tensity (E) are varied so that their product $Et=c$, where c is a constant, the degree of printing is constant, $x=kc'$.

Figure 1 gives the experimentally measured intensities on the surface of coaxial cylinders about a linear quartz high pressure mercury arc with 47-inch arc length operated with an electrical input of 75 watts per inch of arc. It will be noted that the light intensity on the cylinders coaxial with the arc decreases near the ends of the arc. This is a factor in the selection of the diameter of the printing cylinder because the arc lamp must be sufficiently longer than the printing surface to permit the production of a uniform intensity on the cylinder. Practical considerations such as cost and dimensions of equipment limit the radius of the printing cylinder to $\frac{1}{3}$ or less of the arc length. Under these conditions, the arc may be considered to be an infinitely long luminous line, excepting for a few inches at each end.

The light intensity E upon a coaxial cylinder varies as the radius r. If I_0 be the intensity per unit of length of the linear arc,

$$E=bI_0/r.$$

It can be shown that $b=\pi/2$, and that therefore $E=1.57I_0/r$. It follows that the intensity of the light field on a cylinder of 6-inch radius will be just half that on a cylinder of three-inch radius. This is in agreement with the experimentally determined results (see Fig. 1).

If the same angles of circumference of a 3- and 6-inch cylinder are covered by the printing paper and irradiated, and if the angular velo[...] the two cylinders are equal, the expos[...] are equal. However, since the light [...] are in the ratio of 2 : 1, the intensity [...] smaller cylinder being the greater, the [...] on the paper is entirely dissimilar.

If the angular velocity of the larger cy[...] reduced to half that of the smaller cylin[...] exposure time of the paper on the larger [...] will be doubled. Since $Et=c$, the degree [...] chemical reaction resulting in the two [...] are now comparable. The speed at wh[...] paper moves is determined by the pe[...] velocity. If the angular velocities of the cy[...] are varied inversely as the radii, the pe[...] velocities become equal. The paper speed [...] constant.

These results indicate that, provided [...] fective length of the linear arc is ten [...] times the radius of the coaxial printing cy[...] the radius of the coaxial cylinder is not [...] in the printing speed of the paper in [...] minute.

Linear light sources comprising a larg[...] violet component are useful in many [...] chemical processes other than photo[...] When used for the irradiation of liqui[...] gases a coaxial arrangement is entirely [...] and provides a most economical utilization [...] light energy. While in such reactions [...] formity of irrandiation field required for [...] printing is usually not required, the [...] which the light intensity varies with [...] and along the arc is highly important.

Journal of the
OPTICAL SOCIETY
of AMERICA

VOLUME 32 | MARCH, 1942 | NUMBER 3

Optical Problems Facing the Navy*

STANLEY S. BALLARD†
Research Division, Bureau of Ordnance, U. S. Navy Department, Washington, D. C.

OPTICAL instruments find many uses in our Navy, so many that I shall not attempt to enumerate them. The greatest optical problem facing the Navy today is procurement. We need more rangefinders, telescopes, and gun sights than can be produced even by this country's greatly expanded optical industry. The Navy appreciates the efforts in the national defense being made by our leading optical companies, and it is encouraging these companies and others to continue to expand existing facilities. The bottleneck is not so much in raw materials as it is in machinery and men for producing the finished products. Machine tools are needed in the optical industry as they are in other industries, and skilled hands are necessary also. But in order to carry out the two-ocean Navy program we must find production short-cuts and improved mass-production methods. We must search for acceptable simplifications of design and for substitutes that involve different procurement problems. For this reason we are interested in the advent of plastics as a supplement for glass in the optical field, particularly when the processes of grinding and polishing can be partially or totally dispensed with. Again, the production of solid glass color filters is lagging somewhat, so we are encouraging the production of ray filters of the laminated type. These should excel in reproducibility, but the problem of their ultimate stability is not yet entirely solved.

But I should like to turn from the production problem, which is already well understood by those concerned, to a general discussion of the two major uses of optical gear in the Navy. These are: first, navigation, and, second, fire control.

Navigation is a very old science, and it employs what is perhaps the simplest optical instrument of them all, the sextant. This instrument, in combination with the chronometer and the compass, makes possible ordinary navigation. Of course, we have some modern inventions which have come to play an important part in navigation, and the problems of aerial navigation are more complicated than those faced by the navigating officer aboard ship. But it is doubtful whether the day will ever come when the navigator does not shoot the sun and the stars, using an instrument so simple in principle that it could be sketched by any sophomore physics student. Speaking of modern inventions, I should not fail to mention the submarine periscope. This instrument in its modern form is a truly remarkable assemblage of optical parts. It performs searching, navigational, and fire control functions, acts as a telescope and makes possible estimates of

* Presented at Symposium of Optics in the National Defense at the twenty-sixth annual meeting of the Optical Society of America, held in New York City, October 24–25, 1941. The ideas and opinions expressed herein are those of the author, and do not necessarily represent the official opinion of the Bureau of Ordnance or the Navy Department.

† Lieutenant (jg), U. S. Naval Reserve. On leave from the University of Hawaii.

the range, relative speed and bearing of the target, which estimates must be made in the course of a few seconds, and while the submarine skipper is located in the conning tower, perhaps forty feet below the surface of the ocean. Periscopes must be sturdy enough to stand the strain of being pulled through the water at a speed of ten knots or more, must be watertight against a pressure of a hundred pounds per square inch, and must be shaped so as to leave no telltale wake that will reveal to scouting planes the presence of the submarine.

THE FIRE CONTROL PROBLEM

The primary purpose of a present-day shooting Navy is to be able at a moment's notice to hurl defiance at the enemy; defiance that takes the form of shells, torpedoes, bombs, or depth charges. The fundamental problem involved in this hurling operation is that of *fire control*, and fire control is without doubt the most technical problem facing the modern navy. By fire control is meant the process by which shells, bombs, or whatnot, are correctly fired or released so as to reach the desired destination, which is usually an enemy ship or plane. We are all familiar with the elementary concept of pointing the gun at the object you want to hit, with the superelevation necessary because of the parabolic trajectory of the bullet, and with the necessity of taking into account the time of flight of the bullet, in the case of a moving target, by aiming somewhat in front of the target. But the fire control problem aboard ship is much more complicated than this; there is always the pitch and roll of the ship to consider, for example.

The most advantageous position for viewing enemy craft is not, of course, by the main battery guns, but is up in the fire control tower. In present-day battleships, the firing is indeed controlled from this position, which may be many yards away from the guns themselves. This necessitates a complicated and yet accurate system of control which in the most modern ships is refined to the stage where the gunnery officer, from his point of vantage, can di[illegible] the fire of any, or all, guns, both main an[illegible] battery, either simultaneously or [illegible] and at either a single target or at s[illegible]

The new, *big* thing that the present war has brought is the anti-aircraft defense problem, which during World War I was relatively insignificant. But such are the military characteristics of the present-day bomber and torpedo plane that methods of defensive armament have of necessity been profoundly changed. An aircraft target is much faster moving and more highly maneuverable than a surface target. This means greater relative velocities and hence much greater lead angles necessary in firing. It also means that there is much less time available to man, train, and fire the guns, particularly in the case of surprise attacks. In addition, anti-aircraft fire other than that of the machine gun type employs shells that burst at a predetermined range. This adds another variable to the fire control problem, namely, that of fuze setting. The fuze on each projectile must be properly set and the time for handling the shell between fuze setting and firing must be held as constant as is humanly possible.

These remarks have dealt chiefly with the fire control problem as applied to guns. There are also problems concerning torpedo and bomb control, but I shall not discuss these for several reasons, one of which is the lack of time! Suffice it to say that much research is being done along these lines; new bombsights and new processes in bomb control are constantly being considered and developed.

The first step in fire control is to locate the enemy, and to this general problem the term *searching* is applied. We are all familiar with the picture of the lookout in the crow's nest constantly scanning the horizon, and now also the skies, for possible approaching enemies. His is an optical problem. Unfortunately, ordinary binoculars, or ordinary human eyes, are not too successful here. A little haze or smoke will obscure approaching ships most successfully. Glare on the water can be reduced by polarizing goggles, a modern development. But it has been general experience that surprise airplane attacks can come so rapidly that the guns cannot be manned or trained before the torpedoes or bombs are released and the invading planes have escaped. Evidently some more efficient searching method is needed, and [illegible] you know from reading the newspapers, suc[illegible]ods are rapidly being

developed. Suffice it to say that our Army and Navy are letting no grass grow under their feet in this matter.

RANGEFINDERS

Having located an enemy craft, it is necessary to make certain observations and computations before firing the guns. The primary observational instrument is the *rangefinder*. By this instrument, plus its auxiliary telescopes, it is possible to obtain three coordinates, azimuth, elevation angle, and slant range, which serve to locate exactly his position with reference to yours. Then computations must be made which will serve to locate the target at a later time, determined by the time of flight of the projectile. Prediction methods have been worked out satisfactorily by the Coast Artillery, and among other factors must allow for the parallax caused by the distance apart (in some cases, several hundred yards) of rangefinder and gun battery. As mentioned before, the problem is further complicated for both ships of the sea and ships of the air by the necessity of allowing for their pitching and rolling motions. Needless to say, it is here that the gyroscope plays an all-important role.

Rangefinders are of two general types: coincidence and stereoscopic. The modern coincidence rangefinder was developed by Barr and Stroud of England in 1888 and has always been the favorite of the English Navy. It utilizes monocular vision, splits the target image (preferably a mast or smoke stack) into two parts, and indicates correct range when the two parts are brought into coincidence. The coincidence rangefinder is easy to use and is successful in ranging on surface craft where appropriate target images are usually available. It is used in over half of our main-battery turrets. The stereoscopic rangefinder received its chief development at the firm of Zeiss and has always been the German favorite, having been in common use on German ships during the last war. The fact that the Germans used stereoscopic rangefinders while the English used coincidence rangefinders has resulted in a further examination of the results of the Battle of Jutland, the only large encounter between two modern naval forces. However, the results of this famous battle are not clearly enough defined so that they can form the basis for a choice between the two types of rangefinders.

The stereoscopic rangefinder is a binocular instrument in which accuracy of setting depends greatly upon the training of carefully selected observers. It is believed to be the superior instrument for use in ranging on small or indistinct targets. My personal feeling in the matter is as follows: When there are available satisfactory targets, that is, targets with vertical straight lines upon which coincidence settings can be made, the coincidence instrument is faster to set and gives a feeling of confidence—you feel that you simply *cannot* have anything but the right range. On the other hand, it is difficult if not impossible to make a satisfactory coincidence setting on a small, irregular image such as that of a distant airplane. True, an astigmatizer lens may be cut in to elongate the point source into a line, but this can be used to advantage only with bright, contrasting sources such as the masthead lights of a ship, at night. Therefore, in anti-aircraft observation the preference in most countries is toward the use of stereoscopic rangefinders. The surprising thing to one new in this field is that such an apparently difficult judgment as that involved in setting a stereoscopic instrument can be made with the high accuracy and reproducibility that is attained by experienced observers.

Present-day rangefinders vary in length from 12-inch hand-held instruments to the large battleship turret rangefinders that are over forty feet long. The smallest rangefinders in current naval use are the one-meter navigational instruments used for such purposes as maintaining a ship's proper position in formation. The standard formula for rangefinder errors has the base length in the denominator, which means that the greater the length the greater is the accuracy attained. Attention must be given, however, to practical considerations of size and weight. The difficulty of mounting the instruments, and the torque necessary to train them on the target, must be considered. In fact, in deciding on the size to build a new rangefinder, a compromise must be made between instrumental accuracy desired and the space available in that particular position on board ship.

Problems involved in rangefinder operation are caused by the haze encountered at sea, by the necessity, at times, of looking directly into the sun, and by the vibration of the instrument, caused by the ship's operation and by the firing of the guns. Imagine an optical instrument fifteen feet long and measuring angles to *less than one-half second*, all this mounted on a superstructure fifty feet above a rolling and pitching deck, subjected to extreme acceleration when guns are fired and to severe blast pressures. This is the situation faced by the present-day battleship anti-aircraft rangefinder. Imagine the acceleration experienced by the main battery rangefinders that are mounted as integral parts of 16-inch triple turrets, when all three guns fire simultaneously!

The above remarks give some idea as to the problems faced by the manufacturers of these instruments. I have not discussed the more obvious non-laboratory conditions that must be considered, such as rapid changes of temperature and exposure to salt spray and rain.

But particularly in the case of stereoscopic rangefinders, one is dealing not simply with an optical instrument, but with an instrument-operator combination. Thus the physio-psychological response of the operator merits, and is now receiving, grave consideration. The first problem here is the selection, from the thousands of available candidates, of the proper persons for training as rangefinder operators. These men, in a sense, are the prima donnas of the ship (and incidentally, on German ships they enjoy the privileges of prima donnas) for on their rangefinder performance may depend the life of the ship and all its crew. This is particularly true regarding the first few salvos fired, for after that the gunnery officer may introduce arbitrary corrections to account for what appear to be systematic errors in range, elevation, or bearing in the fire. This process is called "spotting" and is carried out, in the case of main battery firing, with the aid of observation airplanes. However, in anti-aircraft fire against dive bombers it may "all be over" before any spotting corrections can be introduced, so the accuracy of the original ranges is all the more important.

But to come back to the personnel [illegible]— having selected operators, the Nav[illegible] m in special rangefinder schools. They must [illegible] up to high standards of precision and reliability before they are qualified for rangefinder operation aboard ship. With our present rapidly expanding Navy this problem of training rangefinder personnel has attained added importance. We are attempting to develop better selection methods and better training methods so that our new ships may be manned by the best possible operators.

Another personnel problem, and an [illegible] important one, has to do with the fatiguing of rangefinder operators. How long, under battle conditions, can a man continue to make accurate stereoscopic judgments? What will be the effect on his precision of performance of his emotional response to the battle—apprehension, startle, perhaps fear and terror? These subjects are receiving careful consideration.

OTHER OPTICAL INSTRUMENTS

The rangefinder is doubtless our most valuable anti-aircraft fire control optical instrument. Another important type of instrument is the gun sight. The simplest gun sight is the so-called open sight similar to the one that we used on 22-caliber rifles, as boys. These are somewhat modified on machine guns to what is known as ring sights; the rear sight consists of several concentric rings which aid the gunner in allowing for the relative velocity of the target. Then the hunting rifle has its telescopic sights, and these find their analogues on naval guns. Somewhat more complicated are the collimating "illuminated" sights in which an auxiliary optical system projects the point of aim to infinity. Gun sights for turret guns are really periscopes, since the line of sight must be carried from inside the turret up through its roof, and then projected parallel to the bore of the gun. There are many other types of sights necessary, particularly for aircraft use, and developments in this field are being given high priority and are proceeding with especial rapidity.

Among other optical instruments in fire control, I will mention two, the gun camera and the machine gun training device. Gun cameras are mounted in place of the actual gun and take pictures of what the gunner hits, or rather what he *would have* hit, had there been a gun actually

firing. These are particularly useful in training aircraft gunners; they save ammunition and allow him to fire at accompanying friendly aircraft with impunity. The machine gun training devices, on the other hand, show by projecting stereoscopic tracer bullet images or simulated shell bursts how the gunner fared in firing against moving-picture-reproduced targets. These devices incorporate mock guns with the same "feel" as the genuine article. They make possible the large-scale training of gunners, both aircraft and anti-aircraft, against realistic target scenes, but without the expenditure of a large amount of target-practice ammunition. The Navy has already under procurement three different types of machine-gun training devices and is interested in several others.

RESEARCH

Persons outside the service, especially scientists, often ask us whether the Navy is doing research along lines to improve its armament efficiency, or whether it is just standing pat on current practices until the war is over. Naturally, detailed information along this line is closely guarded at the present time. But I can assure you that research activity is greater now than it has ever been before in the history of the Navy. I wish I could tell you, as an example, about the research work that is being done on rangefinders. It involves the full-time or part-time services of more than a score of the country's leading scientists, who have been loaned for government work by their respective educational, scientific, or commercial employers. The governmental agency that is administering most of the new defense research work is the National Defense Research Committee, or more properly the Office of Scientific Research and Development, of the Executive Office of the President. The rangefinder work is a small, though important, fraction of the total N.D.R.C. program.

Optical research continues to be carried on directly by the Navy, both in the Optical Section of the U. S. Naval Gun Factory in Washington, and at the Naval Research Laboratory at Anacostia, D. C. In the Navy Department itself there are many officers whose sole duty is to keep abreast of scientific developments. In these days of emergency, production and procurement follow very closely on the heels of research and development. Whereas in pre-war days it was possible to test pilot models in a leisurely fashion before proceeding to large-scale procurement, it is now necessary, in the interests of national defense, to take a new device from the "bread-board model" almost directly to the production line. This means that development details must continually be inserted into the production processes. This is admittedly not the most desirable procedure, but it is the only possible method in a country which, in times of peace, does not fully prepare for possible times of war.

In the Navy Department every effort is made to expedite the development of new and worthwhile ideas. The machinery by which this is carried out in the Bureau of Ordnance is as follows: There is a separate division of Research and Development, which has grown from four officers in March, 1941, to over forty in October—a tenfold gain! Each of the officers of this division must keep in touch with the commercial, industrial, service, and N.D.R.C. developments assigned to his cognizance. This involves the establishing of personal contacts, and the making of frequent trips to research and industrial institutions. New ideas and instruments are evaluated by the Research Division, and, if endorsed, are recommended to the Production Division. The Production Division handles the actual procurement details. The third division of this functionally organized Bureau is the Division of Fleet Maintenance. It is the duty of this group to attend to maintenance, repair, and replacement details on all naval ordnance equipment. Each of the three functional divisions is divided into materiel sections such as ammunition, guns and mounts, torpedoes, and fire control.

It should be mentioned that the drawing up of specifications for the manufacture of fire control equipment is by no means an arbitrary matter. There are only a limited number of manufacturers who have the facilities to produce these highly technical instruments. Therefore, it would be silly to lay down specifications which would be practically impossible to meet. Bureau representatives must consult with the manufacturers in this matter, in an effort to get the best possible instruments in the shortest possible time. In some cases only *performance* specifications are made; the details of arriving at a device which will meet these specifications are left almost entirely up to the manufacturer. All this simply illustrates the cooperation necessary between the armed services and the civilian suppliers of equipment. Naval Inspectors of Ordnance and Inspectors of Naval Material are assigned to many of the larger manufacturing plants. These gentlemen have their offices within the doors of the plant and work in close cooperation with the executives of the company. Their purpose is in no sense to "spy" on the company, but to assist it in meeting its contracts, and in supplying the Navy with necessary materials and equipment with dispatch.

CONCLUSION

I have sketched the general fire control problem, and have spoken particularly about optical matters, as is appropriate on this occasion. I have stated that research and development are proceeding at a greatly accelerated rate. I have indicated that it is the purpose of the Research and Development Division of the Bureau of Ordnance to keep in touch with the newest ideas and the latest inventions. Now I should like to mention a few subjects that will be familiar to you all, to indicate that the Navy is following closely the developments in these fields:

The possible use of plastic materials for lenses and prisms was mentioned above.

Non-reflecting films on optical surfaces have been the subject of much discussion in the scientific literature. We have experimented with the application of these films to the surfaces of binocular lenses as well as in other instruments, and expect shortly to reduce this to a routine production matter.

The infra-red is a region of the spectrum whose potentialities in military matters have been the subject of much discussion, not only in the Sunday supplements, but also in reputable scientific journals. We are following closely the infra-red subject, and have under consideration at the present time several methods for its utilization.

Variable density neutral filters for telescopes and rangefinders are now supplied in the form of Polaroid disks that can be crossed and uncrossed by the observer, to regulate field brightness to the desired amount.

The use of scotopic vision is receiving serious consideration, and will doubtless find wide applicability in searching and fire control problems at night time.

These are but a few of the modern developments in optics that are receiving attention. There are many others, but time and the considerations of security do not permit their discussion today.

MARCH, 1942 J. O. S. A. VOLUME 32

Lenses for Aerial Photography*

R. KINGSLAKE
Eastman Kodak Company, Rochester, New York

THE earliest photographs[1] from the air were made in France, where aeronautics has always exerted a fascination for the man of ingenuity and enterprise. As far back as 1856, M. Nadar took photographs over Paris from a captive balloon, using (presumably) wet collodion plates. Later, in 1885, Tissandier and Ducom used dry plates from a free balloon. Other pictures, somewhat unsuccessfully, were made with cameras supported by a kite. Our earliest record of the use of aerial photography in military work was the photography of enemy fortifications in China from a balloon by Colonel Renard, in 1900. Apparently, the first photographs to be made from an airplane were taken by Wilbur Wright in April, 1909.[2]

PHOTOGRAPHY IN THE WORLD WAR, 1914–18

Just prior to the commencement of the war of 1914–18, one or two workers in the French army, notably a Captain Saconney, were attempting photography from airplanes, but very little official interest was shown in the matter. However, after a Zeppelin captured on August 22, 1914 was found to be equipped with a camera, official interest was suddenly aroused, and the French army at once established a regular aerial photographic service, their example being followed soon after by the British and other Allies. By the end of the war, photography had become a major war activity, and tens of thousands of photographs were made every week. It is estimated that by 1918 over a million prints a month were being made and distributed.

At first, any convenient camera was held in the hand, and merely pointed over the side of the plane at the object to be photographed. However, in 1914, when the demand for aerial photographs increased by leaps and bounds for war purposes, it became apparent that special cameras were necessary. An aerial camera must be very rigid, mounted so as to be free from vibration, and prefocused for infinity but not thereafter adjustable for focus. It must be equipped with a long-focused lens to show fine detail, and at first an adjustable focal plane shutter was used as no large between-lens shutters were available. Also, the size of picture should be as large as convenient to cover a wide angular field.

Prior to about 1922, aerial photographs were invariably made on glass plates, housed in various ingenious forms of magazine or changing box holding from 6 to 50 plates at a time. At first, roll film was found to be unsatisfactory, and it was not adopted for aerial cameras until two or three years after the war had ended. The problem of the use of roll film was twofold: firstly, adequate processing equipment had to be designed to handle large rolls of film, and secondly, some means had to be found to hold the film flat during exposure. A pressure pad and glass plate have been used, but this is likely to cause scratches and static marks on the film; a much better solution was found in Folmer's introduction of a "suction back," to pull the film down against a flat perforated metal plate.[3]

The French[4] adopted from the first a focal length of 25 cm (10 inches) and a 13×18-cm plate (5×7 inch). The 10-inch focus was soon found to be too short for high flying, so cameras were constructed for 50-cm (20 inch) focus, covering an 18×24-cm plate ($7\times 9\frac{1}{2}$ inch), which became the standard focus and plate size for the French army. The speed of all these lenses was $f/4.5$. A little later, the French introduced a lens of 120-cm focal length (47.2 inches), also for the 18×24-cm plate, at an aperture of $f/6.5$, claiming that this was the longest camera in the world! This camera was not particularly popular as it occupied far too much space in the plane, and covered only a very narrow angular field. Towards the end of the war, a moderately wide-angle camera was introduced covering an 18×24-

* Presented at Symposium of Optics in the National Defense at the twenty-sixth annual meeting of the Optical Society of America held in New York City, October 24–25, 1941.

[1] L. P. Clerc, *Applications de la photographie aérienne*, Chap. I.

[2] D. M. Reeves, *Aerial Photography*, p. 3.

[3] U. S. Patent 1,309,798 (1919).

[4] A. H. Carlier, *La photographie aérienne* (1921) Chap. 2.