Reprinted from JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, Vol. 46, No. 11, 944–949, November, 1956
Printed in U. S. A.

Aircraft Flight by an Optical Periscope

CHARLES J. CAMPBELL,* LAWRENCE J. MCEACHERN,† AND ELWIN MARG‡
Aero Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio
(Received May 9, 1956)

A binocular aircraft periscope has been constructed and flight tested. The periscope provided a 70-degree true field of view at a magnification of 1× and mechanically operated azimuth and declination prisms scanned 180 degrees. Flight instruments were included in the field of view. The periscope was installed in the nose of a B-17 aircraft together with a duplicate set of controls. Twenty impartial U. S. Air Force pilots carried out most routine flight operations competently. It is concluded that flight by this type periscope is feasible even by subjects with minimal training.

INTRODUCTION

IN some designs of high performance aircraft, the problem of providing external vision has proven to be unusually difficult. As a possible solution to this problem, a periscope has been constructed. This report describes the aircraft periscope and its installation and presents the results of the flight tests.

U. S. AIR FORCE REQUIREMENTS AND THE PERISCOPE SOLUTION

The design of windshields in high performance aircraft has become increasingly difficult. On occasion, the materials themselves in addition to the design compromises have been found to be unsatisfactory. A periscope is an alternate means of providing external vision.

A periscope was installed in Lindbergh's aircraft, "Spirit of St. Louis,"[1] because the pilot's cabin was located in the rear of the fuselage behind the gasoline tanks. Thus, direct forward vision was sharply limited. It provided a view directly to the front by an angular mirror which projected from the left side of the fuselage. The mirror measured 3×5 inches, and was retractable so that it would be of no aerodynamic disadvantage. According to the designer it proved to be of some utility.

Periscopes may be classified in three groups. In the first, an image is projected on a screen and viewed from some convenient distance. An instrument of this type was mounted in a Cessna T-50 by Roscoe.[2] The square ground glass screen was located at a distance of 15 inches from the pilot's eyes, and its dimensions were variable from 2 to 4 to 8 inches. The magnification was also variable in three steps from 0.86 to 1.20 to 2.00. An instrument pattern was flown by eleven test pilots. Roscoe concluded that an image magnification of 1.29 resulted in apparent unity, and that performance increased as the screen size increased.

The second type of periscope is characterized by a viewing lens and large eye relief, an image being viewed with the eye approximately 15 to 20 inches from the lens. And in the third group, henceforth to be called ocular periscopes, an image is viewed with greatly reduced eye relief so that the eye is in close proximity to the last element. This report deals with the flight evaluation of an ocular periscope.

DETAILS OF PRESENT PERISCOPE

The periscope, illustrated in Fig. 1, was designed and constructed by the Perkin-Elmer Corporation.§ Its shape was generally box-like, fabricated mostly from aluminum plates. The external configuration departs from a long cylinder for optical considerations which will be described. The distance from the oculars to the objective, determined by aircraft dimensions, is 42 inches, and the total weight is 171 pounds. The desiccator, a separate unit, is connected to the periscope by four hoses.

The characteristics of the periscope are tabulated in Table I; Fig. 2 is a diagram of the optical system. The main part of the optical system comprises two telescopes separated by a power changing unit permitting magnification of either 1× or 3×. The front telescope,

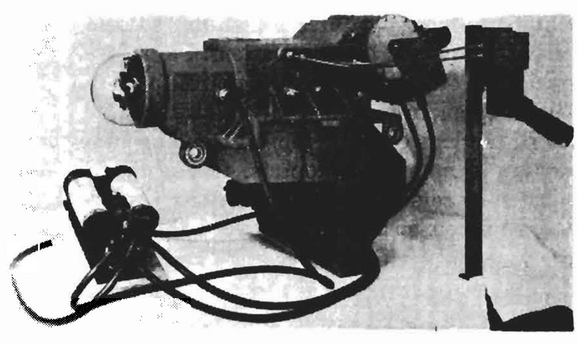

FIG. 1. Aircraft periscope.

* Institute of Ophthalmology, Columbia-Presbyterian Medical Center, 635 West 165th Street, New York 32, New York.
† Captain U.S.A.F.
‡ School of Optometry, University of California, Berkeley, California.

[1] D. A. Hall, "Technical preparation of the airplane 'Spirit of St Louis'," National Advisory Committee for Aeronautics, Technical notes No. 257 (1927).

[2] S. N. Roscoe, Univ. Illinois Bull. 48, No. 55 (March, 1951).

§ Dr. E. Marg initiated this study under Contract AF 33(616)–233 with the Perkin-Elmer Corporation, Norwalk, Connecticut. The project engineer with the contractor was Mr. Thomas P. Fahy, and the design engineer was Mr. Ralph Scalo.

consisting of an objective and front erector, produces a minification of 5.77× while the rear telescope, consisting of the eyepiece and rear erector, produces a magnification of 10. The net effect of both telescopes is, therefore, a magnification of $\sqrt{3}$. A power changing unit, controlled by a two-position knob, also consists of two opposed telescopes. At one orientation its net effect is a magnification of $\sqrt{3}$, while at the opposite orientation its net effect is a minification of $\sqrt{3}$. Thus, depending on the orientation of the power changing unit, the combined effect of the entire optical system is a magnification of either 3× or 1×.

Binocular vision is achieved by splitting the pupil and presenting a semicircular pupil of full brightness to each eye. This is accomplished by a prism located between power changers adjacent to the aperture stop. From this point rearward the instrument consists of two parallel optical systems. This requires three lenses

TABLE I. Optical characteristics.

Vision	Binocular
Magnification	1x, 3x
Real field (1x)	70°
(3x)	28°
Apparent field (1x)	70°
(3x)	70°
Entrance pupil	6 mm
Exit pupil	6 mm diameter semicircle
Resolution (1x) object space	1.4′ (axial) 4.0′ (edge)
(3x)	0.9′ (axial)
Field curvature (left eye)	OD. (axis)+2.5 D. (edge)
(right eye)	OD. (axis)+2.8 D. (edge)
Ocular focusing	+1.0 D. to −2.0 D.
Eye relief	24 mm
Interocular distance adjustment	58 mm to 68 mm
Scan azimuth	180°
Scan declination	180°
Variable tilt angle of eye piece section	45°

for each power, one before the pupil splitting and two duplicates after the split. Moving three lenses out of the optical path, while three different lenses are moved in, is accomplished by three synchronized turrets each carrying a low and high power lens. Stops insure proper positioning of the lenses in the optical path.

Each eyepiece may be individually focused by rotation of the lens cell, the range extending from plus 1.0 diopters to minus 2.0 diopters. Interocular distance is adjusted by rotating a knob just above the ocular which causes motion of a wedge between the eyepieces, and therefore, they either move together as the wedge is withdrawn, or apart as the wedge is introduced. The eyepieces are spring loaded and hence tightly sandwich the wedge. From the optical point of view rhomb prisms, in front of each ocular, are pivoted about the center of their entrance faces while the exit faces which carry the oculars describe a small arc, thereby increasing or decreasing the interocular distance.

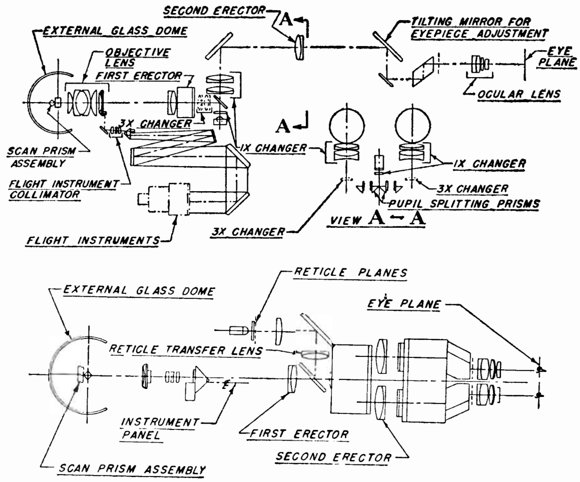

FIG. 2. Periscope optical system.

The eye end of the periscope may be tilted by loosening several screws and tipping the section to the desired angle within a range extending from the horizontal plane to 45 degrees upward. Optically a suitably geared mirror automatically folds the path near the eye end an amount equal to half the angle that the eyepiece section is rotated.

The scanning head mechanism was removed from a B-45 gunsight, and is used with only minor modifications. Scan is directed by a hand control unit which duplicates the axes of the scanning head and is coupled to the periscope by flexible shafts. The control unit is a pistol type grip arranged for left-hand operation. The line of sight is directed to a point by aiming the pistol in the direction of the desired sight line. Detents are provided to lock the pistol grip in the forward direction. Optically, scan is accomplished by rotation of two double dove prisms one of which rotates on a horizontal axis to give declination pointing while the other rotates on a vertical axis to give azimuth pointing.

A reticle of continuously variable brightness indicates the position of the aircraft flight line in the field of view. It is introduced into a collimated section of the main optical system by a beam splitter mounted just behind the first erector. The reticle image is collimated by a folded lens system located adjacent to the main system. The bright line cross hair is in the field of view only while the scan is directed within the 70-degree cone whose center is the aircraft flight line. This means the reticle does not appear to move in the field of view when varying amounts of scan are introduced; the cross hair remains fixed on the aircraft flight line. With increasing amounts of both azimuth and declination scan, the vertical and horizontal reticles will disappear, the time of disappearance of each depending on the relative amounts of each type of scan.

The behavior of the reticle in the field during scan demands that its motion be exactly equal to that of the scan but reversed 180° in direction. Reticle

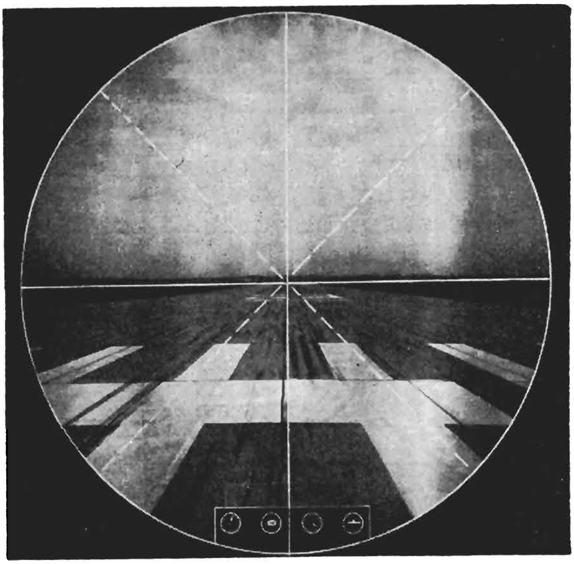

FIG. 3. Photograph through the periscope illustrating a runway and the illuminated recticle and instruments.

motion is accomplished by transporting, in window shade fashion, a thin bronze sheet. Narrow slits in the bronze form the cross hair. Declination is indicated by motion of the horizontal cross hair in the field of view resulting from displacement of the brass plate. Similarly, the azimuth angle is manifested by change in the vertical cross hair but in this case it is caused by rotation of a mirror. The inputs to the reticle drives are the same shafts that feed the scanning head. Motion of the reticle is in rectangular coordinates directly proportional to sight line motions in declination and azimuth. Errors in reticle location in the central 70° field are less than 2 degrees.

Flight instruments are introduced into the field by a small right angle prism mounted on the objective cell and they are imaged at the first focal plane of the periscope. Protrusion of the prism into the field causes a slight obscuration of the scene even when the instruments are not displayed. Illumination of the instruments is continuously variable from zero to a maximum. Figure 3, simulating a view through the periscope, illustrates the orientation of the instruments in a horizontal plane, and reading from left to right, they are air speed, altimeter, direction gyro, and flight indicator.

The periscope is installed forward in the bombardier's compartment of the B-17 with the hemispheric dome of the instrument projecting through the modified plastic nose. The periscope is attached at four points, through the medium of shock mounts, to a horizontally directed reinforced aluminum frame. The shock absorbers are antivibration pneumatic mounts.

While looking through the periscope, the aircraft is operated with the right hand by a specially designed three-dimensional control.|| This control functions

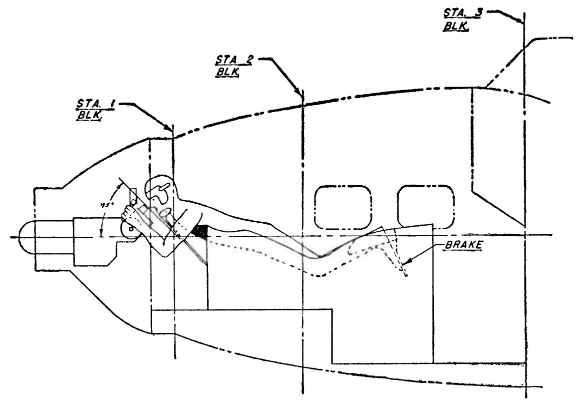

FIG. 4. Prone pilot and periscope with controls.

through the aircraft autopilot system. It consists of a vertical rod or stick with a door-handle type knob mounted on top. Rotation of the knob about a vertical axis provides separate rudder control, while rotation of the entire stick about an axis parallel to the flight axis affords aileron adjustment. Finally, the elevators are actuated by stick rotation about a transverse axis. Of course, any of these actions may be combined or coordinated.

A safety device insures recovery of control of the aircraft by the instructor pilot while the test pilot is flying by periscope. The instructor pilot may also immediately disconnect the controls of the test pilot by a conveniently located switch.

The test pilot lies prone in a nylon net bed¶ to look through the periscope. For maximum comfort, tension on the net is adjustable at $\frac{3}{4}$ inch intervals throughout the length of the supporting aluminum frame. The net extends from the base of the neck to the ankles. Foot-operated brake pedals are adjustable fore and aft for pilots of different heights. Forward and upward vision is limited in the prone position and, therefore, the periscope is useful for providing vision in these areas.

Figure 4 illustrates a pilot in the prone bed and shows his relation to the periscope and aircraft controls. While in the prone bed and looking into the periscope, the pilot's facial plane forms a 45-degree angle with the horizontal. His visual axes are thus also directed downward at 45 degrees. A mirror in the periscope reflects the line of sight 45 degrees to locate it in the horizontal plane.

The pilot's forehead is supported by a foam rubber cushion attached to the periscope just above the oculars. Additional support is provided by foam rubber on either side of the pilot's nose.

Engine controls are available to the left hand, power changes being effected by a toggle switch. For operation of the periscope itself, the controls for scan, magnifica-

|| The three-dimensional control was designed and constructed by Mr. O. K. Heineman, Greenville, Ohio, and was supplied by Mr. Charles A. Dempsey of the Anthropology Section, Aero Medical Laboratory.

¶ The nylon net bed was designed, constructed, and installed in the aircraft under the direction of Mr. Hans T. E. Hertzberg of the Anthropology Section, Aero Medical Laboratory.

TABLE II. Results of flight tests.

		SUBJECTIVE RESPONSES										OBJECTIVE RESPONSES						
PILOT	HOURS FLIGHT EXPERIENCE	FIELD SIZE ADEQUATE	RUNWAY EASILY LOCATED	RESOLUTION SATISFACTORY	HAZE NEAR SUN COMPARED TO WINDSHIELD	GROUND OBJECTS APPEAR TOO FAR, TOO NEAR, NORMALLY	REASONABLY CERTAIN OF ALTITUDE	SCAN VALUABLE	SPATIAL DISORIENTATION WITH SCAN	INSTRUMENTS EASILY SEEN	EYE STRAIN	GENERAL AERIAL PERFORMANCE	FLIGHT PATTERN FLOWN SATISFACTORILY	APPROACH SATISFACTORY	LEVEL OFF	NO OF APPROACHES	NO OF TOUCH DOWNS	TRAUMA TO HEAD FROM OCULARS
1	3000	YES	YES	YES	WORSE	FAR	YES	YES	YES	NO	YES	GOOD	YES	YES	OK	0	0	NONE
2	1600	YES	NO	YES	WORSE	FAR	YES	NO	YES	NO	NO	GOOD	NO	YES	OK	3	0	NONE
3	3000	NO	YES	YES	SAME	FAR	YES	YES	YES	NO	NO	GOOD	YES	YES	HIGH	0	0	NONE
4	3700	YES	NO	YES	SAME	NEAR	YES	YES	YES	NO	NO	GOOD	NO	NO	BALLOON	2	0	NONE
5	4100	NO	NO	YES	SAME	NEAR	YES	YES	YES	NO	NO	GOOD	NO	YES	BALLOON	1	0	NONE
6	2372	NO	NO	NO	WORSE	NORM.	YES	YES	YES	NO	NO	GOOD	NO	YES	OK	1	0	CUTS
7	4870	YES	YES	YES	SAME	NORM.	YES	NO	YES	NO	NO	GOOD	NO	YES	BALLOON	3	0	CUTS
8	2300	YES	YES	YES	SAME	NORM.	YES	YES	YES	NO	NO	GOOD	YES	YES	OK	0	0	CUTS
9	6300	YES	YES	YES	SAME	NORM.	YES	YES	YES	NO	NO	GOOD	NO	YES	OK	2	0	NONE
10	3334	YES	YES	YES	WORSE	NORM	YES	YES	YES	NO	NO	GOOD	YES	YES	OK	0	0	NONE
11	4277	NO	YES	YES	WORSE	NORM	YES	NO	YES	NO	YES	BAD	NO	NO	OK	4	0	NONE
12	1600	NO	NO	YES	WORSE	FAR	NO	YES	NO	NO	NO	GOOD	YES	YES	OK	0	0	CUTS
13	3836	YES	YES	YES	SAME	NEAR	YES	NO	YES	NO	YES	GOOD	YES	YES	OK	4	4	CUTS
14	5679	NO	YES	YES	WORSE	NEAR	YES	YES	YES	NO	YES	GOOD	YES	YES	OK	1	1	NONE
15		YES	YES	YES	WORSE	NORM	NO	YES	YES	NO	NO	GOOD	YES	YES	OK	2	0	NONE
16	3500	YES	NO	YES	SAME	FAR	YES	YES	NO	YES	NO	GOOD	YES	YES	OK	3	0	NONE
17	2546	YES	YES	YES	SAME	FAR	YES	YES	YES	YES	NO	GOOD	YES	YES	HIGH	0	0	CUTS
18	4000	NO	NO	YES	SAME	FAR	NO	YES	YES	NO	YES	GOOD	YES	YES	LOW	5	5	NONE
19	2400	YES	YES	YES	SAME	NEAR	NO	YES	YES	NO	NO	GOOD	YES	YES	BALLOON	4	1	NONE
20	2800	YES	YES	YES	SAME	NORM	NO	YES	YES	NO	NO	GOOD	YES	YES	OK	0	0	NONE

tion, and reticle and instrument illumination are available to the left hand. Right and left wheel brakes are applied by the right and left foot. The right hand operates the aircraft flight control.

FLIGHT EVALUATION

During all phases of flight evaluation, three pilots were in the aircraft. One, the test pilot, performed the indicated flight operations while looking through the periscope. Two, the safety pilot, located in the pilot's seat, operated the plane when it was not controlled by the test pilot, and stood by when the test pilot operated the aircraft. Three, the co-pilot, directed the flight maneuvers to be engaged in by the test pilot and instructed him in the use of special instrumentation. The co-pilot was either a member of the Aero Medical Laboratory (Captain L. J. McEachern) or one familiar with the periscope and specially instructed by the authors.**

The 20 test pilots were highly competent and experienced in testing experimental equipment. Most of them were assigned to the Bomber Test Section, and 18 were classified Senior Pilots by the U. S. Air Force.

All flight operations were carried out over familiar areas and thus the pilots were more easily oriented than over unfamiliar terrain. The test days had at least 2500 feet ceiling and 5 miles visibility. The smoke and haze usual of clear days in semi-industrial areas were present. All operations were in full daylight except for one night flight.

The general procedure was as follows. The co-pilot instructed each test pilot in the operation of the periscope and special controls. The safety pilot controlled the aircraft while the test pilot acted as a periscope observer for a variable period determined by his confidence and capabilities. The test pilot then assumed control of the aircraft and performed the indicated flight operations.

The flight operations performed by the test pilot may be divided into three groups:

1. Aerial performance is concerned with straight-level flying, turns, climbing turns, and descents, all below 10 000 feet.

2. The flight pattern, a procedure preparatory to landing, is the various banks and turns necessary to locate the aircraft about five miles from the runway at an altitude of 2000 feet.

3. The final approach is the course of the aircraft to the runway from the five mile point at an altitude of 2000 feet. The approach is satisfactorily completed when the aircraft, under adequate control, is flying parallel to the runway 15 to 50 feet above it. A touchdown is touching the wheels to the runway or to within an altitude of 10 feet.

RESULTS

Table II summarizes the results of the flight tests. Inspection of these data will reveal their highly qualitative nature, resulting from the character of the tasks involved, and the fact that it was necessary to have

** Major J. Cotton and Captain A. K. McGill, Bomber Test Section, Flight Operations Branch, Wright-Patterson Air Force Base, were most helpful in the flight evaluation.

several different observers score the performances. It is of interest to note that most test pilots, in spite of their inexperience with periscopic flight, believed the size of the field of view to be adequate and that the runway was easily located. On the other hand, the difficulty that was experienced flying the traffic pattern may be attributed to the restricted field of view through the periscope. A second point deals with the small number of test pilots attempting touchdowns. All those attempted were satisfactorily completed. The lower incidence of touchdowns is attributed in large measure to lack of confidence in the equipment by the test pilots and this in turn to their very limited periscope experience and to certain design features of the periscope itself.

Four optical features of the periscope should be considered from the point of view of the flight test results. The small size of the exit pupils means that the test pilot's head must be positioned precisely for adequate vision. Buffeting in rough air does not permit satisfactory head positioning and consequently there results periodic blocking of vision. Additionally, the impact shock at touchdown invariably caused a complete but momentary loss of the visual field. Buffeting and impact shock also resulted in abrasion type injuries, as indicated in the last column of Table II, to the skin covering the orbital margins in six test pilots.

The resolution of the periscope at unit power, as indicated in Table I, is less than that of the normal pilot's eye with 20/20 vision. It is further reduced at the edge of the field. In spite of these differences between the pilot's visual acuity and the resolution of the instrument, no test pilot noticed impaired visibility of detail at unit power.

Three power magnification in the periscope is of no value in enhancing detection of other aircraft or ground objects. This is attributed to the inferior resolution at this magnification, as shown in Table I. The reduced resolution was apparent to most pilots. It is clear that the lower limit of acceptable periscope resolution is between the value at one power and that at three.

Use of the scan during flight causes marked spatial disorientation and greatly increases the difficulty of aircraft control. With flight instruments in the field and by referring to them frequently, it is possible to control the aircraft during scan. The pistol type handle for directing the scan provides only rough orientation; it indicates that the scan is directed moderately or extremely to the right, left, up, or down. The reticle also provides an approximate cue, which as a cue should be capable of considerable refinement with training.

Three visual factors encountered in this study of flight by periscope merit comment. The design of the periscope provides viewing with zero degrees of convergence, visual axes parallel as in the case of fixation for infinity. The focusing range of the eyepieces extends from -2.0 to plus 1.0 diopters; almost all pilots focus for -1.00 to -2.00 diopters, or for a distance of about 26 inches. This means that the stimuli to accommodation and convergence are not for the same distance as they normally are.

Stereopsis may be evaluated by determining the observer's effective interpupillary distance while viewing through the periscope and from it the reduction in the distance of effective stereoscopy. If the eyes are centered in the exit pupils, the effective interpupillary distance is 3 mm and this constitutes a reduction in the distance of effective stereoscopy of more than twenty times for most observers. However, it is generally believed that stereopsis is not an effective cue during normal flying because of the distances concerned. It is of interest to note that no observers were aware of the profound changes in the stereoscopy relations, although many of them were familiar with the phenomenon of stereopsis.

Errors in space perception, as indicated in Table II, are manifested by the pilot's belief that his aircraft is either higher or lower than its true altitude. Most note that their aircraft appears higher, and this may be attributed to apparent minification. Two factors may contribute to apparent minification. First, the pilot's position is abnormal because his eyes in the relaxed position are directed downward at 45 degrees. The angle of the visual axes of the eyes emerging from the periscope depends on the orientation of the scan prism. A field experiment was conducted on a clear day while flying over flat terrain at 1200 feet and at 165 mph. Two experienced subjects, lying in the prone bed, viewed through the periscope varying the scan angle. They compared the apparent magnification while looking through the periscope to that while looking through the plastic nose of the aircraft with the unaided eye. In rapid alternation, they looked through the periscope and then through the plastic nose. The two observers are in general agreement in all observations, both at one and three power. At one power, apparent minification is definite and estimated to be about 0.8 with the scan centered about the flight axis. If the scan is oriented with the center of the field 30 to 60 degrees below the horizon, the apparent magnification of the periscope is very nearly unity. At the three-power position there is no change in apparent magnification with different scan orientations, but is estimated to be generally about 1.5 to 2.0×. It is concluded that the percent minification at three power is about the same as at one power, with the scan oriented directly ahead, that is, 20 to 30%.

The second possibility as a basis for apparent minification was investigated by Imber, Stern, and Vanderplas.[3] They studied the role of the restricted visual field present in all optical instruments. Using a small group of experienced observers no apparent minification was noted for stimuli distances ranging up to 500 feet

[3] Imber, Stern, and Vanderplas, "Visual field restriction and apparent size of distant objects," W.A.D.C.: W.A.D.C. Technical report 54-23 (1954).

with varying degrees of field restriction. However, as an alternate explanation of the apparent minification phenomenon, they re-examined the optical characteristics of unit power optical systems. In unit power systems, the magnification is greater than one at nearer distances. This differential magnification between near and far stimuli may result in apparent minification of the distant stimuli. This, of course, becomes less important at high altitudes.

A final experiment was conducted which has important implications on the visual requirements for periscopic flight. One clear night four satisfactory approaches were completed by a test pilot having several hours of daylight periscope experience. Night operations demand better visibility of the periscope flight instruments, because of the greater reliance placed on them. The attitude indicator was most important since the visibility of the external horizon is greatly reduced. Reticle illumination, even when considerably reduced, caused marked veiling luminance in the field of view and reduced the visibility of ground lights. With the reticle switched off, ground lights were almost as readily visible as with the unaided eye. The importance of this experiment is based on the more complete control of the experimental conditions, specifically visual cues. Runway lights were visible as points of light in the dark surround. At the 200-foot elevation point, the landing lights were turned on and thereafter some ground detail was visible. It seemed that the primary visual cue was the angular subtense of the ground stimuli, in this case runway lights. Additional cues became available with the landing lights.

CONCLUSIONS

In this study it is concluded that most ordinary operations in all phases of routine flight are performed with competence by periscopic vision. Some difficulty was experienced when the test pilot attempted to search for other aircraft and when flying the conventional traffic pattern. Each feature of the periscope has been evaluated resulting in information for future periscope specifications and more detailed knowledge of visual requirements for flying. This study has also brought to light many essential mounting and installation techniques.