The Principles of Camouflage—II

Low Visibility and Optical Illusion on the Sea

By M. Luckiesh

AT the time of the Spanish-American War our battleships were painted white apparently with little thought of attaining low visibility. Later the so-called "battleship gray" was adopted but it has been apparent to close observers that this gray is in general too dark. Apparently it is a mixture of black and white. The ships of the British navy were at one time painted black but preceding the Great War their coats were of a warm dark gray. Germany adopted dark gray before the close of the last century and Austria adopted the German gray at the outbreak of the war. The French and Italian fleets were also painted a warm gray. This development toward gray was the result of an aim toward attaining low visibility. Other changes were necessitated by submarine warfare which will be discussed later.

In the early days of unrestricted submarine warfare many schemes of modifying the appearance of vessels were submitted. Most of these were merely wild fancies with no established reasoning behind them. Here again science came to the rescue and through research and consultation, finally straightened out matters. The question of low visibility for vessels could be thoroughly studied on a laboratory scale because the seascape and natural lighting conditions could be reproduced very closely. Even the general weather conditions could be simulated, although of course the experiments could be prosecuted outdoors with small models as indeed they were. Dr. L. A. Jones carried out an investigation on the shore of Lake Ontario and laboratory experiments were conducted by others with the result that much light was shed on the questions of marine camouflage. This work confirmed the conclusion of the writer and others that our battleship gray was too dark. Of course, the color best adapted is that which is the best compromise for the extreme variety in lighting and weather conditions. These vary in different parts of the world, so naturally those in the war zone were of primary importance. All camouflage generally must aim to be a compromise best suited for average or dominating conditions. For example, in foggy weather a certain paint may render a ship of low visibility but on a sunny day the ship might be plainly visible. However, if ships are rendered of low visibility for even a portion of the time it is obvious that an advantage has been gained. Cloudiness increases generally from the equator northward as indicated by meteorological annals.

A Scale of Visibility

In order to study low visibility a scale of visibility must be established and it is essential to begin with the fundamentals of vision. We distinguish objects by contrasts in brightness and in color and we recognize objects by these contrasts which mold their forms. In researches in vision it is customary to devise methods by which these contrasts can be varied. This is done by increasing or decreasing a veil of luminosity over the object and its surroundings and by other means. Much work has been done in past years in studying the minimum perceptible contrast and it has been found to vary with hue, with the magnitude of brightness, and with the size of the image; that is, with the distance of an object of given size. In such problems as this one much scientific work can be drawn upon. A simple though rough scale of visibility may be made by using a series of photographic screens of different densities. A photographic screen is slightly diffusing, still the object can be viewed through it very well. Such methods have been employed by various investigators in the study of visibility.

Owing to the curvature of the earth the distance at which a vessel can be seen on a clear day is limited by the height of the observer and of the ship's superstructure. For an observer in a certain position the visibility range varies as the square root of the distance of the object from him. Such data are easily available so they will not be given here. So far we have considered the ship itself when as a matter of fact on clear days the smoke cloud emitted by the ship is usually visible long before a ship's superstructure appears over the horizon. This led to the prevention of smoke by better combustion, by using smokeless fuels, etc.

The irregular skyline of a ship is perhaps one of the most influential factors which tend to increase its visibility. Many suggestions pertaining to the modification of the superstructure have been made but these are generally impracticable. False work suffers in heavy seas and high winds.

Countershading to Increase "Low Visibility"

After adopting dark gray as a "low-visibility" paint for ships, perhaps the next refinement was countershading, that is, shadows were painted a lighter color or even white. The superstructure was painted in some cases a light blue with the hope that it would fade into the distant horizon. However, the effectiveness of the submarine demanded new expedients because within its range of effectiveness no ingenuity could render its prey invisible. The effective gunfire from submarines is several miles and torpedoes can be effective at these distances. However the submarine prefers to discharge the torpedo at ranges within a mile. It is obvious that in average weather low visibility ceased to be very effective against the submarine. The movement of a target is of much less importance in the case of gunfire than in the case of the torpedo with its relatively low velocity. The submarine gunner must have the position, range, and course of the target in order to fire a torpedo with any hope of a hit. Therefore any uncertainties that could be introduced pertaining to these factors would be to the advantage of the submarine's prey. For example, low visibility gave way to confusibility in the discussions of defense againt the submarine and the slogan, "A miss is as good as a mile" was adopted. None of the foregoing factors can be determined with high accuracy so that it appeared possible to add somewhat to the difficulties.

THE art of deception in war is as old as war itself, but never has it received such close, scientific attention as in the mighty struggle the world has just passed through. Early in the war it became evident that while an artist might deceive the naked human eye, the deception would be perfectly transparent to the photographic camera. A complete knowledge of the composition of color was imperative. Here the services of the physicist had to be called in. Not only was color used to hoodwink the enemy but all manner of optical illusions; here also the physicist was needed. And so many prominent scientists were enlisted to reduce camouflage to a science.

Among the physicists who had contributed to the scientific development of camouflage was the author of the present article, who is a well known color expert. Mr. Luckiesh, therefore, writes with authority. His first instalment, dealing with camouflage on land, was published in the SCIENTIFIC AMERICAN *of January 25, 1919. The third and last instalment, which will be published in an early issue, will deal with invisibility of airplanes.*—EDITOR.

Optical Illusions to Distort the Lines of a Ship

Many optical illusions have been devised and studied by scientists. In fact, some of these tricks are well known to the general reader. Straight lines may appear broken, convergent, or divergent by providing certain patterns or lines intermingled with them. Many of these were applied to models in laboratory experiments and it has been shown that confusion results as to the course of the vessel. The application of these on vessels has resulted in the grotesque patterns to be seen on ships. It is well known that these illusions are most effective when the greatest contrasts are used, hence black and white patterns are common. Color has not been utilized to any appreciable extent in confusibility although there is a secondary aim of obtaining low visibility at a great distance by properly balancing the black, white and other colors so that a blue gray results at distances too great for the individual patterns to be resolved by the eye. Color could be used for the purpose of increasing the confusion by apparently altering the perspective. For example, blue and red patterns on the same surface do not usually appear at the same distance, the red appearing closer than the blue.

Such apparently grotesque patterns aimed to distort the lines of the ship and to warp the perspective by which we estimate the course. This was the final type of camouflage at the close of the war. Besides relying upon these illusions, ships zigzagged on being attacked and aimed in other ways to confuse the enemy. Little attempt was made to disguise the bow because the bow wave was generally visible. However, attempts have been made to increase it apparently and even to provide one at the stern. In fact, ingenuity was heavily drawn upon and every plausible expedient has been tried.

The convoy system is well known to the reader. This saved many vessels from destruction. Vessels of the same speed were grouped together and steamed in flocks across the Atlantic. Anyone who has had the extreme pleasure of looking down upon these convoys led by destroyers and attended by chasers is strongly impressed with the old adage, "In unity there is strength."

Before the war began a Brazilian battleship launched in this country was provided with a system of blue lights for use when near the enemy at night. Blue was adopted doubtless for its low range compared with light of other colors. We know that the setting sun is red because the atmospheric dust, smoke, and moisture have scattered and absorbed the blue and green rays more than the yellow and red rays. In other words the penetrating power of the red and yellow is greater than that of the blue rays. This country made use of this expedient to some extent. Of course, all other lights were extinguished and portholes were closed in ocean travel during the submarine meance.

Smoke Screens

Naturally smoke screens were adopted as a defensive measure on sea as well as on land. Many types of smoke boxes have been devised or suggested. The smoke is produced chemically and the apparatus must be simple and safe. If a merchantman were attacked by a submarine immediately smoke-boxes would be dumped overboard or some which were installed on deck would be put into operation and the ship would be steered in a zigzag course. These expedients were likely to render shell-fire and observations inaccurate. This mode of defense is best suited to unarmed or inferiorly armed vessels.

Camouflage for Submarines

So far as the writer has been informed no attempts have been made to camouflage submarines under water but that this can be done is evident from aerial observations. When looking over the water from a point not far above it we are unable to see into the water except at points near us where our direction of vision is not very oblique to the surface of the water. The brightness of the surface of water is due to mirrored sky and clouds ordinarily. For a perfectly smooth surface of water the reflection factor is two per cent for perpendicular incidence. This increases only slightly as the obliquity increases to an angle of about 60 degrees. From this point the reflection factor rapidly increases, becoming 100 per cent at 90 degrees incidence. This accounts for the ease with which we can see into water from a position directly overhead and hence the airplane has been an effective hunter of submarines which are submerged. The depth at which an object can be seen in water of course depends upon its clarity. It may be surprising to many to learn that the brightness of water, as viewed perpendicularly to its surface is largely due to light diffused within it.

A submerged submarine may be invisible because:

(1) It may be deep enough to be effectively veiled by the luminosity of the mass of water above it (including the surface brightness) or

(2) It may be of the proper brightness and color to stimulate the brightness and color of the water.

It is obvious that if it were black or white it would have to attain concealment by submerging deeply. If it were a fairly dark greenish blue it would be invisible at very small depths. In fact, it would be of very low visibility at the surface of the water. From the writer's data on hues and reflection factors of earth and water areas it would be easy to camouflage submarines effectively from enemies overhead. The visibility of submarines is amplified by viewing large fish such as sharks from airships at low altitudes. They appear as miniature submarines, dark gray or almost black amid greenish blue surroundings. Incidentally the color of water varies considerably from the shallow inland waters containing much suspended matter to the deep clear ocean waters. The latter as viewed vertically are about one-half the brightness of the former under the same conditions and are decidedly bluer. Inland waters such as the Chesapeake Bay are very greenish in color.