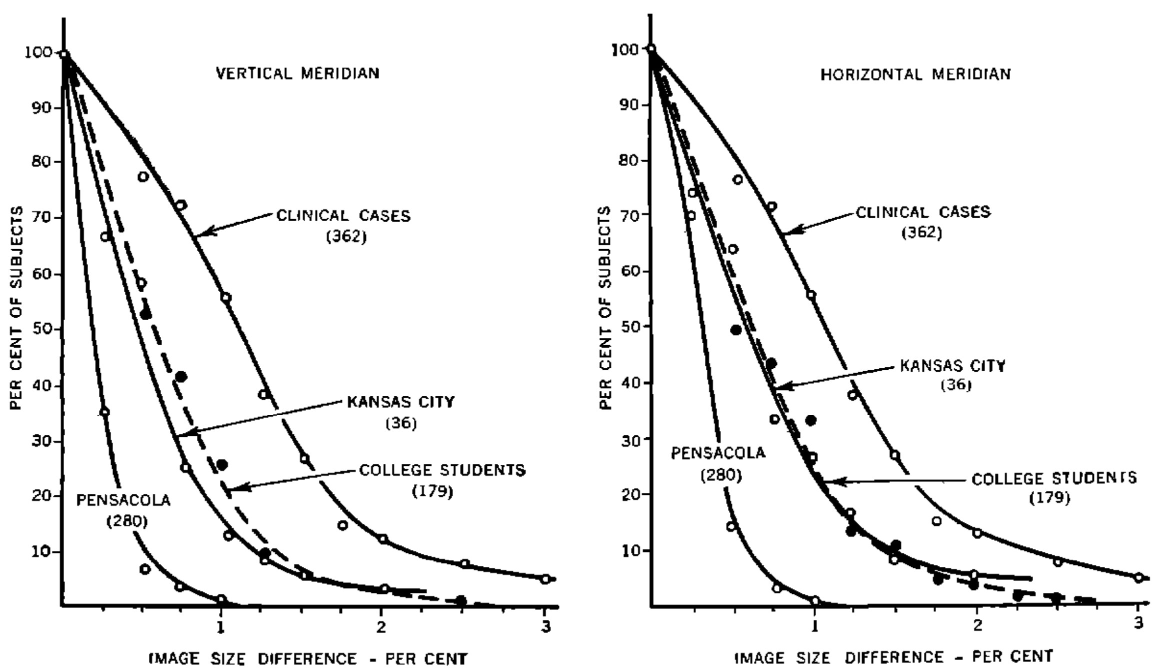

Figure 1—Eikonometer Data, Percentage of subjects having image size differences equal to or greater than any given magnitude.

aniseikonic differences found in the Pensacola subjects become more important and as a result, it might be expected that some of the cadets would have an impairment of their binocular space sense That these small aniseikonic differences could cause faulty binocular spatial localization in some of this group is indicated by the results of the functional tests described below, and is implied in the following theoretical consideration

TABLE I—*Eikonometer Data*

VERTICAL MERIDIAN

Size	Pensacola			Kansas City			College students			Clinical patients		
	Number	Frequency	D C	Number	Frequency	D C	Number	Frequency	D C	Number	Frequency	D C
3 00										8	2 2	2 2
3 00										7	1 9	4 1
2 50							1	0 6	0 6	11	3 0	7 1
2 00				1	2 8	2 8	2	1 1	1 7	19	5 2	12 3
1 75										7	1 9	14 2
1 50				1	2 8	5 6	8	4 5	6 2	45	12 4	26 6
1 25				1	2 8	8 4	6	3 4	9 6	40	11 0	37 6
1 00	1	0 4	0 4	5	13 9	22 3	29	16 2	25 8	65	18 0	55 6
0 75	6	2 1	2 5	1	2 8	25 1	28	15 6	41 4	60	16 6	72 2
0 50	10	3 6	6 1	12	33 3	58 4	21	11 7	53 1	18	5 0	77 2
0 25	81	28 9	35 0	3	8 3	66 7						
0 25	182	65 0	100 0	12	33 3	100 0	84	46 9	100 0	82	22 7	100 0

HORIZONTAL MERIDIAN

Size	Pensacola			Kansas City			College students			Clinical patients		
	Number	Frequency	D C	Number	Frequency	D C	Number	Frequency	D C	Number	Frequency	D C
3 00							1	0 6	0 6	9	2 5	2 5
3 00										15	4 1	6 6
2 50							2	1 1	1 7	17	4 7	11 3
2 00				2	5 6	5 6	2	1 1	2 8	19	5 2	16 5
1 75							3	1 7	4 5	12	3 3	19 8
1 50				1	2 8	8 4	11	6 1	10 6	59	16 3	36 1
1 25				3	8 3	16 7	5	2 8	13 4	28	7 7	43 8
1 00	1	0 4	0 4	4	11 1	27 8	35	19 6	33 0	64	17 7	61 5
0 75	8	2 9	3 3	2	5 6	33 4	20	11 2	44 2	57	15 7	77 2
0 50	32	11 4	14 7	11	30 6	64 0	10	5 6	49 8	10	2 8	80 0
0 25	05	33 9	48 6	4	11 1	75 1						
0 25	141	51 4	100 0	9	25 0	100 0	90	50 3	100 0	72	19 9	100 0
Total	280			36			179			362		

The graph in figure 2 shows the theoretical *maximum* apparent rotation of the binocular visual field that could be expected at different visual distances for different degrees of image size differences Thus, a ½ percent difference could theoretically give rise to a maximum apparent rotation of the binocular field of 16° at a visual distance of 10 feet, and 68° at 100 feet Usually the environment at these larger distances will contain monocular perspective features which tend to outweigh the binocular clues and prevent or reduce the appearance of these large apparent rotations However, it is precisely the existence of these theoretical maximum effects that could occur in unusual situations, which requires a consideration of even the smaller degrees of aniseikonia found in the Pensacola subjects

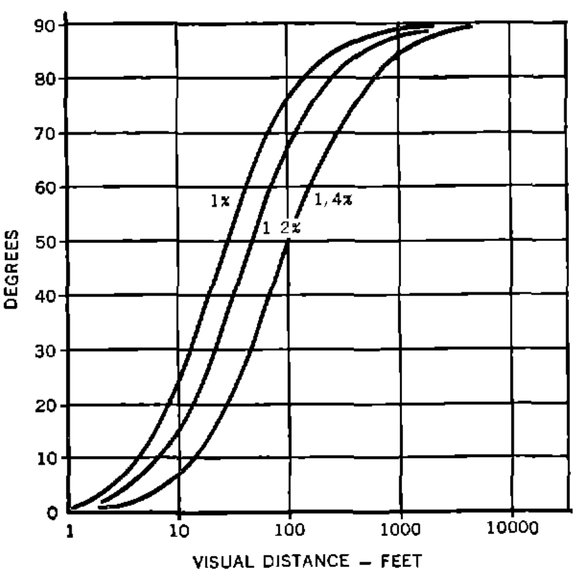

Figure 2—Theoretical maximum apparent rotation of binocular field due to an image size difference in the horizontal meridian

The Eikonometer test, used to measure differences in the sizes of the ocular images, depends upon the resolving power of the eyes, using rather broad test stimuli On the other hand, the functional tests, which include the Frontal Plane Apparatus (in part) and the Leaf Room, depend upon the stereoscopic processes, the sensitivity of which is much higher than resolving power alone Thus, with high visual acuity, which means increased stereoscopic sensitivity, even small differences in size between the ocular images may be detected through disturbances in binocular space localization

THE LEAF ROOM AND FRONTAL PLANE APPARATUS

The data for each subject in each part of the two tests were evaluated by assigning scores according to the number and magnitude of the irregularities and the faulty responses found Figures 3 (A), 3 (B), and 4 are the distribution curves illustrating the important aspects of these tests Figure 3 (A) is a histogram illustrating the percentage of subjects found in different groups according to increased faulty appearance of the Leaf Room Figure 3 (B) illustrates the distribution of subjects according to their sensitiveness to respond to small artificial size differences in the Leaf Room Figure 4 is the distribution of the subjects according to a composite score for various parts of the Frontal Plane Apparatus [8]

As would be expected, the majority of the subjects have small scores There are, however, cadets whose scores occur in the extremities of the curves, and who show disturbances in their binocular space sense that might seriously affect their ability to operate an airplane properly

In general it has been necessary, in the practice of ophthalmology, to set more or less arbitrarily critical values for the visual functions which will define the limits of efficient vision from that which is less efficient For example, the critical value for visual acuity has been set at 20/20 on the Snellen scale In dealing with aniseikonia, it is estimated on the basis of clinical practice that in aviation candidates where visual acuity is high the existence of ½ percent or more of aniseikonia would operate to the disadvantage of the candidate as a pilot, and a cadet having such a size difference would be more of a risk than one with a lower degree

It is difficult to set critical scores for the functional tests at this time However, it is believed that cadets whose score is equal to or greater than 3 in the Leaf Room appearance-test, 7–8 in the sensitivity to artificial aniseikonia in the Leaf Room, and 5–6 as a composite score in the Frontal Plane Apparatus, have a faulty space sense which probably would be a handicap to their becoming successful pilots [9]

[8] See Appendix V for treatment of Frontal Plane data

[9] The actual correlations between the three tests are low, but no high correlation could be expected since it was usually impossible to check the data on any one test More reliance must be placed upon group results than on the individual tests in this study

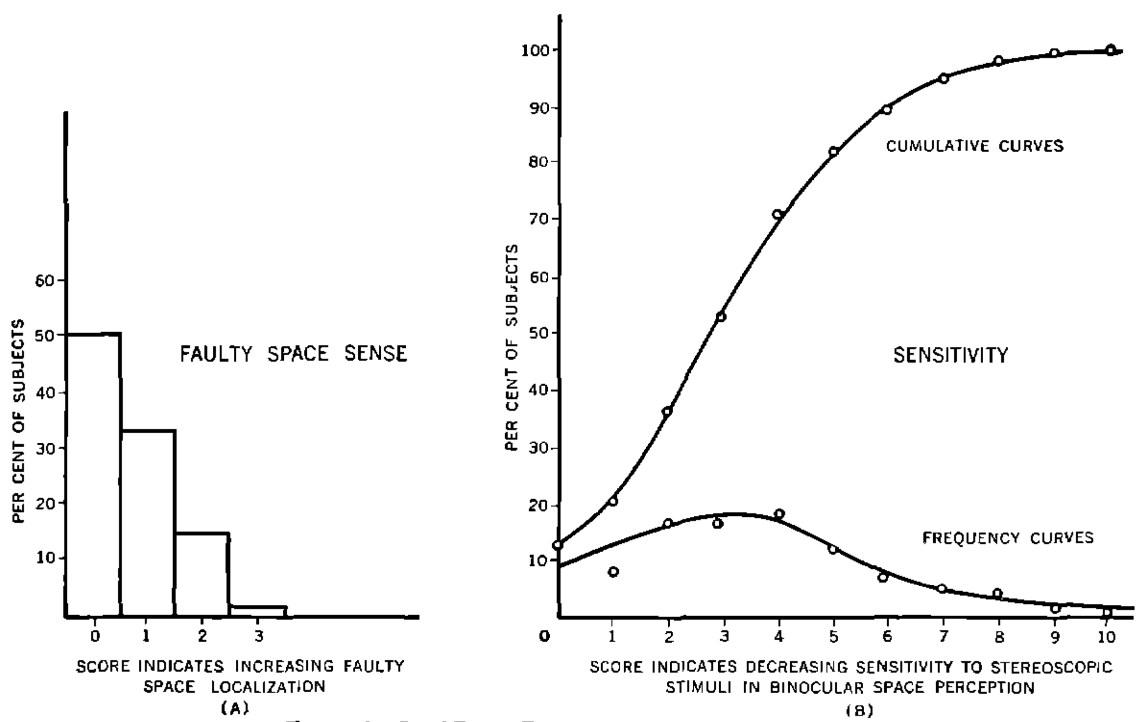

Figure 3—Leaf Room Data Pensacola subjects (280).

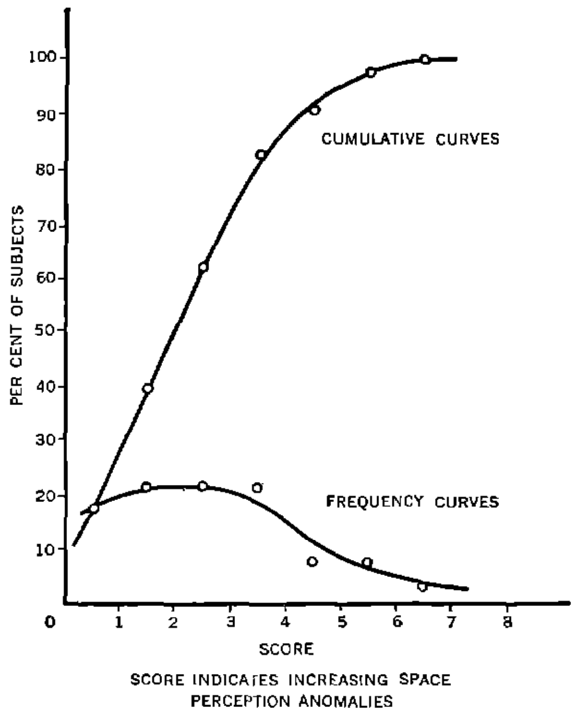

Figure 4.—Frontal plane apparatus data

CORRELATION OF ANISEIKONIA DATA WITH OPHTHALMOLOGICAL DATA

This part of the study consisted in correlating the aniseikonia of each subject, as measured, with the ophthalmological data available. These data include visual acuity refractive errors, phorias, axial steroscopic sensitivity, fusional amplitudes, etc. The X^2 correlation method was used on fourfold table.

In no case [10] can a significant association be found between the aniseikonia or anomalous space sense as measured on the three tests and any of the ophthalmological data.

This lack of correlation suggests that the presence of a false space sense is not detected in the ordinary ophthalmological examination. However, because much of the ophthalmological data available lacks the needed precision, and because the aniseikonia and space sense tests had to be made hastily, this matter should be investigated more carefully. Certainly the low incidence of aniseikonia among the Pensacola cadets as compared with that in other groups of the same age range, suggests that those aviation candidates with larger amounts of image size differences were eliminated either through the ophthalmological examination or through failure to meet requirements in the primary training schools.

It is already known that fatigue and anoxia affect, in a negative way, other ophthalmological functions, especially the accommodation and adaptation mechanisms. Clinical evidence shows that fatigue has a marked effect on the false space sense associated with aniseikonia. There is little question but that anoxia would have similar effects.

The service conditions at Pensacola and Kansas City prevented the obtaining of quantitative data on this project. It is vitally important, however, that provision should be made for studying the effect of fatigue and anoxia upon aniseikonia and faulty binocular space localization.

The essential question raised by these tests is: What degree of faulty space localization can be allowed in a pilot? In considering this matter one must bear in mind the degree of perfection required in spatial localization. This consideration is especially important under modern conditions of high-speed aircraft and continual changes in spatial environment.

Whether or not the degree of aniseikonia and faulty space localization found in many of the cadets affects their success in flying can be definitely determined only by a careful study of the errors and the flying performance of the individual pilots. Since most of the cadets tested have not yet finished their course, it is at present impossible to make correlations, but these data, it is hoped, will soon be available.

Several of the tests gave evidence that the "washout" group showed a slightly higher incidence of faulty space localization and poorer binocular space sensitivity.[11]

In considering these results it is necessary to keep in mind that the data regarding the "washouts" are most meager, not only because of the small number available for the tests, but also for the reason that the specific cause of the individual cadet's trouble is not clearly indicated. Also, the limitation of time made controlled reliability tests on the cadets impossible. The experience and data collected at the clinical division of the Dartmouth Eye Institute, however, indicate that the tests are reliable.

It must be remembered, moreover, that the presence of aniseikonia could be only one out of many possible causes of failure. There is no reason, therefore, why any general group of

[10] It must be pointed out, however, that an association was indicated between the maximum aniseikonia in any meridian and the axial stereoscopic sensitivity (Howard-Dolman test). In this correlation the maximum aniseikonia was used, and the degree of association might be higher if this correlation was made with aniseikonia in the horizontal meridian only. This matter should be studied further with more reliable data from the Howard Dolman test.

[11] See Appendix VII for details.

"washouts" could be predicted to show a higher incidence of either aniseikonia or faulty space perception than a normal group would show Only after a large number of "washouts' have been tested, whose difficulties are directly concerned with flying, can it be determined whether aniseikonia is a factor in their inferior flying performance

CONCLUSIONS

Subject to the limitations under which the data for this report were obtained the important aspects of the study may be summarized

(1) The aviation cadets as at present selected for training at the Naval Air Station, show relatively small differences between the sizes of the ocular images (aniseikonia), as measured on the Eikonometer, compared with those found in other population groups

(2) Even though relatively small, the higher order of the difference between the sizes of the ocular images as found on the Eikonometer could cause faulty spatial localization

(3) The low incidence of aniseikonia (as measured on the Eikonometer) in the cadets indicates that the present method of selecting the candidates, using certain standards of visual acuity, refractive errors, phorias, fusional amplitudes etc, provides a basis for eliminating those who have large differences between the sizes of the ocular images

(4) The functional tests for detecting faulty binocular space localization show that a significant percentage, possibly 8 percent, of the cadets show faulty spatial localization

(5) What degree of faulty space localization should be allowed in pilots can be definitely ascertained only by a careful correlation of the specific types of spatial errors found with the actual flying performance and specific faults of the cadets over a period of time Adequate performance records for the cadets tested so far are not yet available There was, however, evidence of a slightly higher incidence of faulty binocular space localization among the "washout" group than was found among the instructor-pilot group, the two groups which would be at opposite ends of the performance scale A significant difference in these two groups could not be expected on the basis of the data collected up to the time this report was submitted

(6) A consideration of the results from the project suggests that in selecting candidates for activities where the space sense is so important, complete reliance cannot be placed upon the tests now used, that is, high visual acuity, low degrees of phorias, low refractive errors, etc

It is the opinion of the research staff that screening tests for faulty space localization should be given prospective pilots However, such screening tests cannot be adopted now, since adequate data are not yet available from which the critical values or the minimum degrees of false space localization allowable can be determined

It is the opinion of the staff that tests for faulty space localization should be adopted as reference tests Such reference tests would be routine for those cadets having difficulty in handling their airplanes in landings and approaches, or other situations demanding accurate spatial orientation

The investigations carried out at Kansas City and Pensacola, which provide the basis for this report, were directed by Dr Robert H Peckham At Pensacola he was assisted by E Craig Wilson

APPENDIX I

Bibliography Pertaining to Aniseikonia

Ames, A, Jr Depth in Pictorial Art The Art Bulletin, 8 (1) 5–24, 1925

Ames, A, Jr Cyclophoria Amer J of Physiol Optics, 7 (1) 3–38, 1926.

Ames, A, Jr, and Gordon H Gliddon Ocular Measurements Trans Sect on Ophthalm, of the A M A 1–68 (June 15), 1928

Ames, A., Jr, Gordon H Gliddon and Kenneth N Ogle Size and Shape of Ocular Images I Methods of Determination and Physiologic Significance Arch of Ophthalm, 7 576–597, 1932

Carleton, Elmer H, and Leo F Madigan Size and Shape of Ocular Images II Clinical Significance Arch of Ophthalm, 7 720–738, 1932

Ames, A, Jr, and Kenneth N Ogle Size and Shape of Ocular Images III Visual Sensitivity to Differences in the Relative Size of the Ocular Images of the Two Eyes Arch of Ophthalm, 7 904–924, 1932

Ames, A, Jr, Kenneth N Ogle and Gordon H Gliddon Corresponding Retinal Points, the Horopter and Size and Shape of Ocular Images J O S A, 22 538–574 and 575–632, 1932

Ogle, Kenneth N An Analytical Treatment of the Longitudinal Horopter, its Measurement and Application to Related Phenomena, Especially to the Relative Size of the Ocular Images J O S A, 22 665–728, 1932

Madigan, Leo F: Examination and Correction of Aniseikonia. Arch of Ophthalm, 13 (4) 696–698 (April), 1934
Bielschowsky, A. Congenital and Acquired Deficiencies of Fusion. Amer J of Ophthalm, 18 (10) 925–937 (October), 1925
Ames, A, Jr. Aniseikonia—A Factor in the Functioning of Vision. Amer J of Ophthalm, 18 (11) 1014–1020 (November), 1935
Ogle, Kenneth N. The Correction of Aniseikonia with Ophthalmic Lenses. J O S A, 26 (8) 323–337 (August), 1936
Carleton, Elmer H. Clinical Aspects of Aniseikonia. Amer J of Ophthalm, 20 (4) 419 (April), 1937
Ogle, Kenneth N. Changes in the Relative Sizes of the Ocular Images with Asymmetrical Convergence. Amer J of Ophthalm, 20 (4) 418 (April), 1937
Carleton, Elmer H, and Leo F Madigan. Relationships between Aniseikonia and Ametropia—From a Statistical Study of Clinical Cases. Arch of Ophthalm 18 (2) 237–247 (August), 1937
Herzau, Werner, and Kenneth N Ogle. Über den Grossenunterschied der Bilder beider Augen bei Assymmetrischer Konvergenz und seine Bedeutung fur das zweiaugige Sehen. v Graefe's Arch f Ophthalm 137 (3) 327–363 1937
Ogle, Kenneth N. Die mathematische Analyse des Langshoropters. Pflugers Arch f d g Physiol, 239 (6) 748–766, 1938
Bielschowsky, A. Aniseikonia. Acta Ophthalm, 16 (2–3) 188–227, 1938
Ogle, Kenneth N. Induced Size Effect I. A New Phenomenon in Binocular Space Perception Associated with the Relative Sizes of the Images of the Two Eyes. Arch of Ophthalm, 20 (4) 604–623 (October), 1938
Imus, Henry A, John W M Rothney and Robert M Baer. An Evaluation of Visual Factors in Reading. Dartmouth College Publications (March 29), 1938
Bannon, Robert E. Heterophoria and Aniseikonia. Amer J of Optom, 16 (3) 96–109 (March), 1939
Burian, Herman M. Fusional Movements. Role of Peripheral Retinal Stimuli. Arch of Ophthalm, 21 486–491 (March), 1939
Ogle, Kenneth N. Induced Size Effect II. An Experimental Study of the Phenomenon with Restricted Fusion Stimuli. Arch of Ophthalm, 21 (4) 604–625 (April), 1939
Ogle, Kenneth N. Induced Size Effect III. A Study of the Phenomenon as Influenced by Horizontal Disparity of the Fusion Contours. Arch of Ophthalm, 22 (4) 613–635 (October), 1939
Ogle, Kenneth N. Relative Sizes of Ocular Images of the Two Eyes in Asymmetric Convergence. Arch of Ophthalm, 22 (12) 1046–1067 (December), 1939
Bannon, Robert E. Vertigo and Aniseikonia. The Columbia Optometrist, 13 (52) 2–4 (December), 1939
Gliddon, Gordon H. Aniseikonia. J O S A, 30 (4) 142–144 (April), 1940
Ogle, Kenneth N. The Induced Effect. J O S A, 30 (4) 145–151 (April) 1940
Ogle, Kenneth N. Induced Size Effect with Eyes in Asymmetric Convergence. Arch of Ophthalm, 23 (5) 1023–1038 (May), 1940
Bannon, Robert E. Headaches and Aniseikonia. Amer J of Optom, 17 (10) 448–459 (October), 1940
Ogle, Kenneth N, Henry A Imus, Leo F Madigan, Robert E Bannon, and Wilson E Craig. Repeatability of Ophthalmo-Eikonometer Measurements. Arch of Ophthalm, 24 1179–1189 (December), 1940

APPENDIX II

Descriptions of Instruments Used at Pensacola and Their Operation

THE EIKONOMETER

Essentially, the Eikonometer (fig 5) consists of a headrest, two groups of test lens cells, and an eikonic target (fig 6). To insure the required accuracy the headrest is of elaborate design, its purpose being to hold the subject's head so that the eyes are in a fixed position relative to the test lenses.

The test lens arrangement consists of two parts, namely, the cells for holding the refractive test lenses, and the image size measuring units. Corneal aligning devices are attached to the test lens supports in order that the eyes may be placed at the proper distance from the test lenses. The size measuring devices are four adjustable size lense units, each consisting of a telescopic system of two lens elements, designed in such a way that a change in axial position of one lens relative to the other changes the magnification of the combination without appreciably changing its (zero) verging power. One of the two units in front of each eye has variable "over-all" magnifications; the other is a "meridional" magnification unit, that is, its magnification is variable in only one meridian. From a scale on the circumference, the percent magnifying power of the unit can be read corresponding to different separations of the two lens elements.

Since the instrument has been designed for testing at both distance and near vision, the groups of test lenses can be lowered and tilted for the normal reading position of the eyes. Provision has been made for adjusting the test lenses to the correct interpupillary distance, and for convergence at short distances.

The eikonic target and the procedure in the test for aniseikonia can best be described together. This test, which may be referred to as the eikonic test, is made after a careful refractive examination has been made and after the corrective trial lenses, if any are needed, have been placed in the instrument.

The subject, whose head is adjusted to the instrument, directs his attention to a target (the so-called eikonic target) with which the size

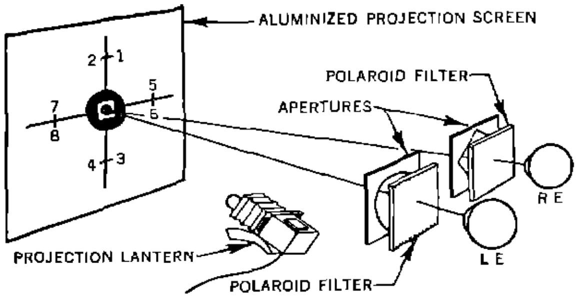

Figure 5—The Eikonometer

differences are detected In the distance test the target detail is projected on an aluminized screen, in the near test it is a transparency mounted in a frame attached to the Eikonometer

The pattern of the target consists of a central configuration specially designed to stimulate fusion At an angular distance of 4° from the center, four pairs of numbered opposing arrows are located in the vertical and horizontal meridians By means of polaroid film, the light coming from the odd numbered arrows is polarized in one direction, that from the even numbered arrows in the direction at right angles Correspondingly oriented polaroid plates are placed before the eyes so that the subject will see the odd numbered arrows with one eye, the even numbered arrows with the other

The reason for this ingenious arrangement is this If both eyes could see only one pattern the subject would be unable to detect possible size differences between the two ocular images On the other hand, if the pattern seen by one eye were totally unlike that seen by the other, the eyes, lacking a fusional stimulus, would respond to their phoria, in which case judgment of size differences would also be impossible It is necessary, therefore, to include in the eikonic target a part of the pattern which both eyes see simultaneously This part is the fusion center

In order to prevent the fusion of objects in the peripheral field, the view for each eye is restricted to the target by unlike apertures The image size differences are measured by having the subject compare the distances between opposing arrows as seen by the two eyes while fusion is maintained for the center of the target Thus, if all odd numbered arrows are seen outside of the even numbered arrows, an over-all size difference is indicated If the odd numbered arrows are outside the even numbered arrows in only one meridian either the horizontal or the vertical, while those in the other meridian are aligned, a meridional size difference is indicated

There is no aniseikonia if all pairs of arrows are seen in alignment In principle, therefore, the amount of an existing size difference can be measured by adjustment of the magnifications of the adjustable size lens units until the subject reports that all the odd and even numbered opposing arrows are seen in alignment In actual practice, however, the measurement of aniseikonia usually requires the determination of the limits of known size differences introduced by the adjustable size lenses within which the subject reports equality of the two images The aniseikonia is ascertained from the mid-points of these limits

First, a record is made of the apparent positions of the arrows of the target with the four sets of lenses in position and adjusted to zero Then the right over-all lens system is increased for an amount sufficient to cause a report that the right image is greater in both horizontal and vertical meridians The right over-all combination is now reduced until an equality is reported in either the vertical or horizontal meridian The right image is further reduced by changing the meridional and over-all combinations by quarter percent steps until equality is reported for both horizontal and vertical meridians They may necessitate a reduction or an increase in either meridians as the examination proceeds All lenses are then returned to zero and a second normal determination is made An increase in the over-all size of the left eye is now made for an amount equal to that of the change made in the right eye or until a report is given that the right image is smaller in both

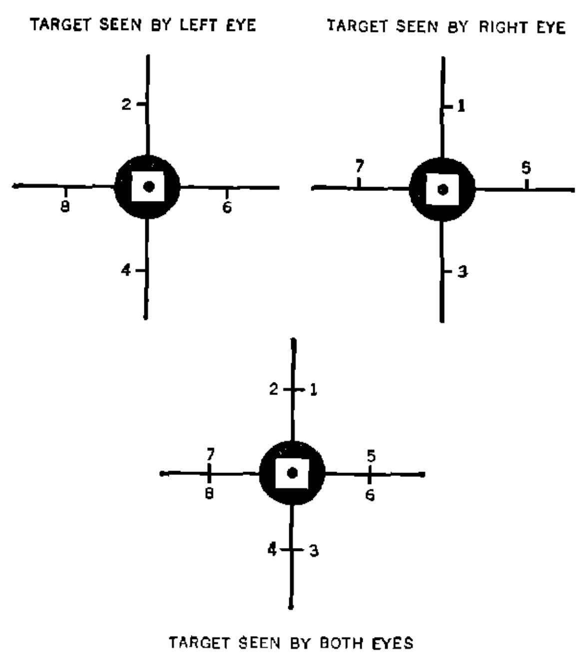

Figure 6—The Eikonometer target

vertical and horizontal meridians The over-all is now reduced by one-quarter percent steps until an equality is reported in either the vertical or horizontal meridian The left image is then reduced in its magnification with combinations of meridional and over-all correction by one-fourth percent steps until equality is reported in both the vertical and horizontal meridians It may be necessary to repeat this process in order to be certain of the subject's response

The responses to the various artificial size differences introduced by the lenses are recorded on a special graph sheet From the charting of the responses the following are determined

(1) The range within which size changes are not noticeable (This is the so-called "size-amplitude ")

(2) The Eikonometer finding, which will be the mid-points of the horizontal and vertical equalities

(3) An estimate of the sensitivity of the subject which will be subject to the judgment of the operator and will be in the neighborhood of one-half the range of the equality

A question is raised as to significant size differences in the data obtained at Pensacola If the given size difference is small, and less than the sensitivity, the measurement might be called significant, e g, $\frac{1}{4}$ percent $\pm\frac{1}{8}$ percent If the sensitivity is large enough to include the zero and the measured size difference, the measurement would not be significant, e g, $\frac{1}{4}$ percent $\pm\frac{1}{2}$ percent In the graph given, this consideration was not taken into account Correcting the distribution on the basis of this significance increases the sharpness of the accumulative frequency curve, since a greater percentage is included in the "no size difference" group

THE LEAF ROOM TEST

A Subjective, Three-dimensional, Functional Test for Ascertaining the Presence of Faulty Space Localization

This test involves the determination of the correctness of a subject's spatial interpretation as indicated by the positions and form in which he sees the walls, ceiling and floor of a special room This room is a rectangular box, open at one end, 7 feet high, 7 feet wide, and 8 feet deep The walls are vertical and the floor and the ceiling are level The subject views the room from the center of the open end The inside surfaces are covered with preserved oak leaves which provide adequate contours and yet do not introduce strong perspective features

Persons with normal space perception will see the room in its true rectangular form Those with abnormal space perception will see it distorted, the nature of the distortion depending upon the nature of the anomalous incongruities between the ocular images A large percentage of an unselected group of persons who have been tested in the room see some distortion

In general, the test consists in ascertaining by questioning the subject (1) Whether or not the room appears in any way distorted (2) If so, the nature of the distortion Often with persons with marked anomalous spatial sense, both the nature and a rough estimate of the magnitude of the distortion can be obtained But many other cases with incongruity of ocular images see little or no distortion because they have learned to suppress their false binocular visual clues and rely on monocular visual clues for their spatial orientation To determine the binocular spatial interpretation of such persons, artificial anomalous incongruities are introduced by means of various size lenses and the nature of the resulting space distortion is determined by questioning If the response to the various size lenses is normal, it indicates that the subject's spatial sense is normal, if not, that it is defective

It often happens that a subject, when first looking into the room, will see it in its correct form At the end of the test when he has been through the various tests with size lenses, he will see it distorted The nature of the distorted form in which a subject may see the room varies with the nature of the anomalous ocular incongruity

There are at least five different types of systematic anomalous ocular incongruities

1 Difference in size in the horizontal meridian
2 Difference in size in the vertical meridian
3 Cyclo incongruities
4 Differences in asymmetric size
5 Difference in size over-all

There may be combinations of the above

The distortions of a rectangular room resulting from each of the above anomalous incongruities are described in the following

I Differences in size in the horizontal meridian

If the horizontal meridian of the ocular image of the right eye is larger than that of the left, a rectilinear room appears with the following characteristic distortions

1 The left-hand wall appears nearer than it actually is, the right-hand wall farther
2 The left-hand wall appears smaller than it actually is, the right wall larger

3 The leaves on the left-hand wall appear smaller than they actually are, those on the right, larger
4 The stereoscopic relief of the leaves on the left-hand wall appears less than it actually is, that on the right, greater
5 The vertical line at the corner where the left-hand and back walls join appears shorter
6 The back wall appears to recede to the right
7 The floor appears to be inclined down to the right
8 The ceiling appears to be inclined up to the right

If the horizontal meridian of the left eye is larger than that of the right, all these appearances are reversed right and left

The magnitude of these distortions within limits varies with the amount of difference between the horizontal meridians of the two ocular images and the size of the room In a room 7′ x 7′ x 8′, the distortion due to a difference of 25 percent is usually perceptible

The foregoing description applies when the room is looked at as a whole Slightly different impressions may result if particular surfaces are observed to the exclusion of the rest of the room

The following questions, to be asked of the subject, taken in order, have proved helpful in obtaining as quickly as possible the desired information regarding horizontal size differences

1 "Is the right vertical line at the corner where the back wall joins the right side wall longer or shorter than the corresponding line on the left and how much?"

Differences will often be noticed when no tipping of the back wall is apparent A reply that the right line is longer will indicate that the right ocular image is larger in the horizontal meridian

2 "Is the floor perfectly horizontal (level) or does it tip, and if so, which way and how much?"

If he says down to the right that observation will check with his observation that the right vertical line on the back wall is longer than the left The slant of the ceiling should then be checked with the question

3 "Is the ceiling perfectly horizontal or does it tip, and if so, which way and how much?"

4 After having been asked to look at first one side wall and then the other he should be questioned as to the apparent distance of the side walls as follows

"Does the side wall on the right appear to be at the same distance as that on the left? If not, which one appears nearer and which farther away and how much?"

5 He should then be asked as to the apparent size of the leaves on the two side walls

"Do the leaves on the side wall to the right appear to be the same size as those on the left? If not, which appear larger and which smaller and how much?"

Certain subjects have difficulty in forming a judgment in answer to this and the previous question Their stereoscopic clues tell them one wall is nearer and the other farther, but because the leaves on the nearer wall appear smaller they may be interpreted as being farther away, and because those on the more distant wall appear larger they may be interpreted as being nearer These conflicting clues may cause confusion, especially to those subjects whose stereoscopic vision is not good

6 He should then be asked as to the relative size of the right and left walls as a whole

"Do the right and left walls as a whole appear to be of the same size? If not, which appears larger and which smaller and how much?"

7 He should further be asked as to the position of the back wall

"Does the back wall appear tipped? If so, does the right or left side appear nearer?"

Many subjects will fail to notice this appearance

With most subjects the answers given to these questions will confirm one another When all the answers confirm each other it leaves no doubt as to the nature of the anomalous spatial sense Even if only two or more of the answers confirm each other, there is evidence that his spatial sense is not normal in this particular and that the subject not only has a particular type of anomalous ocular incongruity that is associated with such appearances, but also that there are present other types of anomalous incongruities combined with it which may mask or contradict the expected appearances, as will be described later

The foregoing procedure will disclose whether the subject sees the room as it is or distorted In either case the next step is to check his spatial response with a weak meridional size lens axis 90°, first before the right eye and then the left If he responds sensitively, i e, if a 0 25 percent lens causes an evident distortion and if the amount of the distortion is the same with the lens in one eye as in the other, it is evident that his space sense is normal in the horizontal meridian If, however, weak lenses do not cause a distortion or if they produce a greater distortion when placed before one eye than they do when placed before the other, it is evident that his space sense is defective If, with the lens before one eye, he still gets a distortion in the opposite direction the power of the lens should be increased, first, until the distorted appearance is just corrected, and second, until an apparent distortion is noticed in the direction called for by the lens The power of these lenses will indicate the magnitude of his defect

It is also advisable to check all subjects at the end of such an examination with plano lenses in the frames Often subjects who see no distortion at the beginning of the examination will notice it at the end

II Differences in Size of the Vertical Meridian

Differences in the relative size of the ocular images in the vertical meridians produce the same types of distortion of the room as result from differences in the horizontal meridians but in the opposite direction If, for instance, the ocular image from the right eye is larger than that from the left in the vertical meridian, the distortions will be the same as if the ocular image from the left eye were larger in the horizontal meridian

As a result, the distorted appearance of the room that a subject may report without any size lenses before his eyes gives no indication as to whether it is due to the fact that one eye is larger in the horizontal meridian or that the other is larger in the vertical meridian

This fact, however, can be determined by the subject's response to size lenses Sensitivity to, and equal response to weak meridional size lenses that increase the ocular images in the horizontal meridians, but not to those that increase the images in the vertical meridians, indicate that the apparent distortions are due to differences in the vertical meridians and vice versa

III Cyclo Incongruities

Cyclo incongruities result from an anomalous cyclo relationship of the two eyes or anomalous declinations of the vertical and horizontal meridians Their presence causes marked distortion of the leaf room If there exists, for instance, a cyclo incongruity such as would be present if the eyes were in an abnormal excyclo position, a room would appear distorted as follows

1 The ceiling appears nearer that it actually is, the floor farther away
2 The ceiling appears smaller that it actually is, the floor larger
3 The leaves on the ceiling appear smaller than they actually are, those on the floor appear larger
4 The stereoscopic relief of the leaves on the ceiling appears less than it actually is, that on the floor greater
5 The horizontal line where the ceiling and back walls join appears shorter than it actually is, the horizontal line where the back wall and floor join appears longer
6 The back wall appears to tip forward at the top
7 The right wall appears to slant to the left at the top
8 The left wall appears to slant to the right at the top

The magnitude of these distortions varies with the amount of cyclo incongruity and the size of the room

If the cyclo incongruity is in the direction opposite to that described above, the apparent distortions of the room are reversed

While the above description applies when the room is looked at as a whole, slightly different impressions may result if attention is given to particular surfaces to the exclusion of the rest of the room

Again, by a series of questions the examiner can recognize the presence of cyclo incongruities Suggestive questions must be avoided

When all the answers supplement each other, there is no doubt as to the nature and cause of the anomalous spatial sense As stated above, even if only two or more of the answers supplement each other, this fact indicates that the subject's spatial sense is not normal in this particular and would strongly indicate that he is subject not only to the type of anomalous ocular incongruity that is associated with such appearances, but also to other anomalous incongruities which may simply combine to give a total effect, or which may mask or contradict the expected appearances as will be described later

Whether or not the subject sees the room distorted, his spatial response in this particular should be checked with size lenses that introduce artificial cyclo incongruities The lenses used are ¾ percent meridional size lenses placed first at 45° R E and 135° L E (axes converging upward) and then 135° R E and 45° L E (axes converging downward)

If these lenses distort the room equally in opposite directions it is evident that the subject's cyclo incongruities are normal However, a greater distortion in one case than in the other shows that the subject's cyclo incongruities are abnormal If, with the above lenses in either eye, the distortion of the room does not reverse, the magnification of the size lenses would be increased The strength of the lenses necessary to produce this reversal indicates the magnitude of the subject's abnormal incongruity

IV Asymmetric Incongruity

This term is used to describe the incongruity between the two ocular images (a) Where both images are progressively larger on the temporal sides and progressively smaller on the nasal sides, and (b) where both images are progressively smaller on the temporal sides and progressively larger on the nasal sides

Asymmetry of this kind can be artificially introduced by placing flat prisms base-out and base-in before the two eyes, the base-in prisms introducing so-called positive asymmetry, base-out prisms introducing so-called negative asymmetry The presence of negative asymmetric incongruity causes a room to appear distorted

1 The back wall appears farther away
2 The back wall as a whole appears larger than the open end
3 The leaves on the back wall appear larger and stand out from the wall
4 The side walls and floor and ceiling slant in toward the subject, the floor near the subject slanting up, the ceiling near the subject sloping down, and both side walls near the subject sloping in

Positive asymmetry causes the room to appear distorted

1 The back wall appears nearer
2 The back wall as a whole appears smaller than the open side
3 The leaves on the back wall appear smaller and pressed against the wall
4 The side walls and floor and ceiling slant out, toward the subject, the floor near the subject sloping down, the ceiling near the subject sloping up and both side walls near the subject slanting out

After the subject's responses have been determined, without size lenses through a series of questions his reactions should be obtained with plus and minus asymmetry lenses of weak power One degree prisms base-in and base-out, whose prism power has been neutralized by 1 degree prisms on 9 base, can be used These should be put on first with the base of the flat prisms base-out and then base-in

If the subject sees the room equally distorted in opposite directions, it indicates his asymmetrical incongruity is normal, if not, that the incongruity is abnormal

V Difference in Over-all Size

The ocular incongruities that result when the ocular image from one eye is larger than that from the other, over-all, have only a slight effect on the localization of the leaf room In general the induced effect from the difference in size in the vertical meridian counteracts the direct effect in the horizontal meridian or vice versa The ratio of the two effects depends on the amount of detail in the field of view In the leaf room where much detail is present, the effects are nearly equal, but there may be certain residual effects which may be described as follows

The right wall appears farther away and the leaves on it larger and in more relief—the left wall nearer and its leaves smaller and flatter on the wall Otherwise the room tends to appear rectilinear although there may be a tendency toward the distortion that results from an increase in the R E in the horizontal meridian There is a sense that either the room has been shifted laterally to the right or the subject to the left If the ocular image of the left eye is larger over-all, the effect is reversed

As in the case of the other types of ocular incongruities, the effect of weak over-all lenses 0 50 percent on first one eye and then the other should be tried

VI Combined Effects

Each of the types of distortions of the leaf room above described results from an anomalous incongruity of a particular type Some subjects may have only one type of incongruity In this case their diagnosis is relatively simple and the method of recognizing it is covered by one of the above descriptions But more often the subject will have two or more types of ocular incongruity In such cases the distortions of the leaf room which he will see will be a combination of the types described in the foregoing

The distortion effects are usually additive in character

In the determination of space sense anomalies in the leaf room, the following procedure should be followed

1 Determine by questioning just how the room appears to the subject without glasses, or with his refractive correction if he wears one These appearances should be marked on the "Leaf Room Data Sheet"

2 The various size lenses should be used as described, the resulting appearances also being recorded on the data sheet

3 From the indications as to the nature and amount of the subject's incongruities one or more lenses in combinations that would correct them should be placed before the subject's eyes and altered until, if possible, he is made to see the room undistorted

Where saving of time is important, as in a screening test for aviators where the purpose is not to provide a correction but to determine the normality of the space sense, the following procedure should be followed

In an anteroom, or where the subject cannot see the leaf room, a trial frame should be quickly fitted to his face with the lens rings as close to his eyes as possible to give him the largest possible field of view A ¼ percent meridional size lens axis 90° should be placed in the frame before the right eye The subject should then be taken to the leaf room and so seated and positioned that his head is at the middle of the open side

The nature of the distortion, if any, produced by the lens ¼ percent axis 90° R E should be ascertained and recorded on the Leaf Room Data Sheet—"Screening Test" by a check (√) under the headings provided

If, with the lens, he sees the room distorted in the wrong direction, the power of the lens should be increased, first, until the room appears normal for that particular type of distortion and the power of the lens recorded in the column provided, second it should be still further increased until the distortion is overcorrected and that power recorded in the column provided

A similar procedure should be followed with the other size lenses

The last step in the examination is to put plano lenses in the frames and determine the nature of the subject's space sense, recording it with one or more checks (√) in the columns provided

This determination is made last because it has been found that often if the room has been distorted in various ways by the size lenses, the subject (if he has anomalous space sense) is much less likely to compensate for it by suppressing his binocular responses

THE FRONTAL PLANE APPARATUS

A Semifunctional Test

The third test involves the determination of the subject's spatial response as indicated by the position in which he localizes an object plane normal to his line of sight The quantitative determination of where he localizes the object plane is given by the amount he must tip it to cause it to appear in his frontal plane

The Frontal Plane Apparatus was designed to give data from which indications of the presence of each of the five types of anomalous incongruities mentioned above, could be found.

The apparatus consists of four wooden tracks (designated as lanes) which converge to the mid-point of the interpupillary base line of the observer At a distance of three meters from the observer, a central rod (¼-inch diameter) is mounted in a vertical position This serves as the central fixation rod in the median plane of the observer On each of the tracks, there are riders free to slide along the tracks and controlled by the observer by means of cords On each rider a vertical rod is mounted A vertical screen with rectangular opening restricts the visual field to the rods, and prevents both the tops of the rods and the riders from being seen Behind the rods a suitable background is provided Both screen and background are painted white and are uniformly illuminated to the same brightness (20 apparent foot-candles) All rods are painted black

On each of the rods three black spherical spools are attached, which are irregularly spaced on the five rods The addition of these spools theoretically introduces empirical factors and may prevent one from obtaining a true longitudinal apparent fronto-parallel plane The spools are added, however, to provide vertical contours so that the induced effect can take place This effect probably is aided also by the contour of the opening in the screen and other details on this particular apparatus

The positions of the rods on the tracks are indicated upon suitable scales The units on these indicate the percentage of difference in the sizes of the angles (specifically the tangents of the angles) subtended at the two eyes by the central rod and any other rod in a given position The particular scales on this apparatus were calculated for an interpupillary distance of 64 millimeters

This method for recording the positions of the rods in their respective lanes is most useful and productive When the angles to the two eyes subtended by a given rod are equal, the rod lies on the so-called Vieth-Muller circle (a circle passing through the central rod and the entrance pupils of the two eyes) The percent value for these positions on all the scales is "zero" The percent values are positive or negative depending upon whether the angles subtended by the right eye are greater than those subtended by the left eye Positive values indicate that the angles are larger in the right eye If the average of the values for all the rods when adjusted for a given criterion is positive, the average of the angles subtended by the right eye is larger than that of the left, but the ocular image of the *left* eye is effectively *larger* than that of the right eye in the horizontal meridian When the rods have been adjusted for an apparent fronto-parallel plane and the positions of the rods recorded, the data should be plotted in the same manner as horopter data The abscissa represent the lane angle and the ordinate the scale reading Under favorable conditions these points should lie on a straight line The intercept of this line on the ordinate axis gives the average effective percentage difference in size of the ocular images in the horizontal meridian for the fronto-parallel plane criterion If the intercept is above the origin, the left eye image is effectively larger than the image of the right eye, if below, vice versa If the rods are set in a rotated position such that the left rods are nearer the observer, the right farther from the observer, the intercept of the line will be positive, that is, above the origin

The slope of the line which best describes the points representing the data on the graph is a measure of the departure of the apparent frontal plane from the so-called Vieth–Muller circle or equivalent in the case that the apparent frontal plane is skew The departure from the V–M condition has been designated as the Hering–Hillebrand deviation The slope of the line on the graph, then, is a measure of the Hering-Hillebrand deviation and is designated by H If the slope is zero the curvature of the apparent fronto-parallel plane as determined by the settings satisfies the V–M condition

When $H=0$ data lie on Vieth-Muller circle
- $H=1$ data lie on fronto-parallel plane
- $H>1$ data lie behind fronto-parallel plane
- $H<1$ data lie inside fronto-parallel plane
- $H<0$ data lie inside Vieth-Muller circle

The method for determining the slope (therefore H) of line on graph which best fits the data is that of least squares

A phorometer head and adjustable chin cup is mounted on the table to support the head of the observer On the phorometer head there are two pairs of rings which can be swung into place before the right or left eye of the observer There is one pair of fixed rings which supports apertures beyond the two just mentioned These apertures restrict the visual field approximately to the opening in the screen of the apparatus Beyond these rings, in a Steven's front, are special size lenses the use of which will be described below In the pair of rings nearest the eyes are 1 percent meridional size lenses mounted at axis 90° When one of these is interposed before one eye, the rods should appear displaced in accordance with the geometrical effect In the second pair of rings 2 percent meridional size lenses are mounted at axis 180° When one of these is interposed before one eye, the rods should appear displaced in accordance with the induced size effect

Cyclo-Declination Test

In front of the screen of the apparatus, a special unit for testing the cyclo declinations of the eyes is mounted This unit consists of two separated horizontal slats of wood with axis in the median plane of the observer The upper slat is suspended from above in a fixed position The lower slat is supported on a rider which slides along a wooden track also in the median plane The rider can be controlled by the observer by means of a cord A long removable rod is suspended in holes at the front ends of the two slats, being free to swing on an axis in the upper slat The slats and rod are painted black, the supports white When the rider is moved along the track, the lower slat moves nearer or farther than the position of the upper slat, carrying the rod along with it The inclination of the rod in the median plane is thus changed with the movement of the rider A scale on the track indicates the angular (degrees) inclination of the rod from the vertical position, the angle being positive when the top of the rod is away from the observer The subject is asked to set the rod until it appears vertical, and the ends of the slats are the same distance. A shutter on the back of the screen is lowered to cover the rods of the horopter apparatus during this test

The unit in front of the phorometer head, a "Steven's front," has two meridional size lenses (¾ percent) When the handle is turned, the two lenses turn about their optical axes in opposite directions Stops on these indicate when the axes are in position (1) R E axis 45°, L E axis 135° (axes converging upward) or (2) R E axis 135°, L E axis 45° (axes converging downward) These meridional size lenses, when at oblique axes, introduce a rotation of the image of vertical objects about the optical axis of about 0 2°, thus altering the apparent declinations of the eyes

The test procedure is as follows First the subject is instructed to adjust the four movable vertical rods so that they all appear at the same distance as the fixed vertical rod It is believed that in general one setting gives sufficiently accurate results The subject may set the rods approximately normal to his median plane, or he may set them at an inclination to his median plane and in a convex or concave curve

The first type of setting indicates that the subject sees his frontal plane oriented where it actually is In the second case he does not If the rods, after setting, are in a tipped curve, or the curve is too convex or too concave, the subject does not see his frontal plane oriented where it actually is

The false spatial localization indicated by a tipped setting may be due to anomalous ocular incongruities of three types

1 Difference in size of the ocular images in the horizontal meridian
2 Difference in size of the ocular images in the vertical meridian
3 Difference in size of the ocular images over-all

The false spatial localization indicated by a setting in which the rods are in a curve too convex or concave, is due to anomalous asymmetric ocular incongruities in the horizontal meridian

But even though the subject sets the rods approximately normal to the median plane, this fact is not conclusive evidence that his spatial response is normal Such an apparent normal setting may be due to particular combinations of horizontal, vertical, or over-all differences in the ocular images or to conditioned compensations to such differences

To determine whether or not this is the case, a further procedure is necessary This consists in placing before the subject's eyes certain size lenses that artificially introduce the characteristic differences in the ocular images The lenses considered suitable for this apparatus are those which introduce (1) a 1 percent difference in the horizontal meridians, (2) a 2 percent difference in the vertical meridian only, (3) a 2 percent difference over-all, and (4) a positive and negative amount of asymmetrical incongruity in the horizontal meridian

With a subject having normal spatial localization these lenses will cause the apparent frontal plane as indicated by the positions of the rods to appear tipped or curved in definite positions If, however, the subject has anomalous ocular incongruities he will not respond symmetrically or quantitatively to the differences introduced by these various lenses and the position of the rods for his apparent frontal plane will not change as it should The nature of the response indicates the nature of the anomalous ocular incongruity When size lenses that increase the horizontal meridian of the ocular images are placed before first one eye and then the other and the expected magnitude of tipping does not take place or if the response differs, depending upon whether the lens is before the right or left eye, one has evidence that correspondence in the horizontal meridians of the ocular images may be abnormal If the expected tipping does not take place when the horizontal meridian is increased in one eye, it is evident that the ocular image of that eye is too large in that meridian Similar conclusions can be drawn from lack of response in the positioning of the rods when the size lenses that introduce the other types of incongruities above mentioned are used

A similar procedure is followed in determining the subject's spatial localization of the apparent vertical in a sagittal sense Such would be related to his cyclo image incongruity or the declinations of the two eyes In front of the apparent frontal plane rods is a long vertical rod than can be tipped about a horizontal axis perpendicular to the median plane The subject is asked to set it apparently vertical A substantially vertical setting would indicate that his sense of the vertical and the cyclo rotation incongruity of the ocular images was normal, if the rod is set inclined, they were abnormal To obtain confirmatory data, the subject is asked to set the rod apparently vertical when lenses that introduce about one-half degree of excyclo and incyclo change in the declinations between the two ocular images are put before the subject's eyes The lack of response or unbalanced response indicates the nature and degree of the anomaly

From this procedure a table of data will be obtained on each subject These data are plotted on the form attached Any variation of the curves in these graphs from the normal will indicate defects in visual localization

The nature and magnitude of defects which a person might show when tested and still be acceptable for training as an aviator can be determined only after such data have been obtained on a large number of flying cadets, to determine the maximum of the defects shown by those who later become good pilots

APPENDIX III

Distribution of So-Called "Size Amplitudes" in the Eikonometer Measurements for the Kansas City and Pensacola Subjects

As pointed out in Appendix I, the procedure in measuring aniseikonia in any meridian must employ "the method of limits", as similarly required in the measurement of other psychophysical quantities The examiner increases the magnification of the image of one eye until he knows from the subject's reports that he sees the image in that eye larger The magnification is then decreased until the subject sees the image in that eye smaller The process is repeated for the other eye, if necessary, to define the limits The interval or range of the artificial image size differences introduced, within which the subject reports equality of the images, is designated at present as a "size amplitude" One-half the "size amplitude" is considered a measure of the sensitivity of the subject to respond to artificial size differences.

Only the distributions of the "size amplitudes" for the Kansas City and Pensacola subjects will be given here Suffice it to state that in the clinical division of the Dartmouth Eye Institute, these amplitudes are seldom under ¼ percent and average about ¾ percent to 1 percent

APPENDIX IV

Distribution of Ages and the Opthalmological Data on the Air Carrier Pilots and the Navy Subjects

The Eikonometer data obtained from the aviators measured showed that considerably less aniseikonia exists in the Navy subjects (280) than in the air carrier pilot subjects (36) In an attempt to determine what factors, of those measured, might account for the difference, visual comparisons can be made between the distributions of the following for which tables and graphs have been prepared

1 Ages —There is, of course, a striking difference in the age ranges of the two groups The Kansas City airline group varies in age from 24 to 45 years with a mode of about 33 years The Pensacola Navy group varies from 20 to 28 years with a mode of about 23 years It is difficult to account for the difference in aniseikonia simply on difference of age range alone, unless there is some concomitant factor between age and incidence of aniseikonia (See fig 7)

2 Visual Acuity —It is believed that both groups have essentially the same visual acuity It must be kept in mind that the scale for differentiating between degrees of visual acuity when that acuity is high is quite inaccurate That is, the significance of the difference between 20/15+20/20− is not precise If the acuity ratings are brought to the nearest whole clinical unit, that is 20/20, 20/15, 20/10, etc, all differences between the Kansas City and Pensacola groups disappear If the data are assumed to be valid, however, the Pensacola group as a whole has slightly better acuity because none of this group had visual acuity less than 20/20 (See fig 8)

3 Refractive Errors —The refractive error distributions of both groups, when regarded without consideration of the sign of the error, are apparently alike When the sign of the error is regarded it will be noticed that in the Kansas City group there is an approximately equal distribution of myopia and hypermetropia, and that in the Pensacola group very little myopia is found This difference may be due to the method of examination since the refractive conditions of the Pensacola group were determined under a cycloplegic by retinoscopic methods using plus spheres only, whereas the Kansas City group was examined without cycloplegics and with plus and minus spheres and minus cylinders It would not seem that the differences in this refraction between the two groups could account for the aniseikonic differences (See figs 9 and 10)

4 Axial Stereoscopic Sensitivity —(Howard-Dolman test) The distributions for the axial stereoscopic depth perception sensitivity indicate that the Pensacola group was less sensitive than the Kansas City group It is questionable, however, whether this difference is significant because it appears that the technique of examination used on the two groups was not precisely the same (See fig 11)

5 Phoria —The distribution curves for the horizontal (fig 12) and vertical (fig 13) phorias for the two groups are not greatly different though there is a suggestion that the Kansas City group showed slightly smaller phorias It is believed this could not explain the difference in the aniseikonic measurements

It would appear that none of the ophthalmological factors could explain the difference in the incidence of aniseikonia found in the two groups The age differences cannot be easily given as an explanation It has been suggested that precision of the Eikonometer measurements was increased between the Kansas City and the Pensacola tests This would be borne out by the smaller, so-called "size amplitudes" found in the Pensacola Eikonometer tests (Appendix III) However, this alone could not entirely explain the aniseikonic differences found, since the centers of the amplitudes (which define the aniseikonia present) would not be displaced appreciably when the amplitudes were increased in width

TABLE II—*Distribution of Ages and Ophthalmological Data*

(1) AGES

Age	Pensacola Frequency	Pensacola Cumulative	Kansas City Frequency	Kansas City Cumulative
20	5.5	5.5		
21	10.2	15.7		
22	17.3	33.0		
23	23.1	56.1		
24	15.7	71.8		
25	12.2	84.0	2.8	2.8
26	11.7	95.7	2.8	5.6
27	2.3	98.0		
28	2.0	100.0	2.8	8.4
29			13.9	22.3
30			2.8	25.1
31			5.6	30.7
32			11.1	41.8
33			5.6	47.4
34			19.4	66.8
35			5.6	72.4
36				
37			8.3	80.7
38			2.8	83.5
39			2.8	86.3
40			2.8	89.1
40–50			11.1	100.0

(2) VISUAL ACUITY—LOWEST IN EITHER EYE

Snellen units	Pensacola Frequency	Pensacola Cumulative	Kansas City Frequency	Kansas City Cumulative
20/15+	0.7	0.7		
20/15	35.8	36.5	42.5	42.5
20/15−	12.8	49.3	2.5	45.0
20/20+	27.6	76.9	5.0	50.0
20/20	22.6	99.5	35.0	85.0
20/20−	.4	99.9	5.0	90.0
20/25+				
20/25			2.5	92.5
20/25−				
20/30+			2.5	95.0
20/30			5.0	100.0

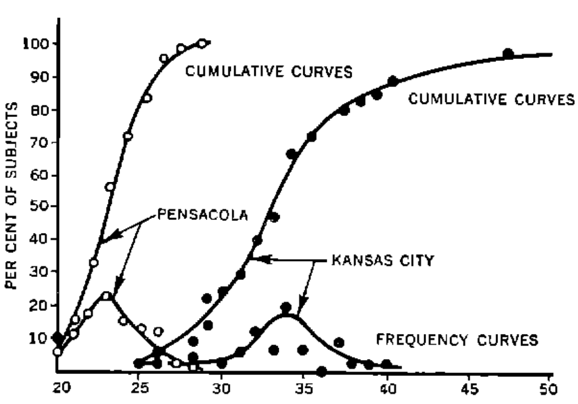

Figure 7—**Distribution of ages on the Pensacola and Kansas City subjects**

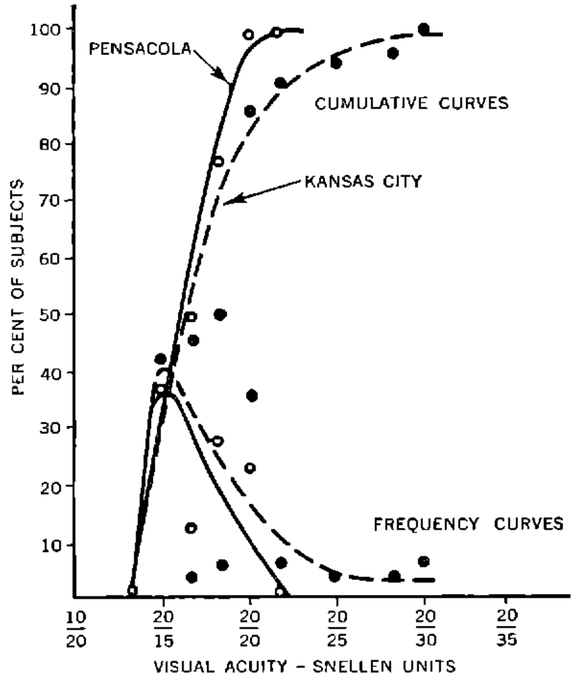

Figure 8—**Distributions of visual acuity**

TABLE III—*Refractive Error*

MAXIMUM MERIDIONAL ERROR OF EITHER EYE

(a) Signs Considered

Refractive error diopters	Pensacola Frequency	Pensacola Cumulative	Kansas City Frequency	Kansas City Cumulative
−2.50			2.5	2.5
−2.00				
−1.75				
−1.50			2.5	5.0
−1.25			5.0	10.0
−1.00			2.5	12.5
−0.75	0.8	0.8	5.0	17.5
−0.50	.8	1.6	12.5	30.0
−0.25	2.5	4.1	10.0	40.0
0.00	29.1	33.2	20.0	60.0
+0.25	15.2	48.4	10.0	70.0
+0.50	18.5	66.9	12.5	82.5
+0.75	14.4	81.3	5.0	87.5
+1.00	9.0	90.3	5.0	92.5
+1.25	2.9	93.2	2.5	95.0
+1.50	4.1	97.3		
+1.75	2.0	99.3		
+2.00	.4	99.7		
+2.25	.4	100.1	2.5	97.5
+7.00			2.5	100.0

(b) Signs Ignored

Refractive error diopters	Pensacola Frequency	Pensacola Cumulative	Kansas City Frequency	Kansas City Cumulative
0.00	29.1	29.1	20.0	20.0
0.25	17.6	46.7	20.0	40.0
0.50	19.3	66.0	25.0	65.0
0.75	15.2	81.2	10.0	75.0
1.00	9.0	90.2	7.5	82.5
1.25	2.9	93.1	7.5	90.0
1.50	4.1	97.2	2.5	92.5
1.75	2.0	99.2		
2.00	.4	99.6		
2.25	.4	100.0	2.5	95.0
2.50			2.5	97.5
7.00			2.5	100.0

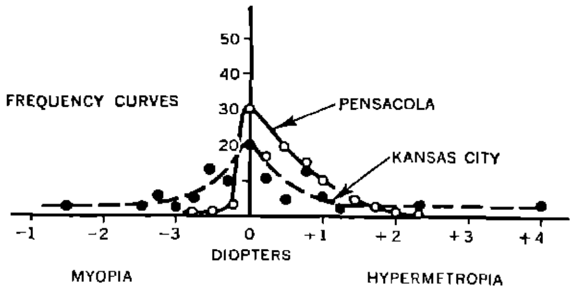

Figure 9.—Distributions of maximum refractive error

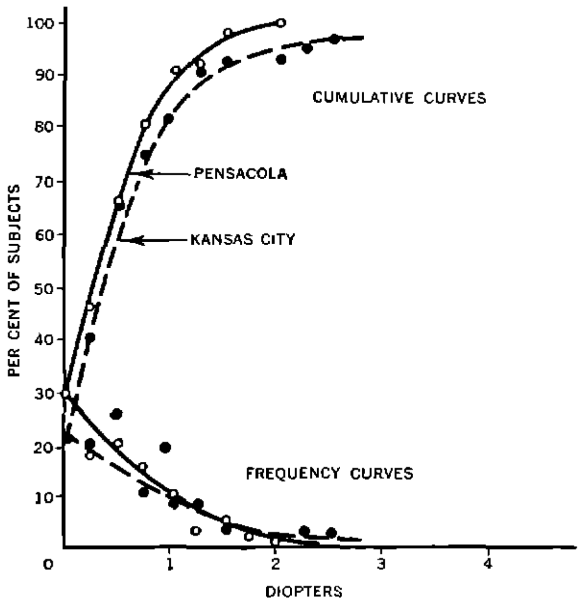

Figure 10.—Distributions of maximum refractive error without regard to sign

TABLE IV.—*Axial Stereoscopic Sensitivity*
(Howard Dolman Test)

Mms at 6 M	Pensacola		Kansas City	
	Frequency	Cumulative	Frequency	Cumulative
1	0.8	0.8		
2	1.2	2.0		
3	.8	2.8		
4	2.4	5.2	8.1	8.1
5	7.1	12.3	8.1	16.2
6	5.1	17.4	2.7	18.9
7	4.7	22.1	10.8	29.7
8	9.5	31.6	27.1	56.8
9	2.0	33.6	10.8	67.6
10	9.8	43.4	2.7	70.3
11	3.1	46.5	5.4	75.7
12	10.6	57.1	5.4	81.1
13	1.6	58.7		
14	10.2	68.9		
15	8.3	77.2	8.1	89.2
16	5.9	83.1	5.4	94.6
17	2.0	85.1	2.7	97.3
18	5.6	90.7		
19	.8	91.5		
20	4.0	95.5		
21				
22	2.0	97.5		
23	.8	98.3		
24	.8	99.1		
25	.4	99.5	2.7	100.0

TABLE V.—*Phoria*

PHORIA (DISTANCE=6 M)

(a) Horizontal

Prism diopters	Pensacola		Kansas City	
	Frequency	Cumulative	Frequency	Cumulative
0.00	32.0	32.0	25.0	25.0
0.25			7.5	32.5
0.50	1.5	33.5	20.0	52.5
0.75			2.5	55.0
1.00	25.0	58.5	27.5	82.5
1.50	.8	59.3		
2.00	23.4	82.7	7.5	90.0
2.50				
3.00	8.2	90.9	7.5	97.5
3.50				
4.00	5.9	96.8		
4.50				
5.00	.8	97.6		
5.50				
6.00	2.0	99.6		
8.00	.4	100.0		
10.00			2.5	100.0

(b) Vertical

Prism diopters	Pensacola		Kansas City	
	Frequency	Cumulative	Frequency	Cumulative
0.00	42.0	42.0	70.0	70.0
0.25	37.1	79.1	17.5	87.5
0.50	19.1	98.2	5.0	92.5
0.75	.8	100.0	2.5	95.0
1.00			2.5	97.5
5.00			2.5	100.0

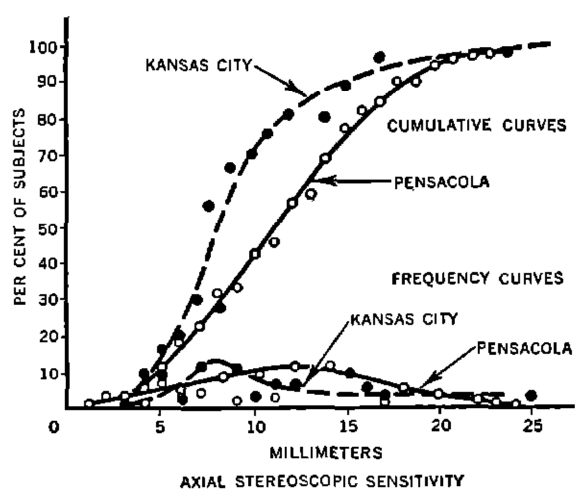

Figure 11.—Distribution of average axial stereoscopic *sensitivity (6 meters)*

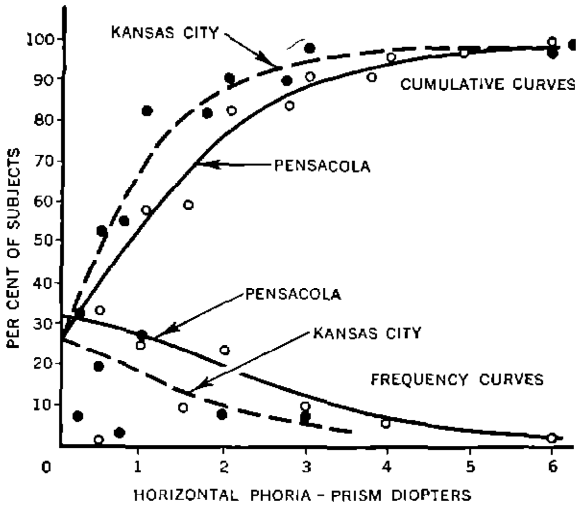

Figure 12—Distribution of horizontal phoria

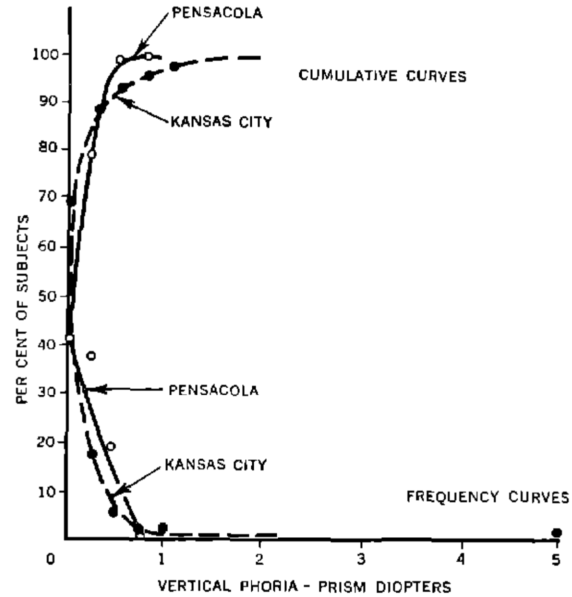

Figure 13—Distribution of vertical phoria

APPENDIX V

Treatment of Data From the Leaf Room and the Frontal Plane Apparatus

Leaf Room

Because of the subjective nature of the Leaf Room test, the only approach to a statistical analysis is by use of an ordinal scoring method There are three parts to this test, and each part must have a different scoring method The methods were agreed upon and are probably satisfactory and descriptive, but obviously are not the only ones that might be devised

Methods of scoring the three parts of the Leaf Room Test

1 The apparent distortion of room with "plano" lenses
  0—no distortion
  1—some distortion
  2—large distortion
  3—more than one type of distortion
2 Response to size lenses, before one or the other eye
  0—equal distortion
  1—unequal distortion
  2—no distortion in one eye
  3—reverse distortion
  4—no distortion in either eye
3 Size correction necessary to remove apparent distortion
  2—1/8 percent to 1/4 percent to correct distortion
  4—3/8 percent to 1/2 percent
  6—5/8 percent to 3/4 percent
  8—7/8 percent to 1 percent

Clearly these scores are not additive and each part of the test must be considered separately Figure 3 (A) of the report is a histogram illustrating the frequency of the four scores for the Pensacola subjects, for the apparent distortion of room when "plano" lenses were used, that is when the eyes were used normally Figure 3 (B) illustrates the frequency and cumulative frequency curves for the sensitivity of response of the Pensacola subjects to size lenses of small magnification, when placed before one eye and then the other

Frontal Plane Apparatus

The bases for ascertaining the presence of ocular incongruities on the Frontal Plane Apparatus test are

1 The initial error in the setting of the four rods, or of the "cyclo" rod
2 The unequal response or the failure to respond on the part of the subject in setting the rods so as to appear 'frontal" or all at the same distance, when a specified size lens is placed before one eye and then the other
3 The irregularities and lack of repeatability in the setting of the rods

The 12 raw scores obtained from the data from the Frontal Plane Apparatus for each subject are as follows

1 Average of the two normal intercepts
2 The average slopes of all lines, excluding the data obtained with the asymmetry lenses
3 The average scatter of the data points from the best fitting lines
4 The change in the slopes of the two lines representing the data obtained with the asymmetry lenses, from plus asymmetry to minus asymmetry
5 The mean intercept of the two lines representing the data obtained with size lenses R E x 90° and L E x 90°
6 Same for lenses R E x 180° and L E x 180°
7 Same for lenses R E Over-all and L E Over-all
8 The separation between the two lines representing the data obtained with size lenses R E x 90° and L E x 90° This value is proportional to the response to x 90° size lenses
9 Same lenses x 180° R E and L E
10 Same for lenses Over-all R E and L E
11 The "normal" deviation of the "cyclo" setting from the truly vertical
12 The sum of the response to cyclo lenses converging upward and to cyclo lenses converging downward

From the cumulative frequency curves for each of the parts of the test, three cardinal scores, 1, 2, and 3 were derived to describe the various parts of a given test The limits of the variable within which a given score was assigned, were determined as follows If the cumulative frequency curve approached a normal one it was divided into three parts as follows

1 group limits=0 percent—15 percent of the subjects
2 group limits=15 percent—85 percent of the subjects
3 group limits=85 percent—100 percent of the subjects

Depending upon which direction of X the increased proficiency was indicated, the scores 1, 2 and 3, in sequence, and 3 indicate less proficiency Sometimes the limits were slightly changed so that more nearly equal limits of the variable were obtained These limits are roughly Σ from the mean value

If the cumulative frequency curve was of the "error" type when the sign of the error was ignored (still approaching "normal"), the curve was divided into parts as follows

1—group limits=0 percent–y_1, y_1 is usually determined by the average sensitivity of the test
2—group limits=y_1 percent to y_2 percent
3—group limits=y_2 percent to 100 percent

y_2 is usually selected so that the limits of the variable in the A and B groups are nearly equal y_2 averages about 85 percent again

Each part of the Frontal Plane Apparatus was thus scored in terms of these cardinal numbers They could therefore be used for gross correlations, singly or in combination for testing associations It does not seem worthwhile in this report to go into further detail on the description of handling the data on the various parts of the test

Figure 4 of the report was drawn from the distribution of a combined score for all the parts of the test A large total score then indicates generally poor behavior in many parts of the test It is believed, however, that this total score tends to mask certain differences which might be sought, and can be used only for placing a given subject into one of three groups that describes roughly the quality of his binocular space perception

APPENDIX VI

Relationship Between Aniseikonia As Measured on the Eikonometer and Available Opthalmological Data

The nature of the data in certain parts of the ophthalmological data makes it impractical to make linear correlations on the material It is best under these circumstances to see whether a rough correlation exists before attempting to render the data capable of linear correlation A preliminary study can be made by dividing the distribution of the various measures made into 5 parts and thus making it possible to set up a contingency table of 25 squares

Accordingly, the data were divided into 5 parts with approximately 20 percent of the cases in each part No attempt was made to separate into finer groups those cases which are borderline, but these were distributed evenly about the dividing lines of the various groups

The groups for the various ophthalmological data were as follows:

1. Visual acuity
   - Group I: 20/15+ and below
   - Group II: 20/15
   - Group III: 20/15−
   - Group IV: 20/20+
   - Group V: 20/20
2. Maximum Refractive Error in Either Eye
   - Groups I and II: 0.00 D
   - Group III: 0.25 D
   - Group IV: 0.50 D
   - Group V: 0.75 D and over
3. Axial Stereoscopic Sensitivity
   - Group I: 0–6 Millimeters
   - Group II: 7–10 Millimeters
   - Group III: 11–13 Millimeters
   - Group IV: 14–15 Millimeters
   - Group V: 16 and above Millimeters

(4–a) Horizontal Phoria
- Group I: 0Δ
- Group II: ¼ and ½Δ
- Group III: 1 and 1½Δ
- Group IV: 2Δ
- Group V: Over 2Δ

(4–b) Vertical Phoria
- Groups I, II, III: 0Δ
- Group IV: ¼Δ
- Group V: Over ¼Δ

The Eikonometer data, which for this study were chosen as the maximum image size errors found in any one meridian for each subject, were divided as follows:

O. E. Data (Pensacola Only)
- Group I: 0 percent
- Groups II and III: ⅛ percent
- Group IV: ¼ percent
- Group V: ⅜ percent and over

When an effort was made to set up the tables for this contingency, it was apparent that it would be impossible to determine the index of contingency in this case because the necessarily ragged distribution could not be divided evenly into five parts. In certain cases, as for example the distribution of the maximum Eikonometer data, the 20–40 and 40–60 percent groups must be brought together in one group. For the purpose of analysis, therefore, this group has been divided by two in each case. Further inspection of the tables suggested that the essential part of the analysis can be obtained by adding the four distributions in each of the four corners of the table and setting up a fourfold table. The degree of association of these distributions can then be studied by X^2, "chi-square," treatment.

In the following the values of X^2 and the probability that the particular distribution is due to chance are given for the association between the maximum aniseikonia and the various ophthalmological data.

1. Visual Acuity	$X^2=0.1$	$P=0.75$
2. Refractive Error	$X^2=0.5$	$P=0.5$
3. Axial Stereoscopic Sensitivity	$X^2=5.8$	$P=0.014$
4. Phorias		
a. Horizontal	$X^2=0.4$	$P=0.5$
b. Vertical	$X^2=0.0$	$P=1.0$

It is clear that there is a significant association only in the case of the Axial Stereoscopic Sensitivity. This is a positive association. In the other cases, namely Refractive Error, Visual Acuity, Horizontal and Vertical Phorias, there are no significant associations.

APPENDIX VII

Comparison of Tests on the "Washout", and Instructor-Pilot Groups In An Attempt to Find Indications for Differences Between Aniseikonia, Faulty Binocular Space Perception, and Flying Performance

As pointed out in the report, whether or not the degree of aniseikonia and faulty space localization found in many of the cadets is important to their success in flying can be determined only by a careful study of the errors and the flying performance of the individual pilots. A truly satisfactory study of the correlation of the results of this investigation with flight performance of the subjects measured would be quite valuable. From such correlations a rating for prognosis of failure, difficulty in learning, and for specialization could be established. Since this cannot be done, there remains only the crude separation of the data of the instructor-pilot (37) and the true "washout" (33) groups. The unselected cadets could be used as a control group. It will not be necessary to present all the details of this separation for all the various tests on the three instruments. It is important to keep in mind in evaluating the results that both groups are *very* small, and care must be made in arriving at final conclusions.

Eikonometer

The data of the eikonometer failed to show any difference between the two groups. The fourfold tables for the vertical and horizontal meridians are

Aniseikonia	Vertical meridian		Horizontal meridian	
	Instructors	Washouts	Instructors	Washouts
<3/8%	30	26	28	24
>3/8%	7	11	4	8

Leaf Room

The leaf room data consists of three parts (1) The determination of the appearance of the room when "plano" lenses are before the eyes of the subject (2) the determination of whether the appearance of the room changes in response to certain "size lenses" before the eyes and (3) if an equal response is not found with a lens before one eye and then before the other, that lens is determined which, before the lower response, induces an equal response For this study only the first and second need be considered

The "Plano Lens" test—The data from this test were scored with ordinal numbers as follows

0—no distortion of the room
1—slight distortion of the room
2—large distortion of the room
3—more than one type of distortion of room

The tabulated percentages of subjects among the four scores are as follows

Score	Unselected cadets	Instructors	'Washouts
0	52	65	49
1	31	28	32
2	15	6	16
3	2	0	3

These are illustrated in figure 14 An inspection of the table and histogram indicates that as a group the instructor-pilots show less faulty space perception than do the "washouts" How significant this difference is will depend on tests on more subjects

The response to size lenses—The data from this part of the Leaf Room test were scored according to the lens necessary to correct distortion, as follows

2—⅛ percent to ¼ percent
4—⅜ percent to ½ percent
6—⅝ percent to ¾ percent
8—⅞ percent to 1 percent

The tabulated approximate percentages of the subjects are as follows

Score	Unselected cadets	Instructors	'Washouts"
0–2	36	50	24
3–5	47	31	62
6–8	15	19	14
9–10	2	0	0

This table would also suggest that the Instructor group showed slightly better responses to size lenses in the Leaf Room than did the "washout" group

Frontal Plane Apparatus

There are many parts to this test and the combined score of all the parts proved of little value in differentiating the instructor group from the "washout" group In Appendix V the various parts of the test are listed Of these there were slight indications of a difference between the two groups, in

(a) The total response in the rotation of the configuration of the rods in order that they appear "frontal," when an overall size lens was used before one eye and then the other

(b) The total response in the two inclinations of the "cyclo" rod, in order that it appear vertical, when meridional size lenses are placed at oblique axes before the two eyes, first, with lens axes converging down and second, with the axes converging upward

It must be borne in mind however that these results could not be tested for significance because of the small numbers in each of the two groups The above differences may be due to errors in sampling and no reliance should be placed in them at this time

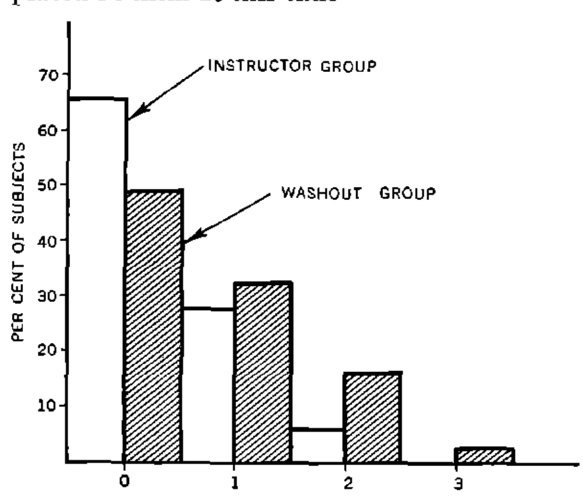

Figure 14—Distribution of faulty appearance of leaf room, of instructors and "washout" group