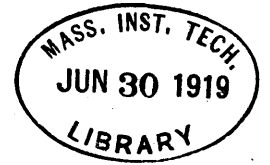


Ship Camouflage

by

**Leo S. Blodgett
N.A. Department - M.I.T. thesis
1919**

This case



Foreword.

The following thesis on ship camouflage is based on the work produced during the Great War, aiming at the apparent distortion of ships by the use of contrasting colors, according to the system termed the "British Dazzle".

A quantitative treatment of the subject has been attempted, with a greater or less degree of success in accomplishing this end. The latest apparatus devised by the camouflage section of the United States Navy, was available for observing models, together with practically all data compiled in this country, and reports from Europe. All material was an uncoordinated mass, and most of it without practical value in developing the subject. The work of the Navy Department, during the last two months of hostilities, approached the matter from a definite standpoint and results were just commencing to be apparent when the armistice was signed.

The subject is of very great interest, and although it probably will never again come into prominence as a means of protecting ships against the submarine, the results of the work here, indicate the possibilities of marine camouflage, if approached from a scientific view point.

The writer is deeply indebted to Professor C.H. Peabody, of the Department of Naval Architecture and Marine Engineering, at the Massachusetts Institute of Technology, for his kind suggestions and aid during the work, and for making possible

the use of the necessary equipment.

Leo S. Blodgett.

Massachusetts Institute of Technology.

May twelfth nineteen hundred and nineteen.

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Marine Camouflage as many other methods of defensive and offensive warfare had its origin in the early ages of history. When the Greeks went on voyages of conquest, their ships were painted blue, purple, green and vermillion, in order that they might be less conspicuous to the enemy. Mention is made in accounts of the pirate ships during the fourteenth and fifteenth centuries, of elaborate and conspicuous designs in purple, violet, green, white and other colors, painted on the sides of the vessels. During the latter part of the nineteenth century the navies of the world were painted either black or white. Both these colors had certain qualities that made them undesirable, especially in war times. Germany recognized the need of a neutral tone and to this end had her ships painted a blue gray. England soon followed her lead, then France, the latter using a khaki colored gray. About 1905 the United States adopted a low visibility flat tone gray that is used even to the present on line of battle ships.

Not until the Great War broke out in 1914 and the U boat menace threatened to wipe the transport and supply ships of the Allies from the seas, did the question of a system of protective painting arise. As land camouflage developed and proved its value in deceiving the enemy, various individuals in Europe and this country, many of them artists of note attempted to work out similar methods of ship painting. Mackay and Herzog of New York seem to be the pioneers for this important work. About June 1917, keen interest was aroused in

the matter both here and abroad. In October 1917, the Treasury Department and the Bureau of War Risk Insurance issued an order requiring all ships travelling under supervision to be painted in a manner which should prove of protective value while crossing the danger zone. A penalty of one half percent increased insurance was imposed, if instructions were not followed. The Submarine Defense Association organized by shipping interests in New York, attempted to have all ships coming within its control, painted with some design approved by the Government. To aid research for designs, the cooperation of the Eastman Kodak Laboratories at Rochester, New York was enlisted for carrying on experiments in Low Visibility painting.

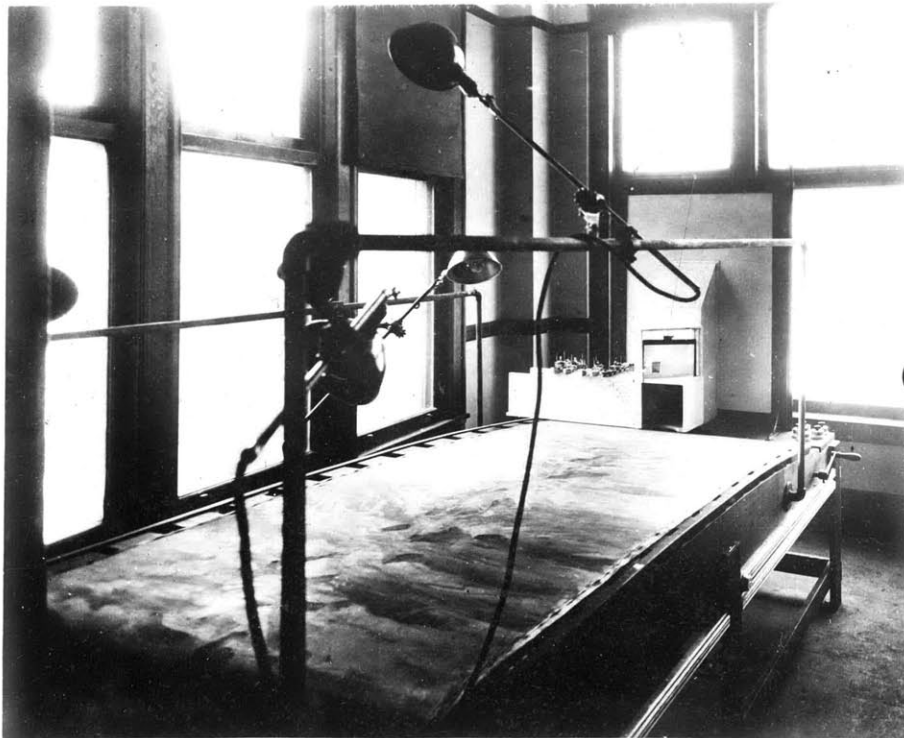
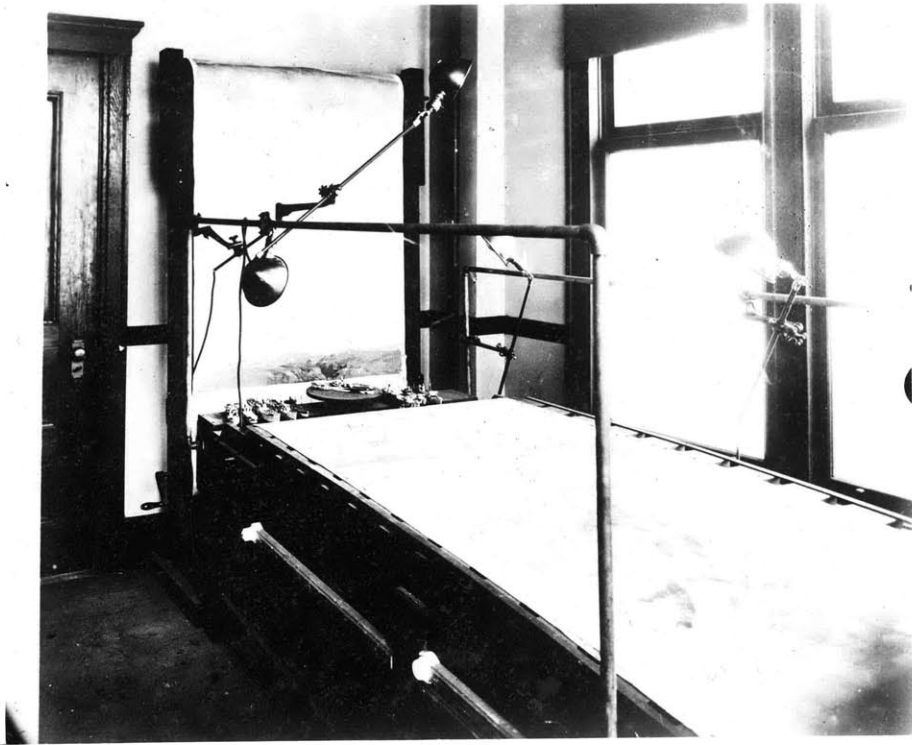
Until March 1918, practically all systems attempted to lower the visibility of ships at sea by painting them out of the sky-line. While research in low visibility was being carried on in this country, Lieutenant Norman Wilkinson R.N.V.R. discovered an entirely new and effective system of camouflage, in England. This was called the British Dazzle and replaced all preceding ideas on the subject of protective coloration for ships. Designs were immediately sent to Washington from the Admiralty, and Wilkinson made a short visit to the Bureau of Construction and Repair to initiate certain Constructors in what was

then known of the subject. Two Lieutenants, Jones and Van Buskirk were designated as the organizers of a Department of Camouflage under the supervision of the Bureau. The Shipping Board appointed various individuals mostly artists of more or less merit, to carry out designs on the ships as they might be supplied by the Navy Department, and to attempt the development of the subject using such means for research as could be made available. The Dazzle System was established as the basis of all designs. To this end each of the Camouflage Districts developed and improved apparatus for studying the subject under conditions which would simulate actual weather at sea. At first the apparatus was anything but satisfactory, consisting of a periscope with a minus lens, and mirrors, through which models might be studied, when placed before a screen on which sky scapes were painted. Later the Boston District worked out what is considered by the men interested, a theater of observation, that is strides ahead of any similar theater in the country. It includes all essential features of sea and sky illusion, light effects, periscopic means of observation comparable with actual conditions. This apparatus has been used in developing the subject matter of this thesis, so a description may be given at this point.

The question of the illusion of water was first considered, and it was solved by building up a curved painted

surface, which most nearly approached the appearance of the sea as observed from a submarine. An endless belt of canvas painted with various sea scapes was run over rollers, in order that a variety of weather might be simulated. The scenery for sky was treated in a similar manner in the vertical plane, so that various conditions and shore lines might be obtained. Hand cranks were attached to operate the canvas belts. The bed over which the sea canvas rolled was given a downward turn, in order that a true representation of water in the horizontal plane would result, and the visual center of the periscope brought low enough to the horizon to approximate the relationship existing under actual observations.

In the case of the periscope, it was not possible to follow the true one exactly, for it was found necessary from the size models used to produce a virtual image, reduced in size, where actually a real image, enlarged would result. The models were made to such a scale that at distances available they gave a true representation of the ship. To render conditions of observation rigid, the ranges were made 1100 to 2200 yards, which are somewhat less than most cases of attack at sea. Two mirrors and two lenses comprise the working parts of the periscope, the mirrors being fixed parallel to each other and at a forty-five degree angle with the vertical-



the lenses placed between the mirrors. The lower lens is fixed and has a diameter of four inches, with a focal length of thirty, while the upper lens is a three inch minus or reducing lens, which will allow the image to be varied in size as desired. A fog producing device was installed directly in front of the bottom opening of the periscope. It consists of a semi transparent mirror, placed vertically at a forty-five degree angle to the line of vision. A ground glass screen is placed in the vertical plane parallel to the line of vision. Fog densities may be varied by adjusting a light enclosed near this mirror. Blue and ground glass screens are used to give the correct tone to daylight fog. Horizontal light carriers were erected along the sides of the frame, and nitrogen, daylight lamps used for effects on the sky and sea.

A turntable was installed between the horizontal edge of the sea and sky scenery, and so arranged that as it was turned by a hand wheel, the indicator on a compass card pointed in the true direction taken by the ship. This card was conveniently located near the eyepiece of the periscope so that as estimates of direction were made by the observer on another dial, the two might be compared directly and the amount of error ascertained. Models were constructed on a scale of $1/32" = 1 \text{ Ft.}$, as this dimension gave a true representation of the ship as observed through the periscope.

The apparatus is without question the nearest approach to conditions as they might occur at sea, and shows a great deal of study on the part of the men interested in the matter, in developing it. However there are various defects and drawbacks, that should be noted. No definite, scientific study of the details of the apparatus was made. The curve of the sea belt, the arrangement of the periscope, lighting, the painting of the sea and sky, all were determined, so that they appeared natural to artists familiar with sea painting. A little too much was left to the artistic temperament and imagination of these men. Nevertheless, if models are tested rigidly, leaving as little as possible to the imagination of the observer, good comparative results may be obtained with the equipment.

An idea of the appearance of a ship, as seen through a periscope, as well as a general description of the instrument as used by the Germans, is necessary in a treatment of the matter of Camouflage. For torpedo and gun fire attack, accurate observations of the speed, range and course, of a vessel must be made. In the case of torpedo attack, all such observations are made through the periscope, for the submarine is usually running below the surface, while for gun fire, after the ship is within range, the accuracy of shooting is determined by spot-firing. Periscopes are fitted with range finders, but range as well as course and

speed is rather uncertain. To allow for error, ten degrees in course, and two knots in speed are incorporated in plotting the position of the ship. An error of two thousand yards, at a range of ten thousand, has been noted in the log of one British submarine.

Dr. F. Weidert a German periscope expert expresses the difficulties of range finding from a submerged U Boat.

" Now it is already well known that correct estimations of range with the naked eye, without some means of assistance is extremely difficult, and for many people actually impossible. With one eyed vision, through an optical instrument, this is even more the case. On the other hand precise knowledge of the range is essential for many purposes, especially for the firing of torpedoes. To unite with the periscope a range finder, of sufficient merit meets indeed with serious difficulties, inasmuch as one cannot apply apparatus whose use will cause one to be prematurely seen by the opponent."

(Entwicklung und Konstruktion der Unterseebootensehrohr.)

To estimate range from a periscope there are two available methods, one to project into the eyepiece of the instrument, crosshairs divided in hundredths both vertically and horizontally, or telemeter scales. The Goerz double imagemeter may be used as well. Lindell T. Bates describes the system in his report, " The Science of Low Visibility".

"Two pictures of the same object are made to cut each other in the lens, and are shifted with reference to one another until the tops of the masts or other high points of a ship under observation in one picture are level with the water line in the other. The angle of shift is measured to determine the distance. This method too is only roughly approximate, for it has to deal with the measurement of a very small angle, and it assumes the height of the selected part of the vessel, and uses this figure for the length of base line."

In all methods used, the ship is in motion and estimates of her length on the cross hairs are necessarily very approximate, unless the observer has had long practice. Estimates in course depend on the alignment and perspective of masts, funnels, and superstructure. If the ship takes a zig-zag course it is hard to make correct estimates, and if her masts and structures are out of line either by actual construction or by perspective painting, the difficulties are greatly increased. Speed calculation depends on the triangulation method of observation, which in turn depends on the accuracy of range estimate. If the latter is in error, the speed will also be incorrect.

The efforts of the Submarine Defense Association in developing a Low Visibility painting for ships,

deserve a description at this point. Lindell T. Bates and Loyd Jones, carried out extensive experiments in the Eastman Kodak Laboratories, studying colors, and combinations of color that would blend to a flat tone at a given distance, when applied in areas of definite proportions. Actual tests of gray painting on models were made on Lake Ontario and on the Atlantic. The U.S.S. Gem, a 125 ft. patrol boat, was assigned to them by the Navy Department for such tests as might have a bearing on the matter. Under a range of 5000 yards, in clear weather, low visibility is beyond hope of attainment. Colors may blend at shorter distances, but do not give the desired tone. No flat tone pigment or paint of any description will totally absorb the light that falls upon it, and the reflective quality however slight destroys the desired effect under 5000 yds. At this range the ship will actually fade into the sky line, if painted a gray, or with such colors as will blend to gray; that is unless the ship happens to be between the sun and the attacking submarine. In which case it is impossible to hide it. Mackay and others who developed the low visibility idea, combined colors in definitely proportioned areas, and obtained a resultant gray. Any colors as red, green, and violet, that superimposed will give a white, may be used. Bates and Jones determined that a shade of gray known as Omega Gray, was best adapted

for use in the northern part of the danger zone, where the weather is about seventy percent cloudy. South of Lat. 45 degrees North, a gray of bluer tone, called Psi Gray was best. Combinations of color to give these resulting grays were Alpha blue and Beta White in equal parts for Omega Gray, and Gamma Blue and Delta White for Psi Gray. Very little difference in the result could be noted between colors applied in mixed areas or painted on as a monotone. All of which would lead to the conclusion that the desired gray be painted directly on the ship, and since such painting has not proved particularly effective as camouflage, all the work done in the matter has to a certain extent been futile. No ship however invisible can remain so very long, because of the remarkable hydrophone equipment carried on all submarines. With the apparatus in the hands of an experienced operator, it is possible to detect the presence of a ship at a range of ten or twelve miles, and to determine her approximate direction. The submersible would approach her until observations on her could be made through the periscope.

The greatest efforts have been carried on investigating systems of dazzle as invented by Lieut. Wilkinson. Any system that is to have a degree of merit, must distort the ship at a range of 1000 yards or less, so that

accurate observations may not be taken at that point. By painting the ship with bright or contrasting colors, outlines, and structures, will be broken, and if the design is good the range, course, and speed of the vessel will be in doubt, thus causing the submarine to remain near the surface longer than is altogether safe for her, while corrections in plotting are made. Her painting must be such that a maximum distortion be obtained under all conditions of weather, and light. From the slight inaccuracy of the periscope, in combination with the effect due to the human element, an error of 15 degrees in course will be sufficient to accomplish the complete upsetting of torpedo control from the submarine. If in addition an error of 2 Knots in speed or of 200 to 300 yards in range be attained, the sub is effectively blocked as a menace to shipping, so far as torpedo attack is concerned. Shell fire on the other hand necessitates the submersible coming to the surface, and resorting to spot firing. Then the only defense of the ship attacked is her armament, and the possible help of destroyers. A surprising lack of really good information in the matter is very evident, and not until the last two months of hostilities, was apparatus developed, that could in any way be depended upon to even approximate actual conditions. A few good principles were discovered, and all systems of painting

must depend on these. Nevertheless with few exceptions these principles have been completely ignored and the individual camoufleur given free rein to his imagination, and the results of his work applied to ships regardless of merit.

It would seem obvious in examining the matter that certain principles of distortion and perspective worked in a definite scheme, and with colors of sufficient contrast would accomplish all results desired. Then if the tests on such systems be reduced to as nearly a mathematical basis as is possible with so indeterminate a matter as obtains under sky and light conditions at sea, the results would be of value.

All experimental work of this thesis, has been based upon principles of distorted perspective, in combination with colors approved by the Navy Department, and which are not effected by color screens to any appreciable extent. An effort has been made to reduce the matter to a mathematical basis. With perspective designs, any desired concentration of dark or light color may be made, in order to satisfy the principle that large masses of color at bow, stern and superstructure, have a distorting effect. It is a fact that no actual perspective design appears in the approved list of the Bureau, until nearly the end of the war. Then several such designs were distributed for

application to ships, showing that the value of the method had become apparent. As a matter of fact it had become certain towards the cessation of hostilities, that the effectiveness of the submarine as a weapon of offense had been greatly lessened in value, because of the perfection of the hydrophone as applied to fleets of small, swift craft, in conjunction with the use of the depth charge. A submarine in motion, within the range of a listening device was surely doomed. The ferrets of chasers, could find her, and stay with her, until an "egg" could be successfully dropped, when she might either come to the surface disabled, and surrender or lie to on the bottom and perish. In spite of this fact, the subject has a certain fascination, and the work of this thesis will strive to bring out certain points that may be of value, if the matter should ever come into prominence again, as it will probably never do. There is the possibility of sound and vibration deflectors being used by submarines, so that the effectiveness of the hydrophone may be greatly lessened. Such general principles as proved of value in research, have been used here, and will be incorporated in the aims of the work, while in addition an effort will be made to prove the value of certain basic principles of perspective painting. The apparatus described in the first pages has been used in such a manner as to simulate actual

conditions and to reduce the results to as nearly a scientific basis, as the rather vague and artificial conditions will allow. In general the apparatus has four distinct sky scapes, clear blue sky; hazy, dull sky, in which cumulus clouds predominate; dark storm clouds, touched with color, including tints of orange, yellow, and patches of blue; finally, the typical ragged shore lines that occur along the English and French coasts. The sea scapes have the effect of toning the sky and reflecting lights on the ship, but do not occur directly as a background. In this case four types of sea are painted on the canvas belt: calm blue, summer sea; bright green water, slightly ruffled; dull gray, hazy sea; and rough white capped choppy weather. It is very difficult to determine exactly which sea or how many different seas may be combined effectively with a given sky, to seem real, and have the basis of possibility. A short table of effects used in tests made will show the difficulties of the matter.

It was assumed that the following sea scapes might occur with a given sky.

With
Clear Blue Sky.
It is very important
consider the angle from
which the sun strikes
the ship.

On a calm day, with a slight
haze, the sea might be blue; then
with hard metallic sunlight, a
green sea might result; and on

a clear, windy fall day a choppy blue sea would occur.

Hazy Sky.

All four effects of sea might occur, if the lighting were properly regulated.

Storm Sky.

Either the dull, flat sea if the wind had not ruffled it, or if the squally or puffy, winds were blowing the dark rough chop would result.

Shore line.

Practically any one of the four might occur with proper lighting.

It must be remembered that the play of light is ever changing, toning down in places, increasing brilliancy in others, and at every change having some effect on whatever object appears on the face of the sea. To extend a series of observations on actual painted ships under such conditions would be long, tedious, expensive and of doubtful accuracy, because but one or two ships could be obtained for such experiments. In trying to attain some reliable simulation of actual conditions on painted scenery, and artificial light, one is convinced of the rather hopeless aspect of the task. However the work will be carried on

using any little knowledge acquired at sea and along the New England coast, of lights and shadows, applied to the apparatus at hand. As many combinations of sky, sea and light will be used as seem possible, and because it is not practicable to use a moving model and a given range, there remains but one object to attain., that of altering the course. It is true that if this can be done successfully, the range and the speed will almost automatically be changed. Although there many atmospheric factors entering the problem of the ship at sea, and all of them, as refraction , and haze, helping towards a distortion, since the tests under artificial conditions must be made as severe as possible, an alteration of course of not less than 18 degrees must be made by the painting. Two angles for each design will be judged by each of six observers, and under the four different skies, with changing sea and light. It will be attempted to have no two scenes alike, that is either the light or the sea will change, and the resulting shadows will tend to alter the aspect of the ship. The actual angle of progress will be noted, the estimated angle, and the error, in tables prepared. Errors for each ship will be averaged for each observer, and compared, then the average of all the observers taken. This seems to be the only way of reducing the matter to anything near a fair basis. A study of the methods of

precision of measurements, although usually understood to apply to direct mathematical measurements, may also be applied to indirect measurements, and the case in hand is comparable to certain calculations entailed in chemical combinations, where precision has been applied. The final average angle of deviation on each ship will be used as the basis of the effectiveness of design. Distances at which observations are to be made, must be severe, in trying the ship, so ranges of 1100 yards in four cases, and of 2200 yards in the other two have been chosen. Actually very few attacks at such range would occur. Any attempts at low visibility dazzle seem rather impossible here, but in one or two cases tried that prove of value, the results will be analyzed for a possible bearing on the subject.

Fortunately the first observer is a Lieutenant in one of the European Navies, and is entirely familiar with ships, periscopes, range finders, and conditions at sea in general, under which observations might occur. Before estimating course he became familiar with each design, so that any errors made will be in spite of a previous knowledge of the ship. Repeated observations on a design with no limit to the time allowed, would seem to ably care for possibility of the submarine commander becoming familiar with a given design. If errors are per-

sistently made and greater than the required 18 degrees the object would certainly be gained, especially at sea with atmospheric conditions aiding. The second observer has been very closely in touch with the evolution and application of each design, and has made repeated observations on them, in fact offered valuable suggestions in the progress of the work. The third set of observations was made by four different individuals. None of them was familiar with the painting, previous to his observations on the apparatus, so that all were unbiased by a previous knowledge of what to expect from a design. All of these last are entirely familiar with ship structures, with principles of perspective, and optical illusions, as well as conditions of light and shadow at sea. Conditions of observation have as stated been made as severe as could possibly be expected, and results obtained will indicate fairly the merits or failure of the following principles.

From reports and data available it is certain that camouflage must accomplish the following results. All high vertical points, as masts, stacks, superstructures, must be distorted, so that no estimate of course can be made by lining them up. To accomplish this, one mast alone should be used, and that as short as compatible with the efficient operation of the wireless.

If two or more masts are absolutely necessary, they must not be placed on the center line of the ship, but staggered. The stacks must be short, if necessary forced draft should be resorted to, in order that the desired result be accomplished. False superstructures may be used, but it is better not to depend on them, for they must be of rigid construction to stand weather, are cumbersome and more or less of an expense to construct. To aid in preventing the lining up of masts, corresponding parts should not be painted the same color. That is, the tops should not both be white, or both black, if these two pigments were to be used. One top should be white, the other black. Now at no time will both be plainly visible, one will blend more or less with practically any background. This is increasingly true of colors to be discussed later. There are two methods of concealing superstructure and false works, and between them there is little to choose in results obtained. One is somewhat more simple of application to the ship than the other. Any scheme of distortion, or perspective painting on the hull should be adequately and consistently carried into the superstructure. The other method depends on black or some other dark color as violet for its effect. In this case the entire structure, the forward and aft vertical surfaces, the lower part of the stack, are all painted the dark monotone, and the result is quite remarkable, in that it is almost impossible to determine angles or lengths.

This method really carries out any hull design and more less accentuates contrasts. The top of the stack should be painted with the lighter tones used on the hull. In approaching the treatment of the hull, a word of the lines on which the Bureau was proceeding at the time hostilities ceased. The ship was considered to have three main divisions, bow, midships, and stern. The bow is made to turn away in the painting, by the use of light, pale colors, in small divisions. The midship section is devoted to breaking of outlines, The stern is made to turn towards the observer. Production of shapes in the three divisions should be made with three things constantly in mind.

a. that there should be a continuous perspective design through the three spaces;

b. that the important forms be constructed with a large and a small end, and the small end painted forward;

c. in every case where it is possible, that all important lines point downward from the stern to the bow.

This last may be questioned in the light of experiment, and will be considered later in the results obtained.

Instead of trying to imitate the stern on the bow, as often practised, the stern should be brought forward to the quarter.

These principles are the basis of the work here, that while breaking of outline is absolutely necessary it is not essential

to blotch colors on the side of the ship in contrasting masses, in an artistically hit or miss way, but all effects striven for may be combined with some phase of application of principles of perspective. Any color of desired intensity may be applied at any designated part of the ship, but in such a way that it has a definite part in the scheme of things. Lines may be smooth but not monotonous, that is simply because a line or painted strip may be followed by the eye it may not be possible to determine direction, particularly if it is given a turning movement. The same curve appearing concave at one moment with a very slight change of light will seem to be convex. When contrasting colors are arranged in any good perspective design it is practically impossible to determine the ship's course accurately. Twenty four designs have been used in this work, and all of them employ some perspective or converging line principle. No two are in any way similar and might be painted with practically any one of the combinations to be discussed later and be of value. The best twelve designs will be carried through a complete discussion, and conclusions as to their respective merits drawn. All observations will be made under the foregoing conditions.

In deciding on colors that may be used advantageously it is safe to discard brilliant colors. All those described will be designated by standard Navy Camouflage terminology. Twenty flat tone pigments have been prepared and tested.

Some of these have been discarded, while those used are as follows:

Black, white, Gray white, No. 4 Gray, No. 1 Gray, No. 1 Gray Pink, No. 3 Pink, No. 1. Gray Green, No. 1 Green., No. 1. Blue, No. 3, Blue, Lavender, Violet. Yellow.

Any intensity or tone with this range has been possible, but none of the designs have made use of other tones than those indicated. Decks have in each case been painted with No. 1. Gray. It will remain for the results of experiment to give various combinations in which these colors may be used effectively. Designs have been made as simple as possible with the idea always in mind that they have to be applied to the side of a vessel. As few colors have been used in a design as will attain the object of contrast.

Black.



No. 4. Gray.



No. 1. Gray.



Gray White.



No. 1. Gray Pink.



No. 3. Pink.



Yellow.



No. 1. Green.



No. 1. Gray Green.



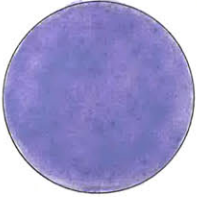
No. 1. Blue.



No. 3. Blue.



Lavender.



Violet.



Design 1.

This design is the simplest possible application of perspective. All lines converge at a point either actually, as the arrow head at the bow, or the bounding lines of the other figures produced. The masts are treated so that the gray and the pink divisions will at no time stand out from a background simultaneously. The gray patches from the hull are produced to stack and superstructure. At first glance the choice of the gray and pink would seem rather poor, but they have a very decided degree of contrast and have proved most effective in actual tests.

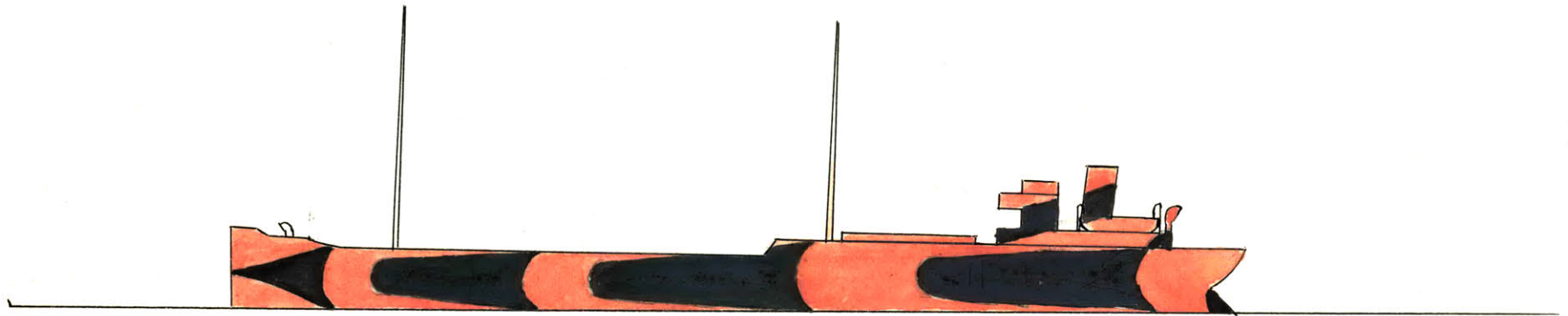
Design 1.



No. 4. GRAY



No. 3 PINK



The photographs of the various models give a slight idea of the ship as observed through the periscope. It was impossible to focus the camera through the periscope lens, so the pictures were taken from a slight elevation; that is the camera lens could not be brought close enough to the water level to absolutely eliminate the sea from the background. Because of this fact it is possible to guess the direction travelled by the ship, much better than if it appeared wholly against the sky.

These photographic reproductions represent the maximum effect that can be attained by the use of color screens. In order to approximate this effect in actual observations, it is necessary to devise a system of screens that in a very short interval of time will eliminate the red and green tones from the ship, and cause it to approach a flat painted surface in appearance. Observations may not be prolonged more than thirty or forty seconds.



In this case the single mast is quite effectually blocked out of the skyline, with the exception of the very top, which would not be useful in determining the size or course of the ship. The design is simple, but the actual effect of the colors is necessary for distortion.

Ship is headed 30 degrees away from the observer.

Design 1.

	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual Angle	Estimated Angle	Error Angle	Actual	Est.	Error
Clear	140	110	30	64	280	216	50	64	14
	60	190	130	52	68	16	122	90	32
Hazy	135	122	13	54	44	10	52	120	68
	58	110	42	128	56	72	130	240	110
Storm	112	62	50	128	72	56	135	42	93
	75	60	15	58	72	14	52	50	2
Cliffs	112	66	46	46	110	64	51	52	1
	112	66	46	126	66	60	126	136	10

Average angle of error 50 degrees.

Average of three sets of observations for each sky. Results used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees.	38	53.5	73	38

Average angle of error assuming that with a white or black background no error would be made. 36.

Black used on the ship as it would be painted in
Normal times.

Angles of Error in Observation.

	Clear	Hazy	Storm	Cliffs
Degrees.	2	8	5	3

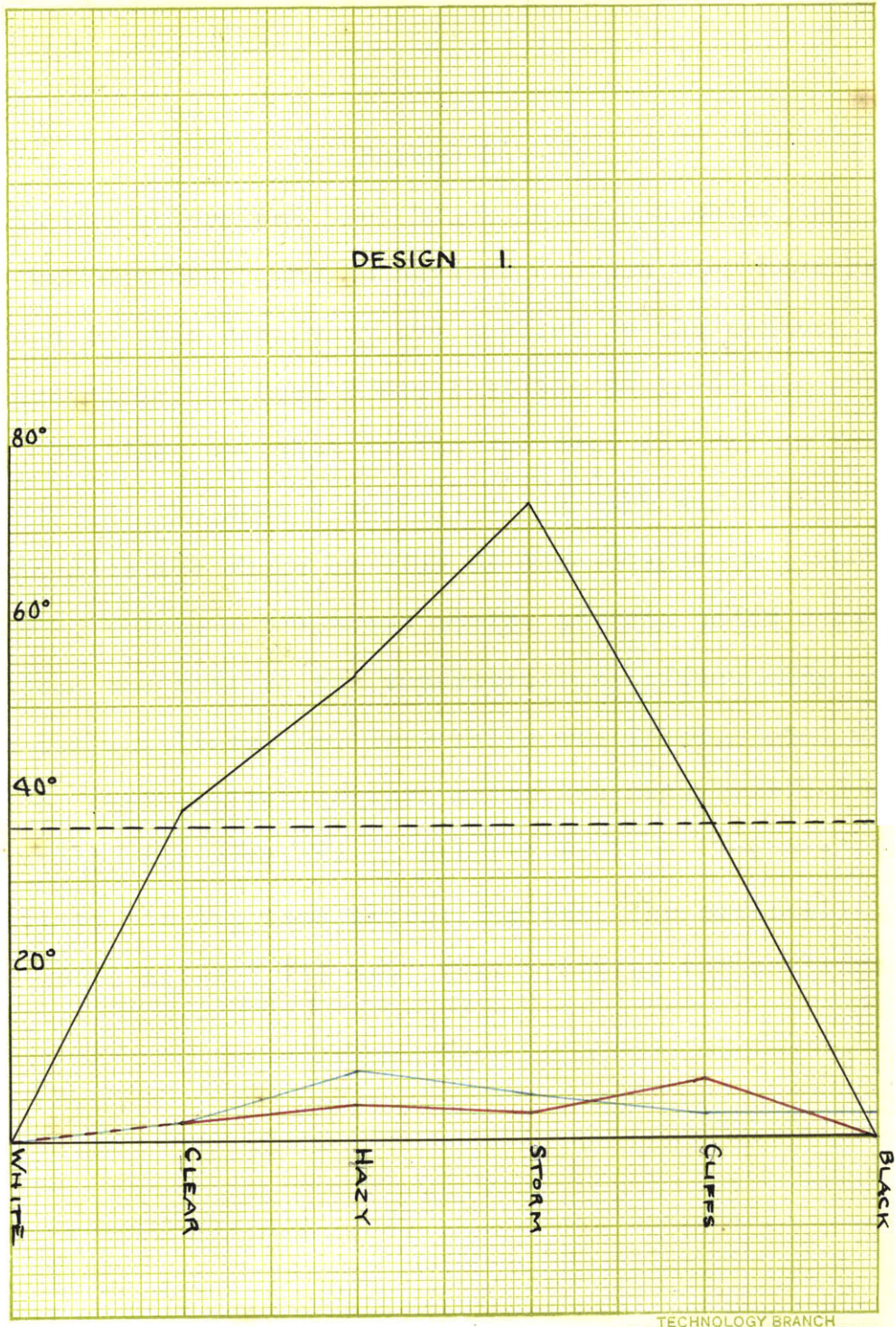
Gray used on ship as it would be painted in
normal times.

Angles of Error in Observation.

	Clear	Hazy	Storm	Cliffs
Degrees	2	4	3	7

These results are plotted with each design in order that a di-
rect comparison may be made in each case.

A word is necessary in explanation of the method of plotting the results of observations, so that a direct comparison of designs may be made. The average angle of error for each sky has been plotted against that sky as abscissa. With a white background the error has been assumed to be zero, which assumption is borne out by actual test. It will be noted that starting with white the sky scapes are graduated as clear, hazy, storm, cliffs and black. In the latter case the error is assumed to be zero. The areas under the straight line plots are a quantitative measure of the effectiveness of the designs as camouflage, and by comparing them the relative merits of designs are clearly brought out. The results of observations on black and gray ships as painted in a monotone are incorporated in each plot, so that the camouflaged ships may be compared with these. The solid black curve indicates errors in the case of the camouflaged ship. The broken black line, indicates the average under all conditions of weather. The blue line, represents the errors in the case of the black ship. The red one, errors made in estimating course for the gray one.



Design 2.

It was determined that black, blue and white had a maximum contrast, and in several designs they have been utilized. In this case they are applied in the converging line principle, in such a way that the peaks of all areas cannot be lined up, that is the eye does not follow from one point to the next directly. It is very difficult to determine the shape or size of superstructure, when painted black, and here the broad stripe of this color carried from the hull to the superstructure effectually blots the out lines. No. Gray white was incorporated with the idea that against certain skies and under various weather conditions, the sections so painted would be lessened in visibility, in the same proportion that the contrasting parts would attract the eye, thus breaking the outlines.

DESIGN 2.



BLACK



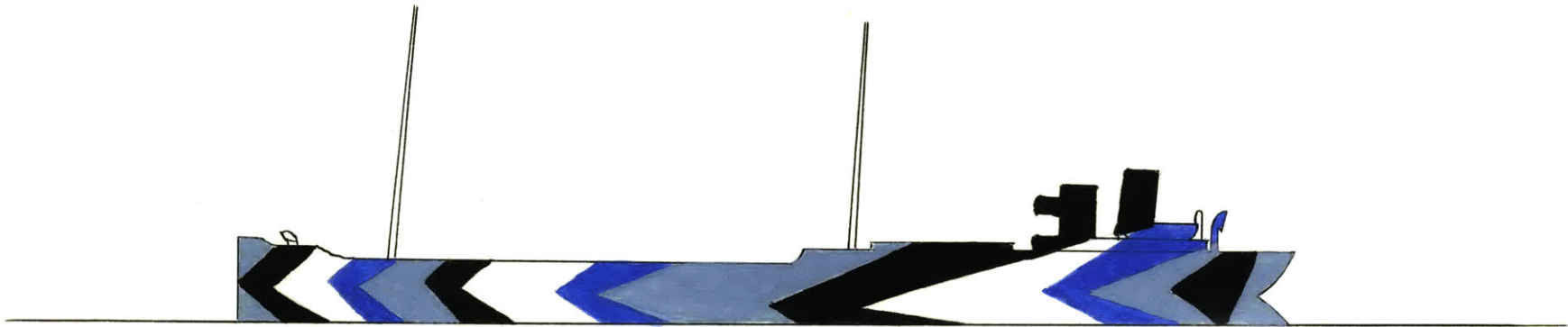
WHITE



NO. 2. GRAY



NO. 4. BLUE





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Page 34 has been omitted due to a pagination error by the author.



From this picture it might be assumed that the ship was approaching the observer at an angle of maybe ten degrees from the horizontal. Actually it is much greater than this being 30 degrees.

Design 2.

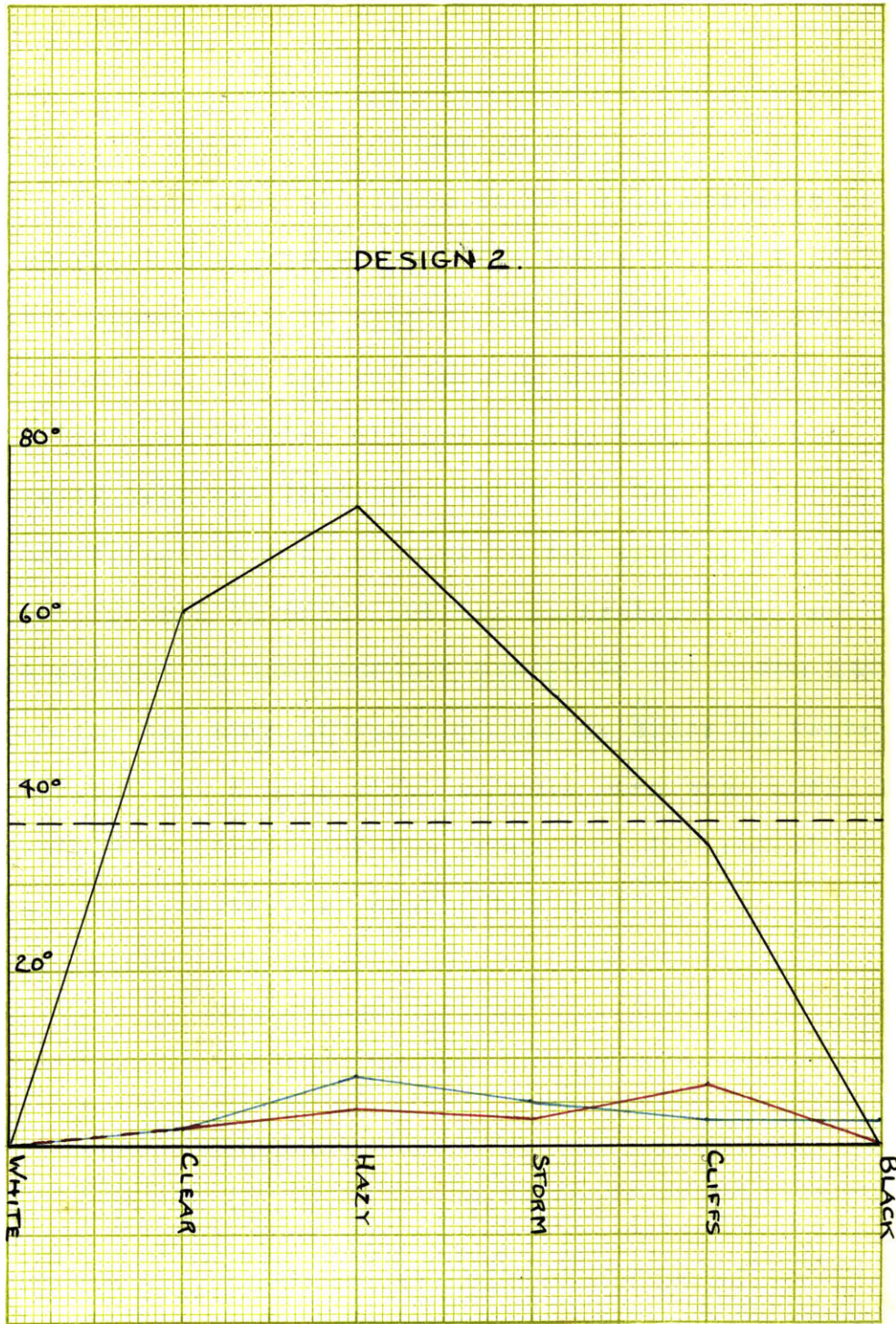
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual Angle	Estimated Angle	Error Angle	Actual	Est.	Error
Clear	232	300	68	292	294	2	302	322	20
	225	318	93	-	-	-	235	296	61
Hazy	300	244	56	296	230	66	300	130	170
	238	246	8	230	290	60	230	310	80
Storm	314	298	16	234	292	58	302	286	16
	250	290	40	312	300	12	242	62	180
Cliffs	292	300	8	242	280	38	240	124	116
	242	258	16	308	286	22	303	310	7

Average angle of error 54 degrees.

Average of six observations for each sky. The results to be Used in plotting.

	Clear	Hazy	Storm	Cliffs
Degrees	61	73	53.6	34.5

Average angle of error, assuming that with a white or black background no error would be made. 37 degrees



Design 3.

In this case all lines on the hull converge at a point, forward of the ship and a little above it. This vanishing point system used in nearly all cases is most effective in obtaining the desired turning movement of the ship. The narrower lighter stripes at the bow, also tend to turn it from the observer, while the heavier striped stern brings it into prominence and towards the observer. Black is used to paint out the superstructure, and the masts are painted in the accepted manner. No. 1. Green has been used for the sake of variety, and in order to test its value, but No. 3 Blue might as well have been used. It is possible to screen out the green, but the resulting black will serve very nearly the same purpose in distortion.

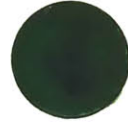
DESIGN 3.



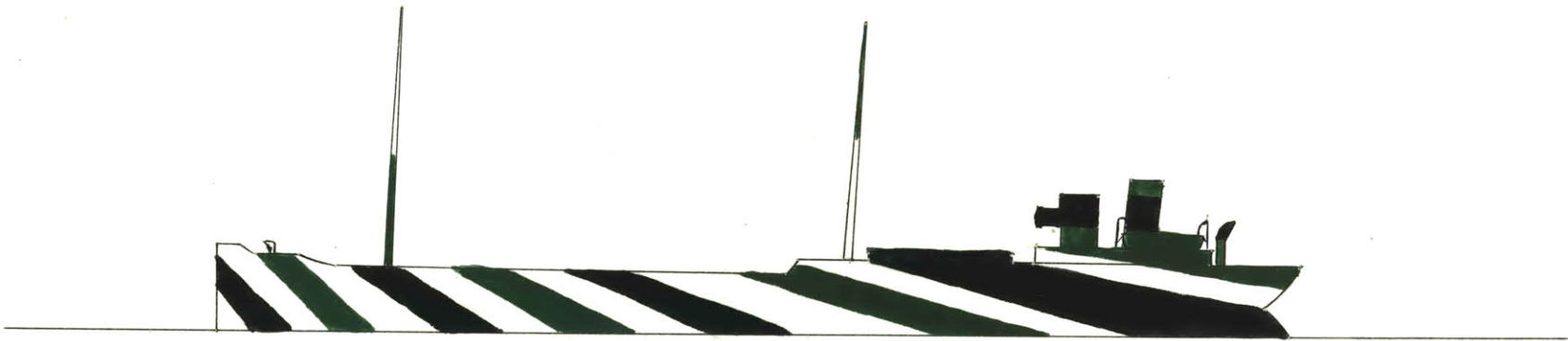
BLACK



WHITE



NO. 1. GREEN





The ship would seem to be headed away from the observer. It is coming ahead at an angle of 30 degrees. The masts are out of line, which helps the distortion. The design indicates very well the effect of lines converging at some vanishing point, and also that even a simple one may give excellent results.

Design 3.

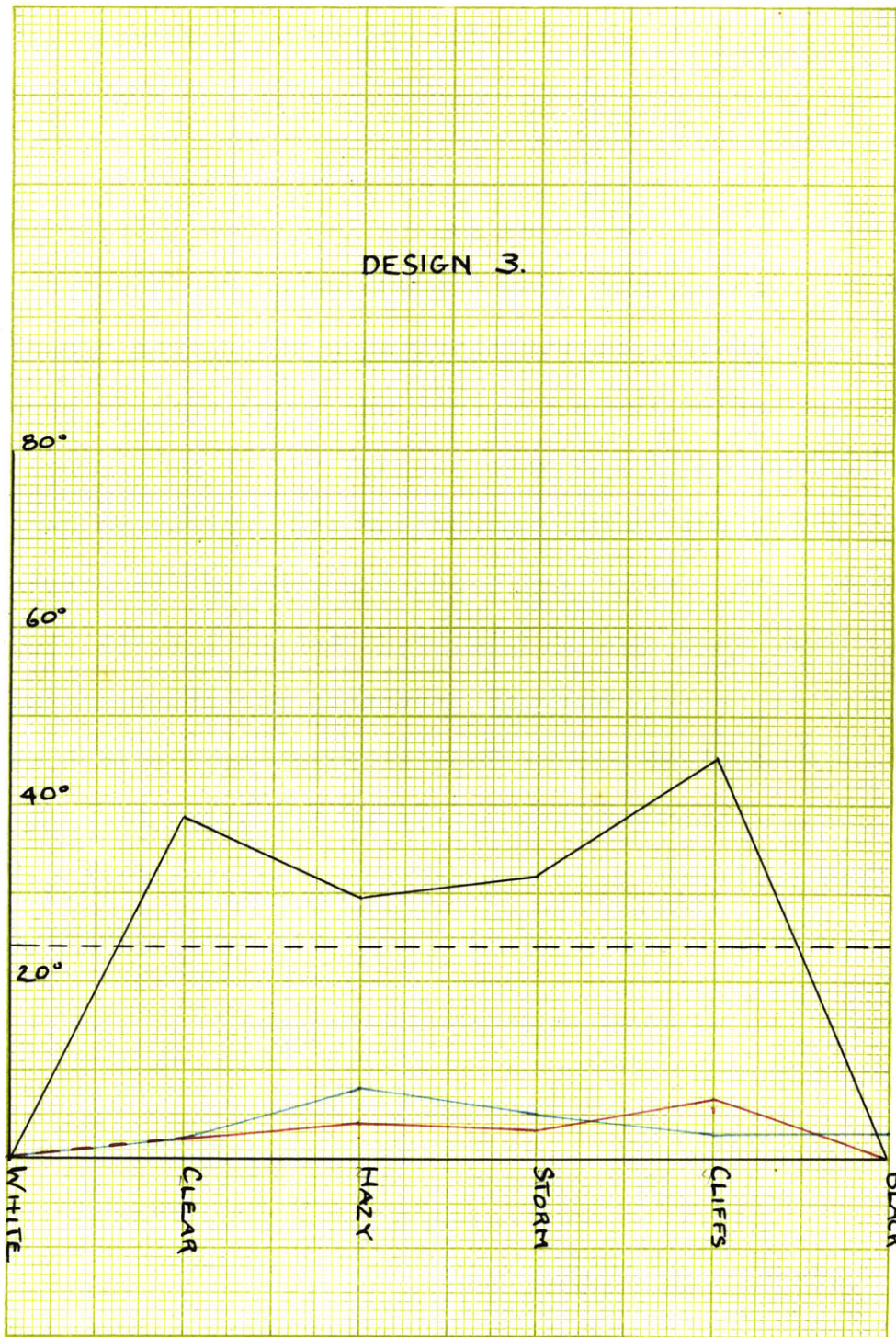
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	46	126	80	57	56	1	60	120	60
	49	52	3	118	70	48	130	130	0
Hazy	112	118	6	112	90	22	120	135	15
	58	30	28	60	60	0	50	126	76
Storm	120	70	50	60	58	2	128	54	74
	140	150	10	176	54	52	64	58	6
Cliffs	110	60	50	120	76	44	56	150	94
	120	60	60	52	60	12	130	120	10

Average angle of error 36.2 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs
Degrees	38.4	29.6	32	45

Average angle of error, assuming that with a white or black Background there would be no error. 24 degrees



Design 4.

The first three designs were painted on a tramp steamer having her superstructure and stacks aft. Because of this fact, the distortion was rather harder to affect, than in the present case where the structure comes amidships. Two vanishing points, one above the bow forward of the ship and the other below, have been used. It is intended that the bow turn away, and the stern towards the observer. The combination of black, No. 3 Blue, and White is good in all designs, the black and white for contrast, and the blue because it is very difficult to focus the eye upon. Here the design is carried from the hull into the superstructure.

DESIGN 4.



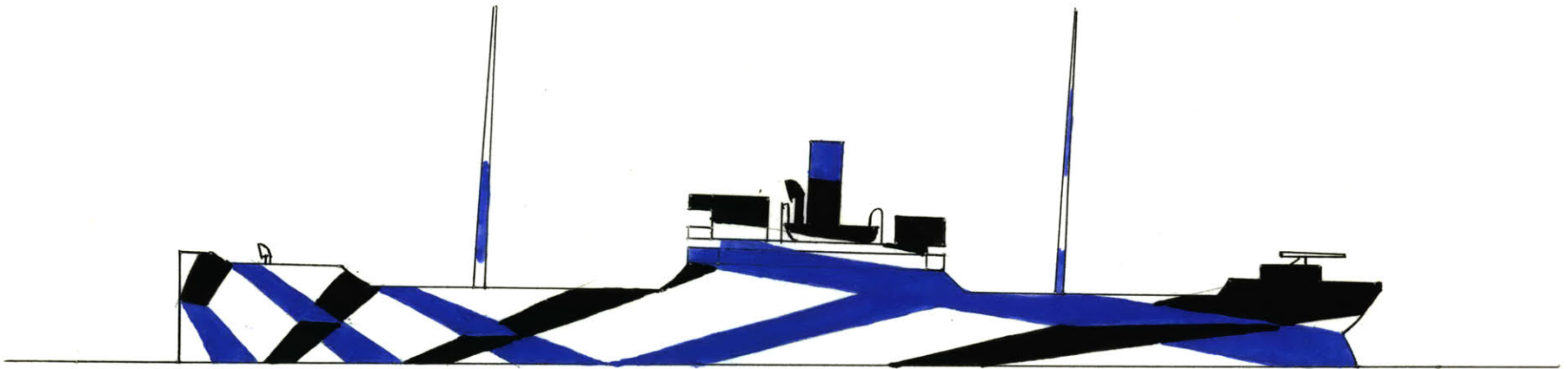
BLACK



WHITE



No. 3 BLUE.





Here the double vanishing point turns the ship farther away from the observer than it actually is. Its true direction is 20 degrees astern, but it might be anything up to 45 degrees.

Design 4.

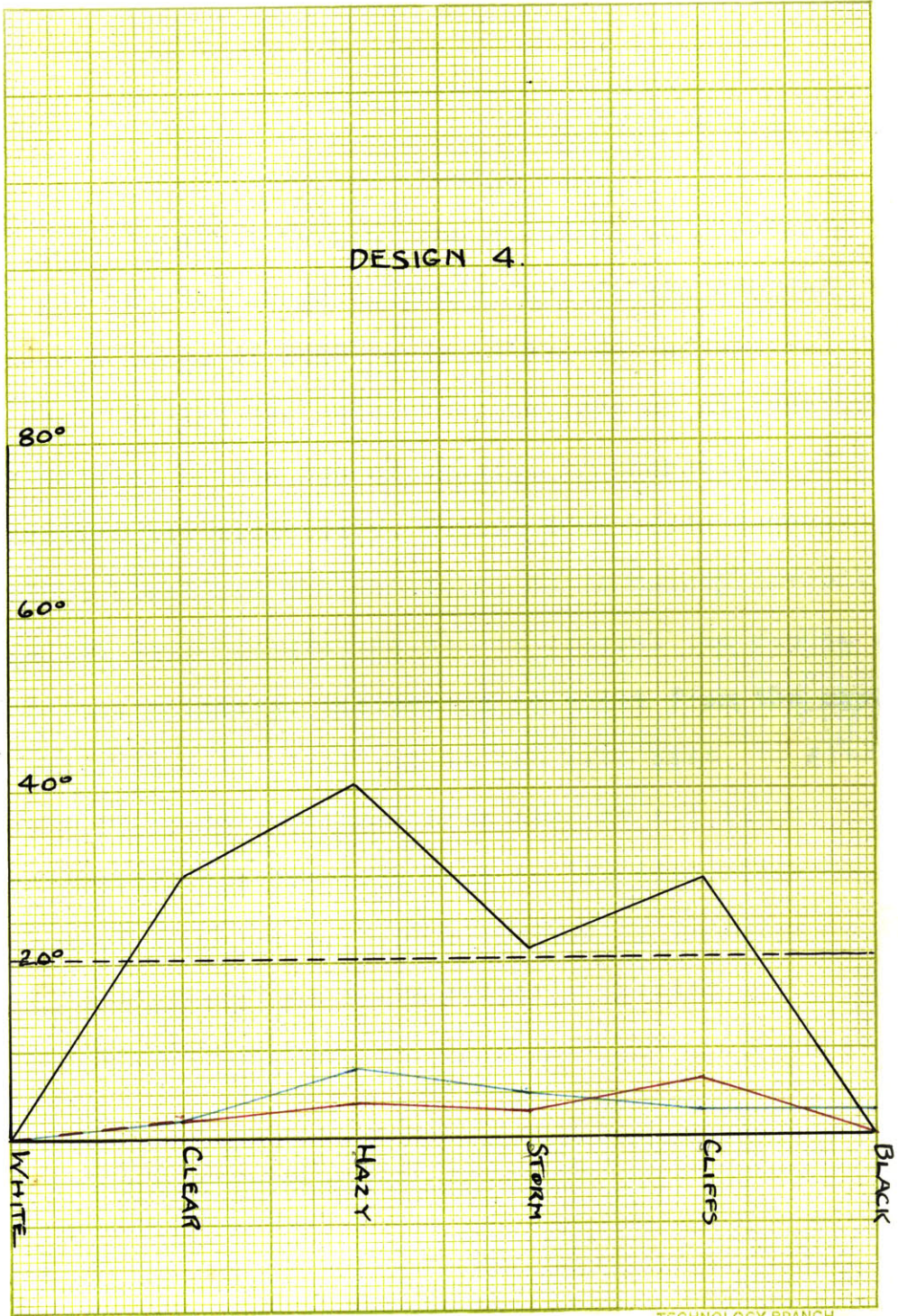
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	46	54	8	47	74	27	120	60	60
	114	86	28	128	77	51	235	228	7
Hazy	54	118	64	126	62	64	50	64	14
	116	124	8	128	112	16	128	50	78
Storm	120	110	10	44	60	16	118	60	58
	42	45	3	117	80	37	54	48	6
Cliffs	120	62	58	46	86	10	128	54	74
	78	76	2	122	80	42	35	148	113

Average angle of error 35.5 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs
Degrees	30	40.6	21.6	29.6

Average angle of error assuming that with a white or black background there would be no error. 20.3 degrees



Design 5.

Low visibility has been discussed at considerable length in the foregoing pages, and it was decided that under a range of 5000 yards it was not effective. The present design was made with the idea of at tempting to dazzle, by the use of colors, in themselves of comparative low visibility. Beyond 3000 yards however the colors blend and the monotone, while nearly invisible against some backgrounds has in general the faults of monotone painting. The design is built from the arcs of circles, and if other colors had been used, to give contrast it would have been effective at all ranges. As it is however, the interest lies in its distortion to the range of 3000 yards. Superstructure is included in the hull design and masts are properly treated.

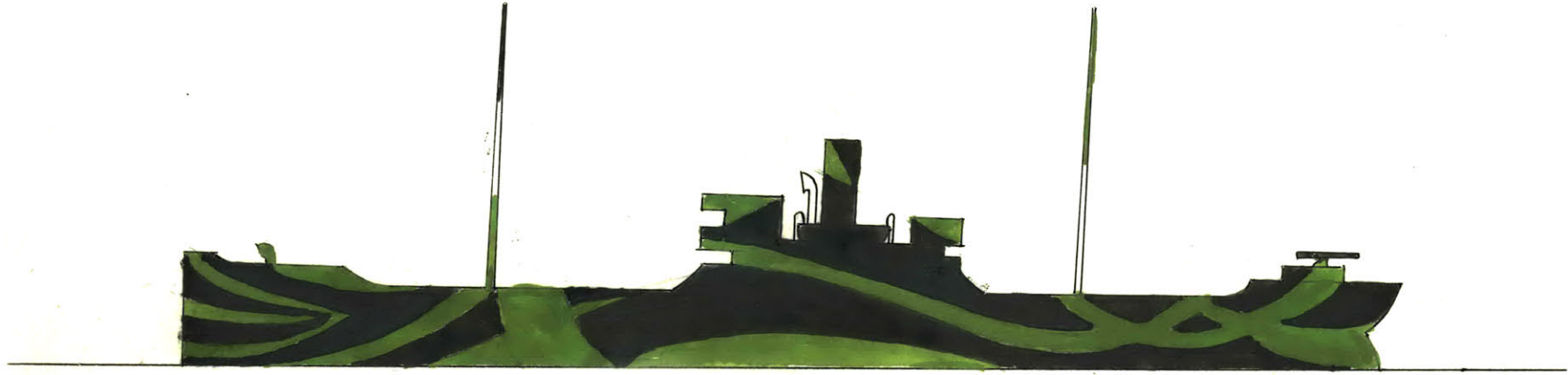
DESIGN 5.



No. 4. GRAY



No. 1. LIGHT GREEN.





The gray and green used here blend to a flat tone, on the plate and quite effectively alter the course. This gray is the result of using two colors of marked contrast yet even with the naked eye at a range of about fifteen hundred yards, the colors have a tendency to blend.

Actual direction 25 degrees towards the observer.

Design 5.

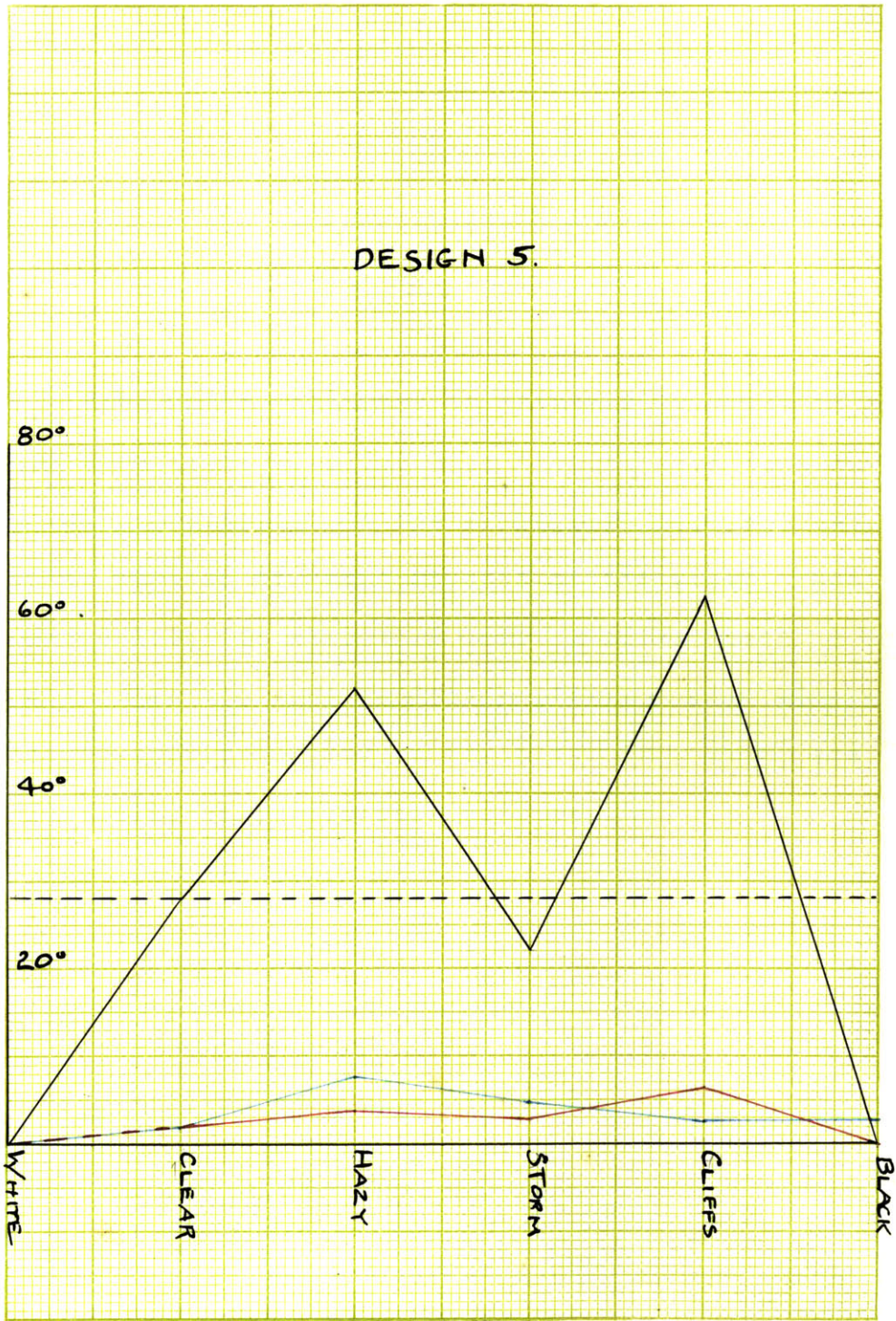
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	125	112	13	128	114	14	125	68	57
	46	38	8	126	120	6	126	54	72
Hazy	130	146	16	80	100	20	120	280	160
	50	64	14	142	102	40	160	98	62
Storm	48	72	24	126	78	48	60	86	26
	122	110	12	52	68	16	48	50	2
Cliffs	122	70	52	49	62	13	128	114	14
	60	68	8	120	116	4	136	116	20

Average angle of error 41.1 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees	28	52	22	62.5

Average angle of error assuming that with a white or black background there would be no error. 28 degrees.



Design 6.

Here again, contrast is obtained by means of colors, that were never considered in the research work during the war. The design is one of reverse perspective. Violet applied in broad stripes at the stern, when carried into the structure acts as effectively as black would under the same conditions. It is a very simple design, easily applied to the side of a ship, and effectually breaks up the outlines.

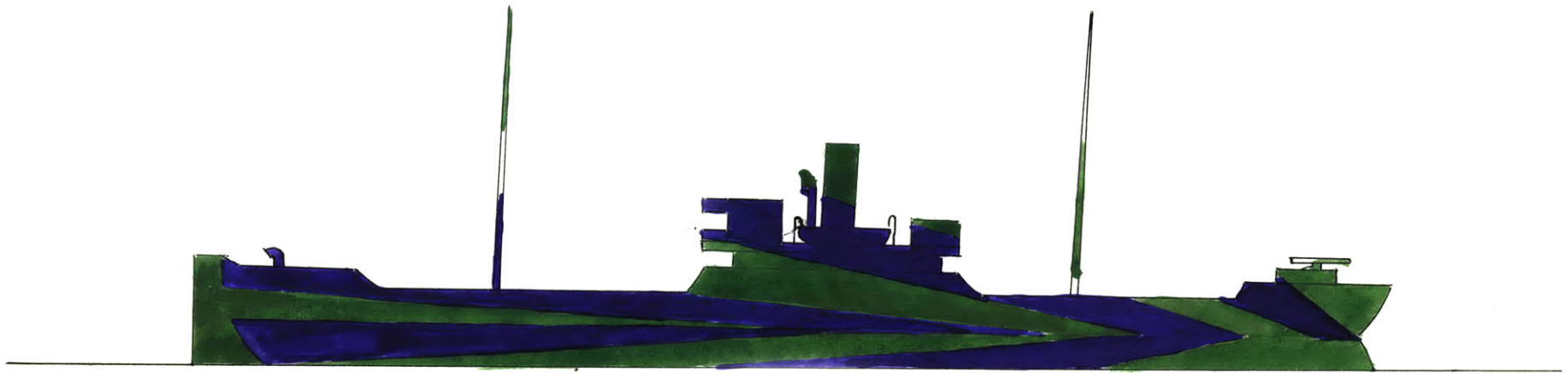
DESIGN 6.



VIOLET



NO. 1. GREEN.





In this case as in the last, the gray results from a combination of contrasting colors, dark purple and bright green. Both examples of low visibility show the good qualities of this method of painting, that is the ability to blur outlines, by their use. Maximum effects however are attained with colors of more decided contrast.

Actual direction 20 degrees towards the observer.

Design 6.

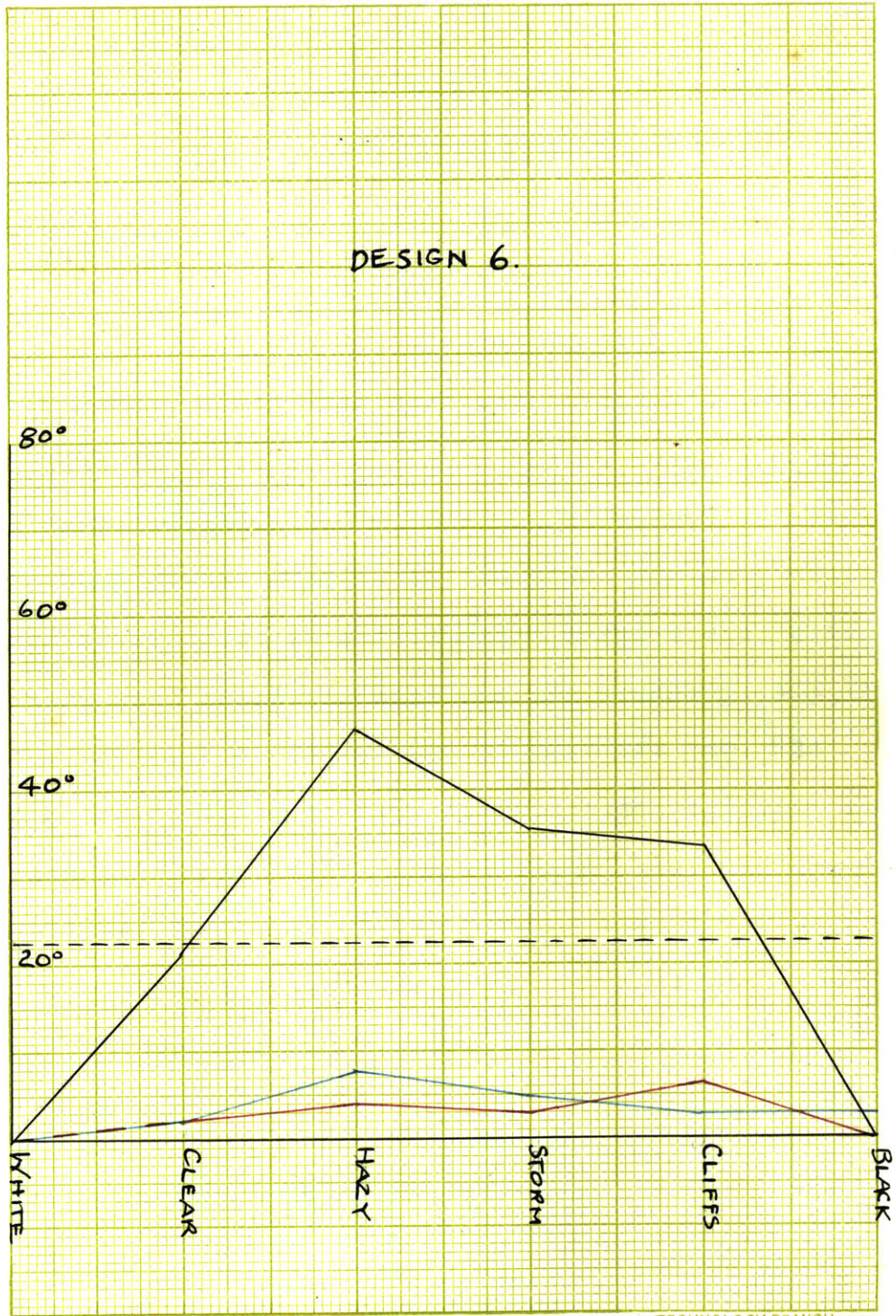
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	45	124	79	49	74	25	114	112	2
	52	130	8	134	86	38	46	50	4
Hazy	138	42	96	64	100	36	122	128	6
	130	70	60	136	130	6	42	120	78
Storm	122	66	56	38	72	34	131	60	71
	46	34	12	32	60	28	309	300	9
Cliffs	60	42	18	41	66	25	123	92	31
	42	120	78	134	106	28	72	52	20

Average angle of error 38 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees	21	47	35.3	33.3

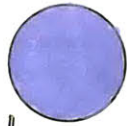
Average angle of error, assuming that with a white or black background there would be no error. 22.7 degrees.



Design 7.

Mackay determined that red, green and lavender, applied in small areas, would give a resulting gray tone of warm hue, and would attain the effect of low visibility. The same colors applied to the passenger ship of the type here considered, in sufficiently large areas, gives a very good result in dazzling the observer. All lines converge at a vanishing point, near the bow. The lavender attracts the eye less than the brighter colors, green and pink, and has the effect of blotting the outlines. The curve at the bow has a tendency to twist it away from the observer.

DESIGN 7.



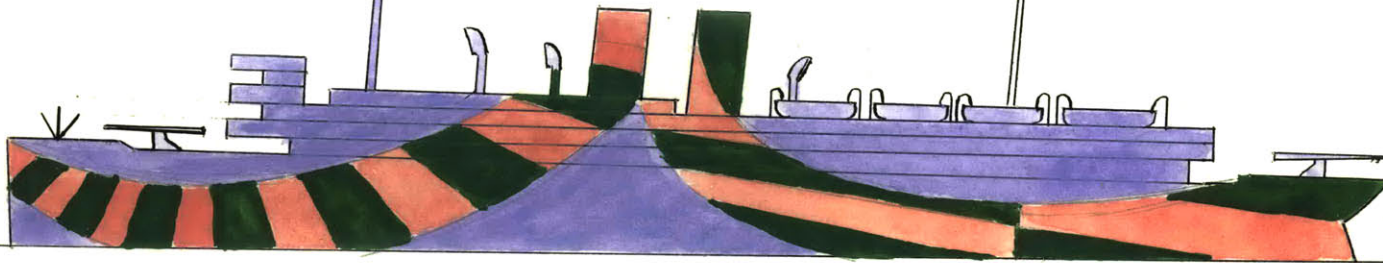
LAVENDER



NO. 3. PINK



NO. 1. GREEN.





The combination of curves and vanishing points actually turns the ship away, very effectively in natural colors, while here the camera has nearly neutralized the effect.

Actual direction 30 degrees towards the observer.

Design 7.

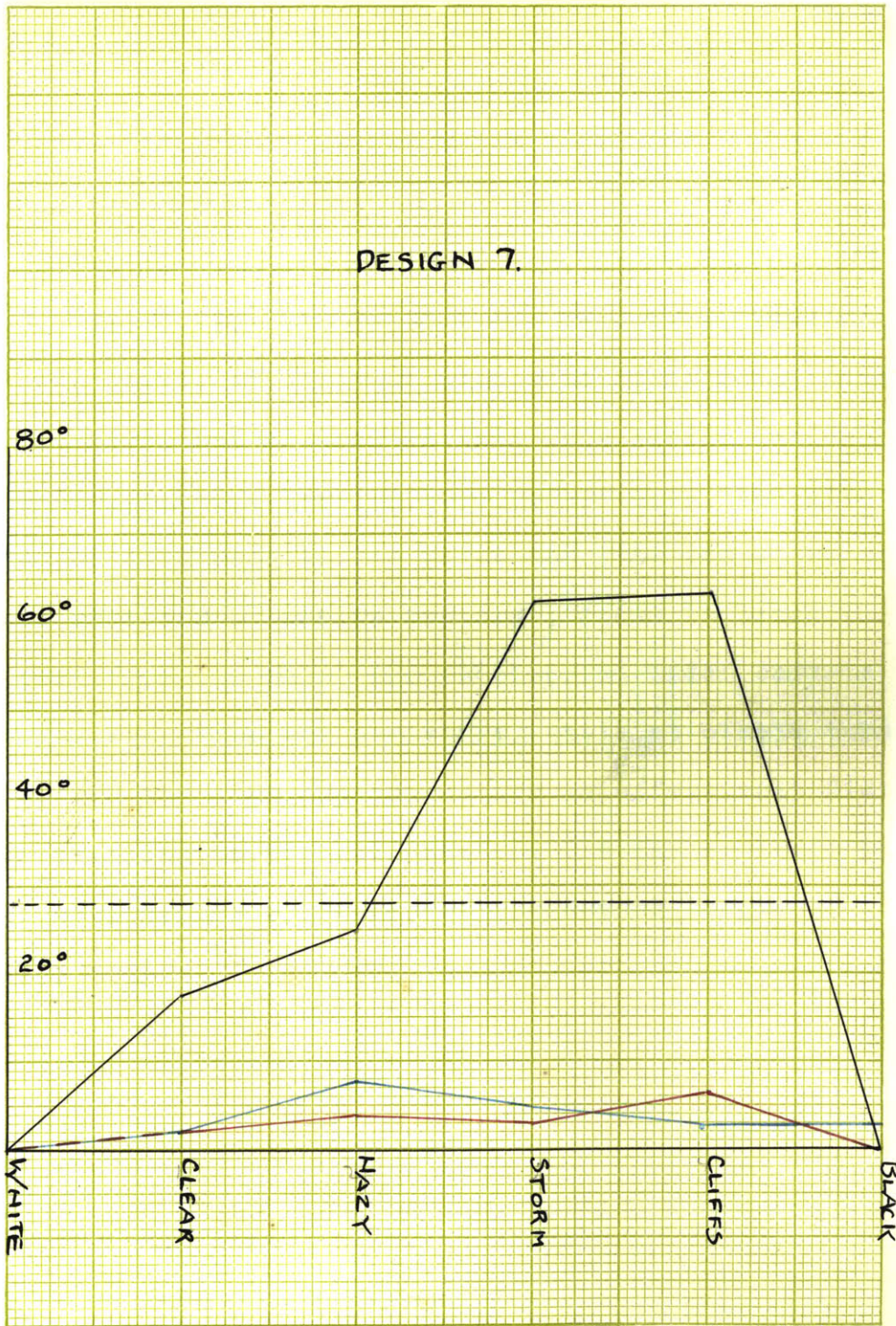
	First Observer			Second Observer			Third Observer.		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	230	252	22	232	260	52	303	302	1
	216	220	4	307	294	13	130	150	20
Hazy	312	240	72	308	314	6	232	240	8
	238	240	2	232	290	58	316	308	2
Storm	242	60	178	300	260	40	305	350	45
	314	314	0	306	270	36	232	220	12
Cliffs.	232	304	72	302	250	52	303	302	2
	230	270	40	232	260	28	224	40	174

Average angle of error 39.2 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees	17.5	25	62	63

Average angle of error assuming that with a white or black background there would be no error 28 degrees.



Design 8.

No. 3 Blue and light green used here, have not the great degree of contrast that some other combinations will give, but as used in this type design, which might be designated a herring bone perspective, they give rather good results. The point near the bow at which the two sections of design converge, seems to break the bow apart from the ship, and as observed under certain light, turns away from the periscope, while at others turns towards the lens. Superstructure is effectively distorted by carrying on the hull design. The rather large masses of blue at the stern render the actual length of the ship vague.

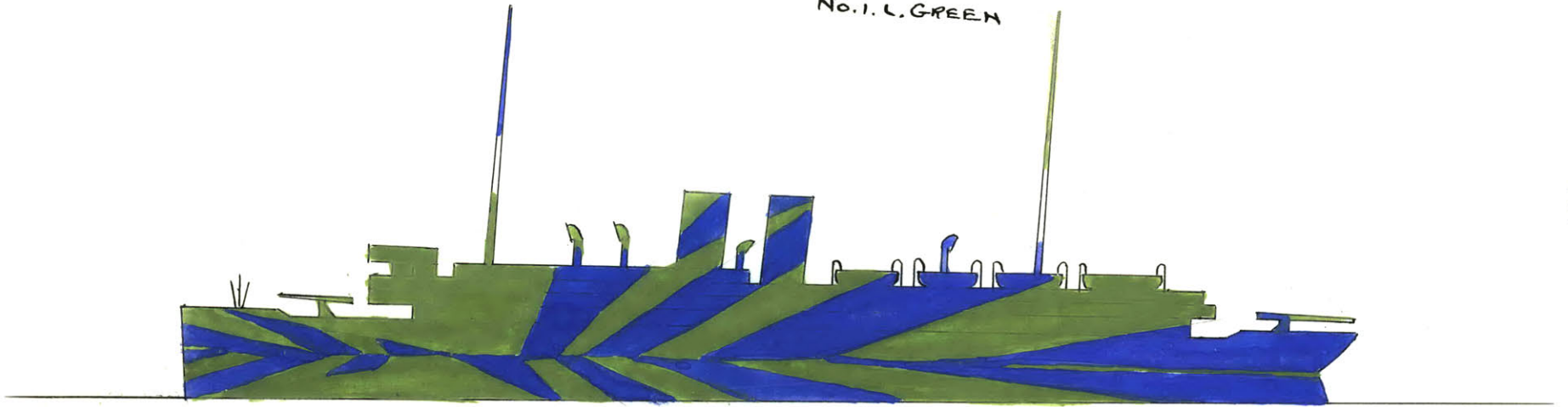
DESIGN 8₃

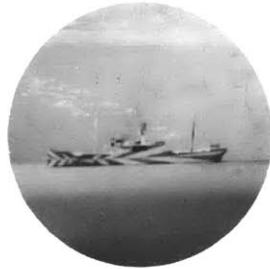


NO. 3. BLUE



NO. 1. L. GREEN





The pattern has been decidedly altered on the negative, while actually the light parts of the picture are a medium blue on the ship, and the dark are light green. In spite of this change the contrast is about the same.

Actual direction 30 degrees towards the observer.

Design 8.

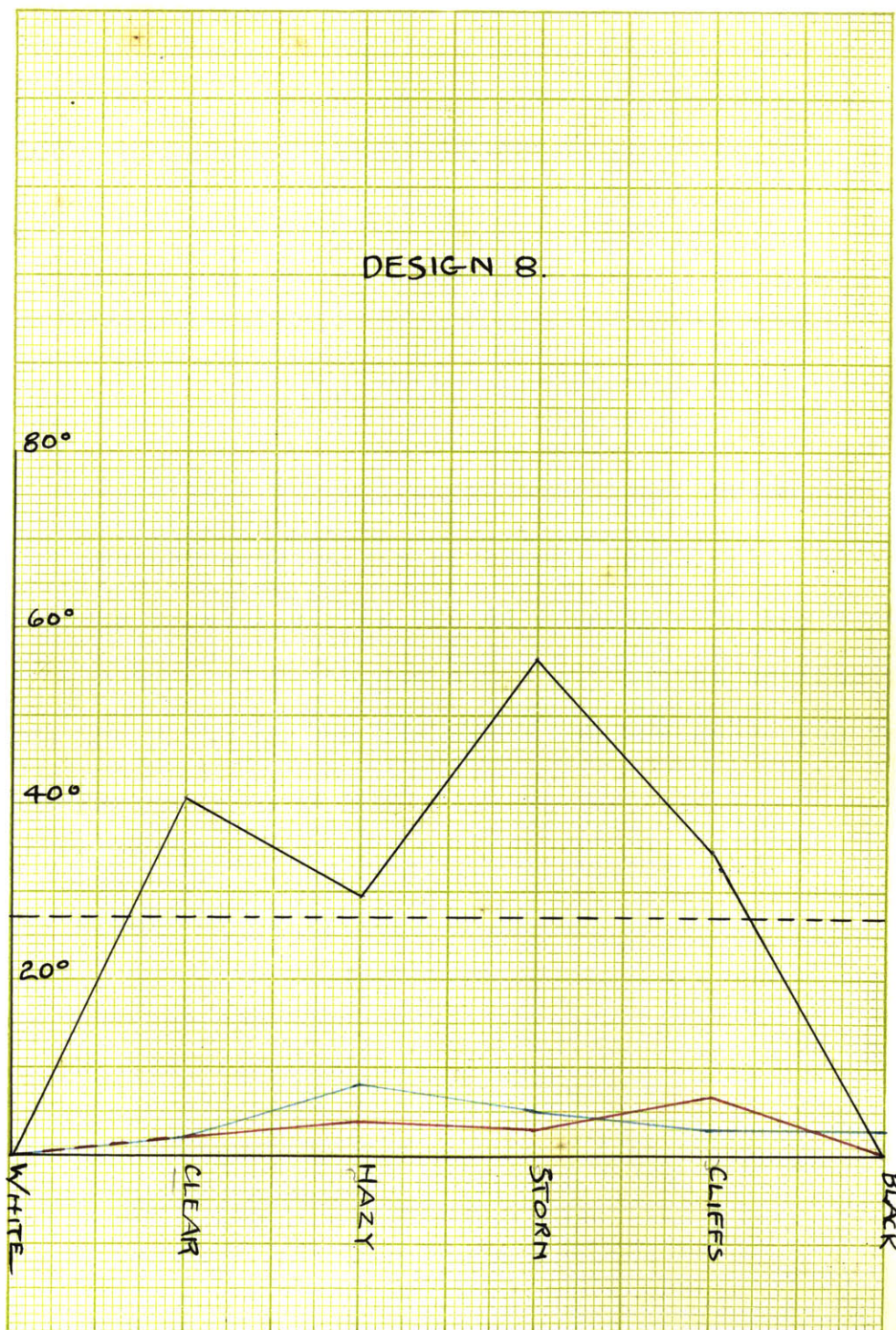
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	238	108	130	235	240	15	230	224	6
	294	298	4	226	286	60	310	280	30
Hazy	230	248	18	242	282	40	310	300	10
	230	312	82	224	242	18	238	242	4
Storm	230	310	80	301	292	9	305	250	55
	130	130	0	232	250	18	128	238	110
Cliffs	226	338	112	240	264	24	313	310	3
	280	250	30	298	280	18	233	252	19

Average angle of error 36.8 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees.	40.8	29.6	56.4	34.5

Average angle of error assuming that there would be no error with a white or black background 27 degrees.



Design 9.

Another combination of black, No. 3. blue and white in large regular curves, proves effective in application to this type of passenger ship. All curves working towards the point at the bow twist the bow away from the observer.

DESIGN 9.



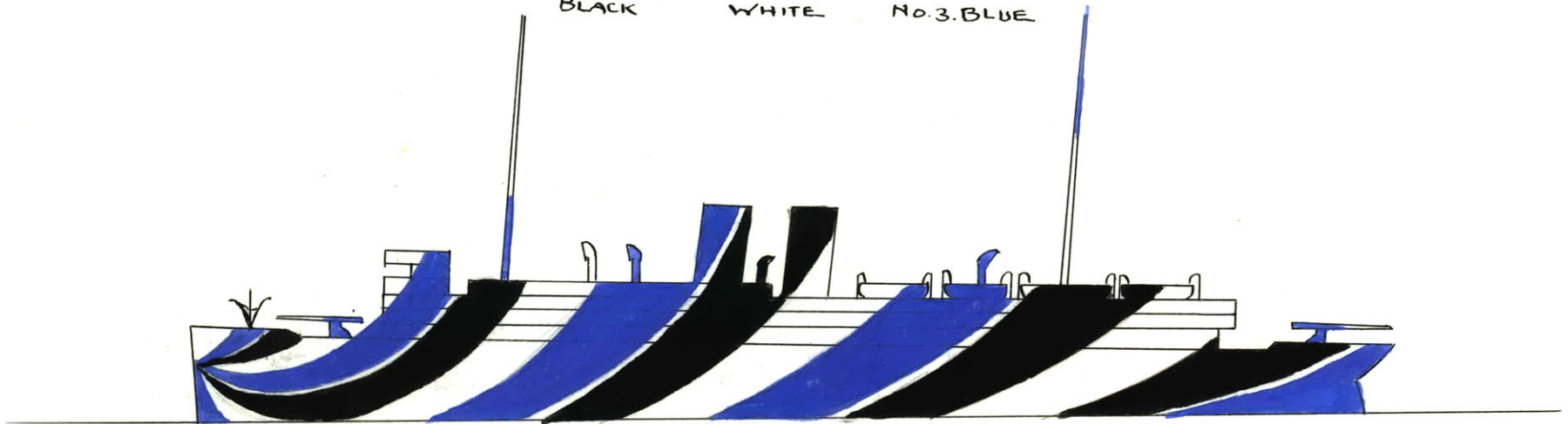
BLACK



WHITE



NO. 3. BLUE





This is a very good ~~example~~ of the twisting effect of long curves converging at a point either on the hull or at a vanishing point outside away from the ship.

Actual direction 30 degrees towards the observer .

Design 9.

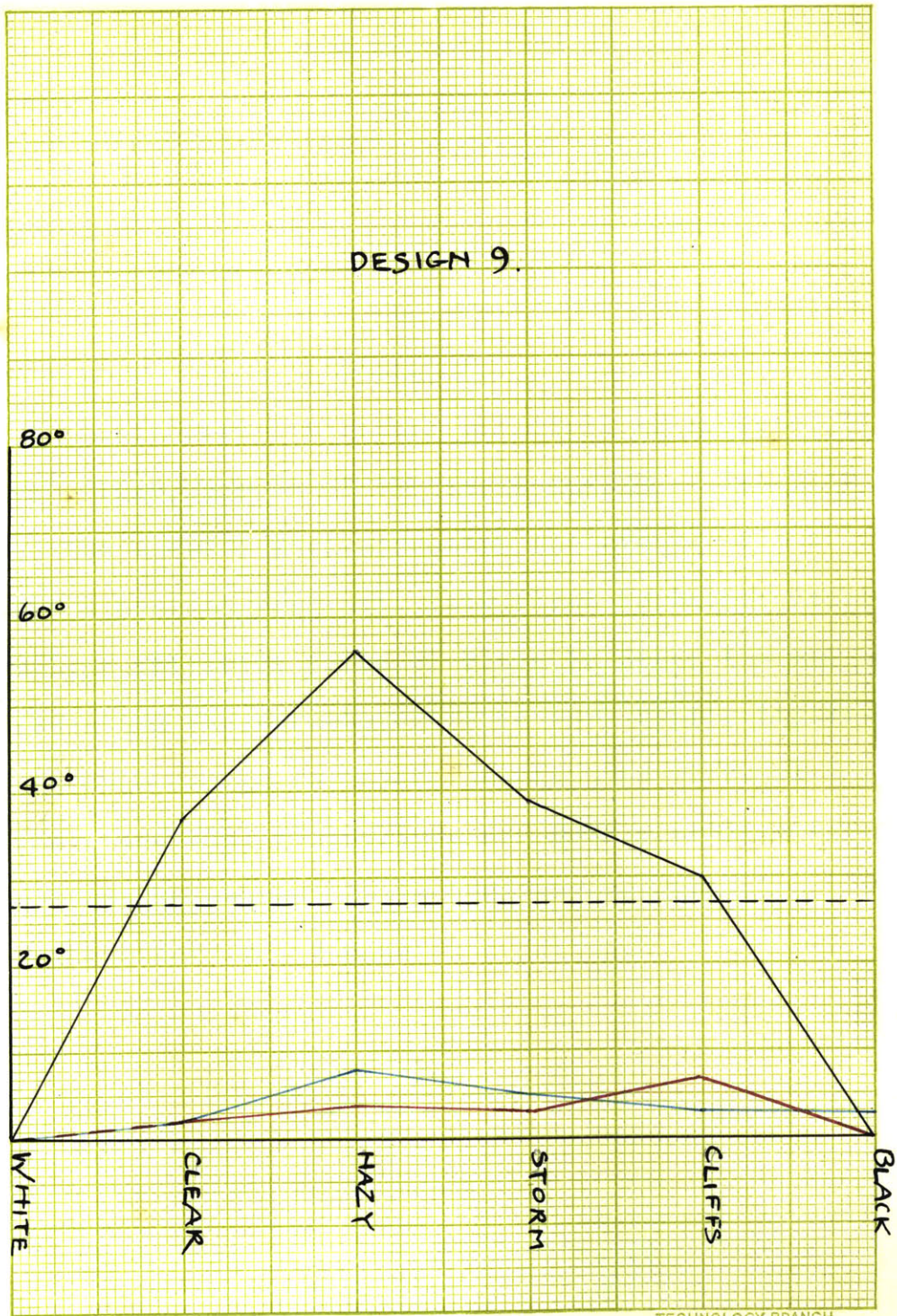
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	222	30	168	294	284	10	236	232	4
	236	240	4	238	247	9	248	222	26
Hazy	220	62	168	226	310	84	240	280	40
	308	294	14	304	290	14	310	294	16
Storm	306	298	8	240	260	20	246	214	132
	230	288	58	300	288	12	306	300	6
Cliffs	288	296	8	243	274	31	237	294	57
	230	240	10	324	280	44	310	240	30

Average angle of error 58.9 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees	37	56	39	30

Average angle of error assuming that there would be no error with a white or black background. 27 degrees.



Design 10.

Destroyers are rather difficult to successfully camouflage, because of the small amount of freeboard, and the massive superstructure and stacks, all of which have a decided rake aft. This first destroyer design employs extensive areas of black to serve the end in distorting the structure. It is very nearly impossible with this design to determine the type ship, or direction travelled. No outlines are sufficiently clear to determine the course. It is a rather successful combination of the black, No. 3 Blue, and yellow.

DESIGN 10.



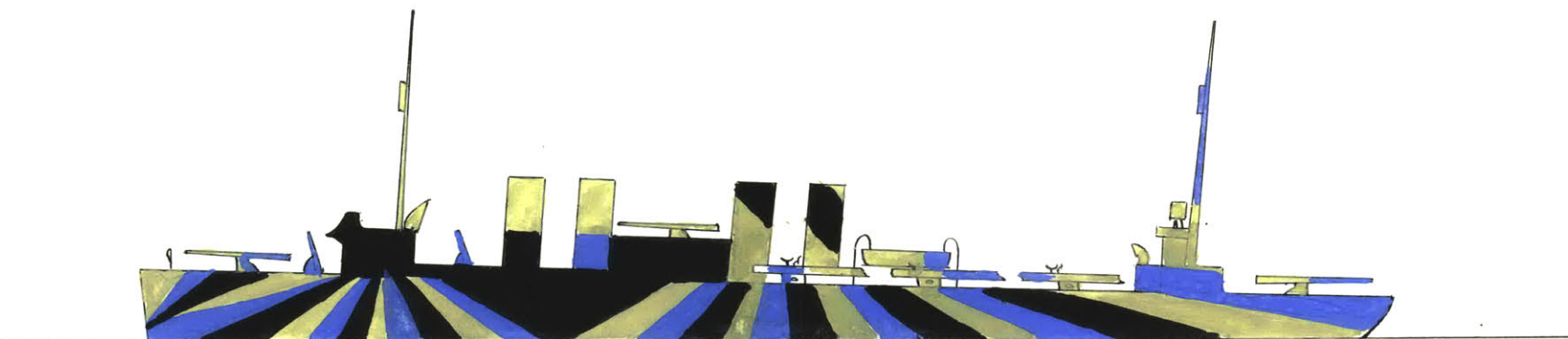
BLACK

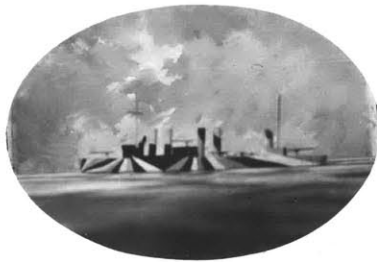
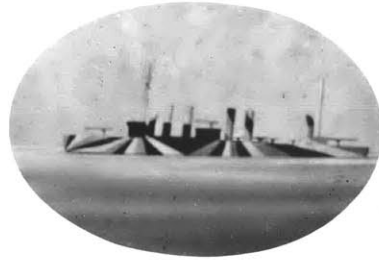


GRAY YELLOW



NO. 3. BLUE





It has been noted that it is difficult to disguise a destroyer or to alter her superstructure. The three following designs indicate the possibilities of distortive painting in this connection. The actual colors of course render more marked the effect that is indicated in the pictures.

Actual direction 25 degrees astern.

Design 10.

	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	229	240	11	311	296	15	310	230	80
	310	308	2	234	312	22	56	46	10
Hazy	220	220	0	308	260	48	300	302	2
	324	224	100	218	240	22	223	242	19
Storm	304	312	8	308	300	2	306	90	16
	226	226	0	230	294	64	141	50	91
Cliffs	228	308	80	312	297	15	250	110	140
	306	294	10	231	254	77	320	320	0

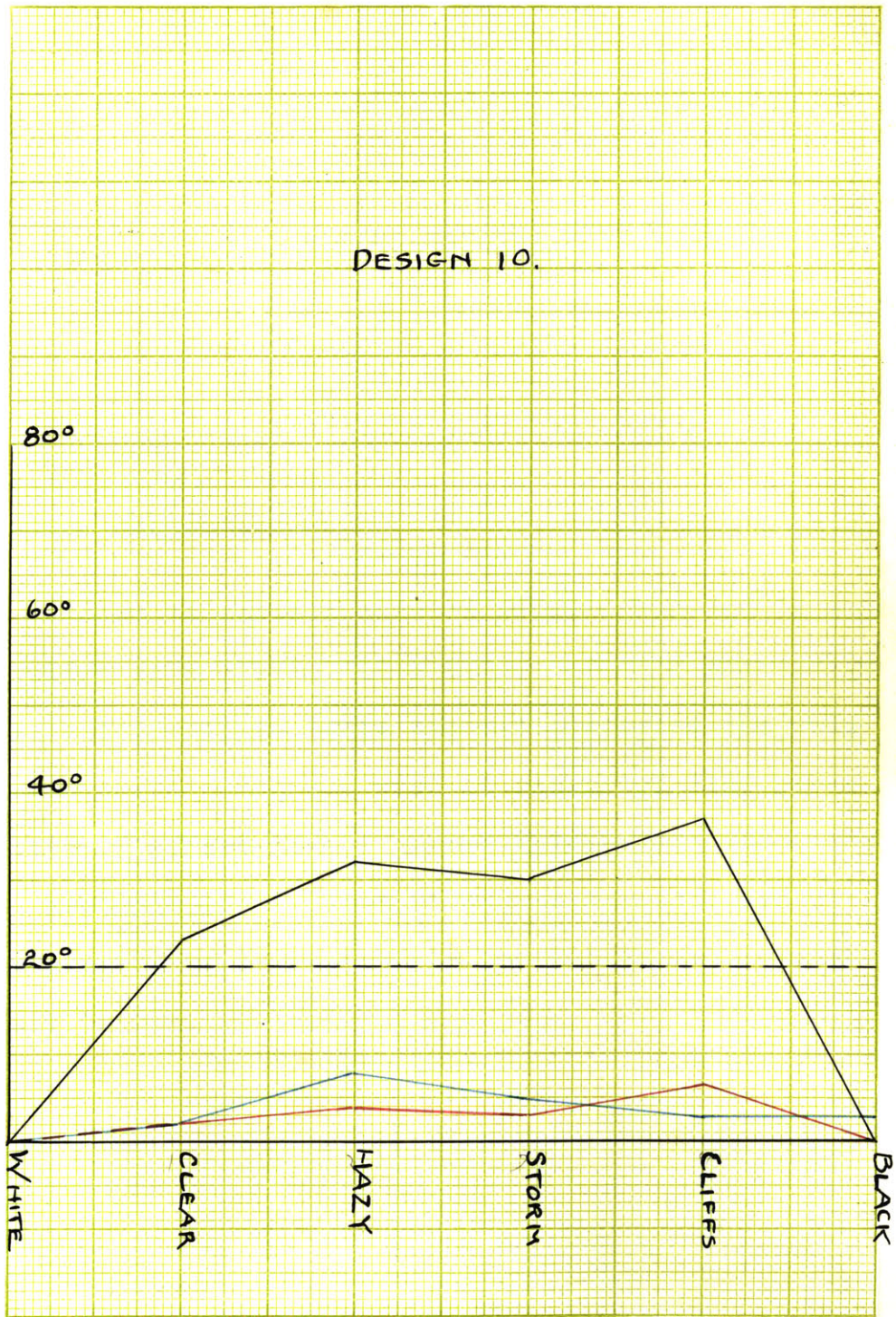
Average angle of error 38.9 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs.
Degrees	23	32	30	37

Average angle of error assuming that there would be no error with a white or black background. 20 degrees

DESIGN 10.



Design 11.

Here is another case of pink, green and lavender, applied as a dazzle. As a matter of fact the design has a tendency to lower the visibility of the ship under certain lights, even at ranges of 1100 yards. Whatever effect is not gained by lessening the visibility is accomplished by distortion, so that the results attained make it acceptable. The out lines are rather well broken.

DESIGN II.



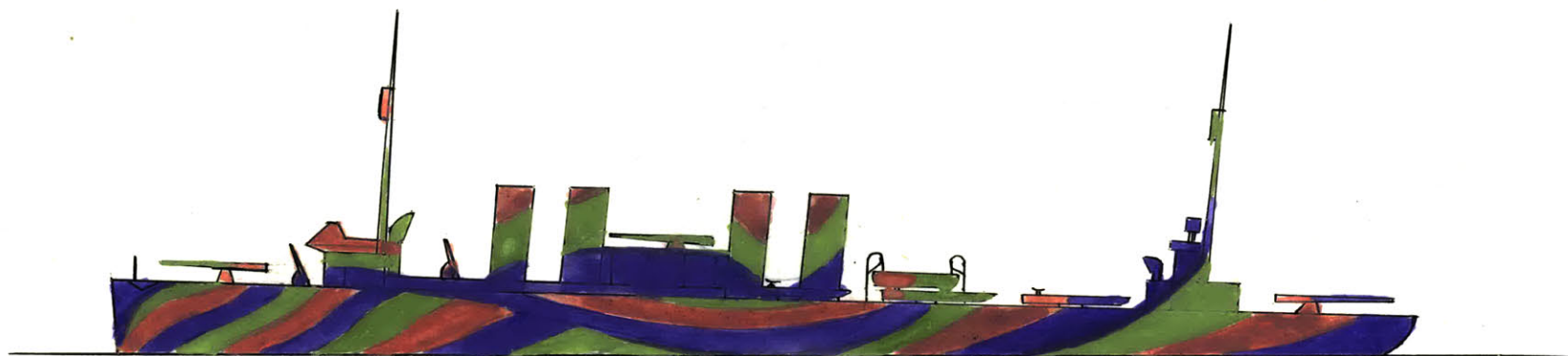
PURPLE

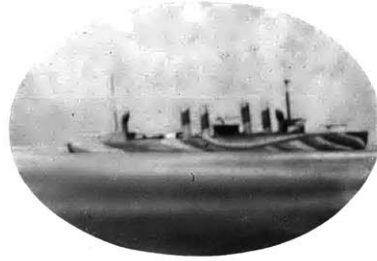


NO. 3. PINK



NO. 1. L. GREEN.





It was believed that this painting would prove of low visibility, when photographed. Against certain backgrounds the visibility is reduced. The results here are passable but not as good as in some other cases.

Actual direction 20 degrees towards observer.

Design 11.

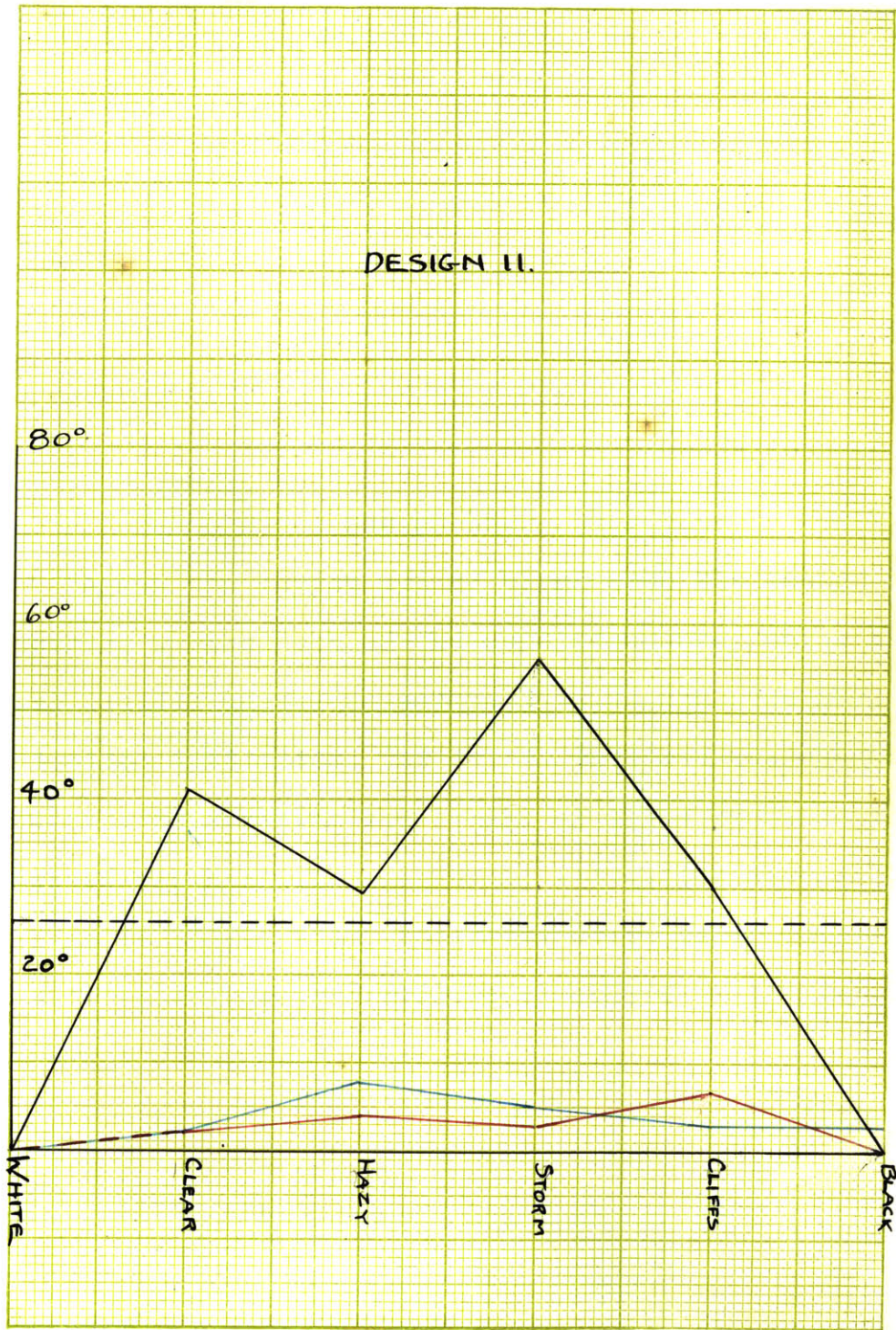
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	123	62	59	130	96	34	128	52	76
	115	58	57	52	56	4	312	296	16
Hazy	130	128	2	130	110	20	122	70	52
	128	48	80	35	45	10	56	60	4
Storm	122	80	42	56	76	20	114	62	52
	46	62	16	122	96	26	52	220	178
Cliffs	122	104	18	55	72	19	40	72	32
	68	100	32	123	96	27	56	110	54

Average angle of error 39.2 degrees.

Average angle of six observations. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs
Degrees	41	29.6	44.6	32

Average angle of error assuming that there would be no error with a white or black background. 22 degrees.



Design 12.

Again the lavish use of black aids the design in breaking up the form of the superstructure, while the long regular curves in contrasting colors give the bow a decided distortion. The No. 3. Blue stern prevents the eye from determining the length of the ship while the mass of black on the quarter by attracting observation serves to shorten any estimate. Other color schemes for the foregoing designs will be discussed in the conclusions.

DESIGN 12.



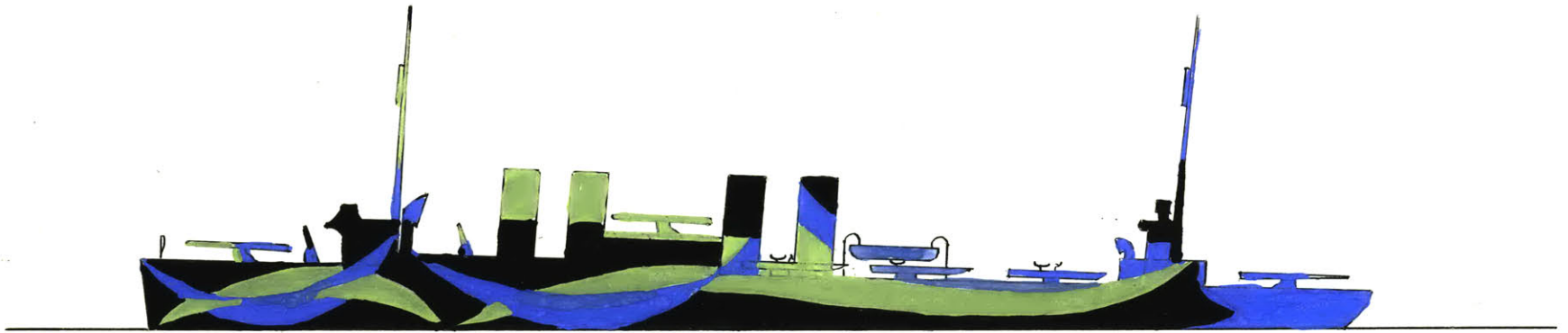
BLACK.

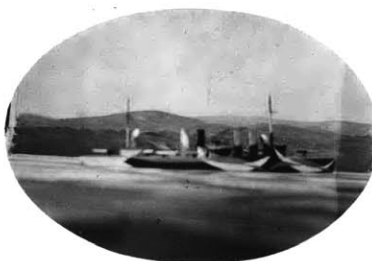


NO. 1. L.G. GREEN



NO. 3. BLUE





This painting indicates how effectively the ship may be distorted and superstructure broken by the use of black and medium blue. It is difficult to determine the length of the ship either in the photograph or in observing the model through the periscope. It equally hard to decide on the number of stacks, and the disposition of deck works.

Actual direction 30 degrees astern.

Design 12.

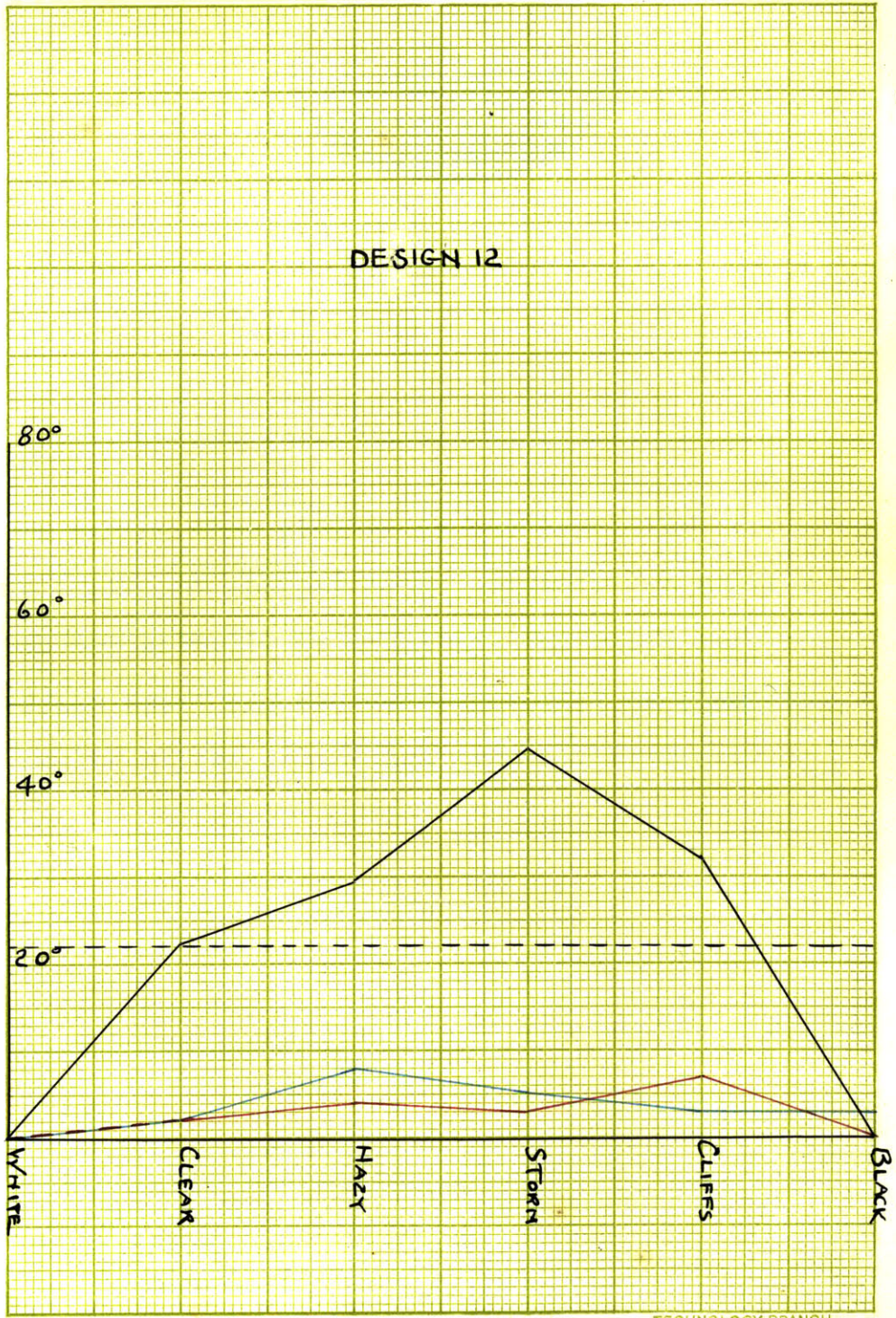
	First Observer			Second Observer			Third Observer		
	Actual	Est.	Error	Actual	Estimated	Error	Actual	Est.	Error
Clear	119	58	61	130	96	34	45	135	90
	120	60	60	58	70	12	310	230	80
Hazy	130	58	72	120	62	68	48	54	6
	60	50	10	68	90	22	310	310	0
Storm	38	52	14	54	66	12	50	310	100
	98	128	30	122	94	28	50	134	84
Cliffs	38	50	12	47	44	3	121	80	41
	122	110	12	126	102	24	42	142	100

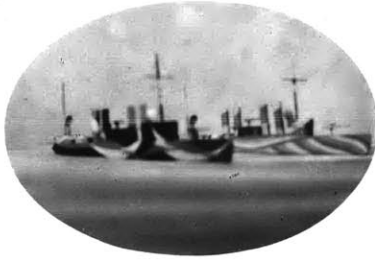
Average angle of error 40.5 degrees.

Average of six observations for each sky. The results to be used in plotting.

	Clear	Hazy	Storm	Cliffs
Degrees	22.5	29.6	44.6	32

Average angle of error assuming that there would be no error with a white or black background. 22 degrees.





In taking this picture, it was hoped that a comparison of two destroyer designs would indicate how great a distortion may actually be attained. The ships were placed about six inches apart and as nearly parallel as possible. The results of the camouflage are self evident.

The results of the foregoing experiments would seem to indicate that the method of formulating designs was an advance on preceding work, and that the efforts were conducted in the right direction. In general the vanishing point system, built up with curves or straight lines, where they converge at ^{or} towards the bow is correct. Black may be used to block out superstructure or the design carried into the deck works in a convincing manner. The treatment of masts and stacks has been discussed previously and is understood. Any of the colors used in a given design may be almost as well used in any other. For example, design two might have used black, green and white instead of blue, gray, white and black; design eight might as well have been painted with dark gray and pink rather than the blue and green.

The attempt to standardize the tests by using the same backgrounds with each model was done in order that any future work with the same apparatus might be compared with the results here given. Under like conditions the straight line plots measure the effectiveness of the design and may be compared with each other for relative merits. It will be noted that the majority of errors are between twenty and thirty degrees (that is the averages for the plots), so that the poorest of them would certainly cause sufficient error in a submarine observation to protect the ship against the torpedo attack. The errors would no doubt be accentuated with weather and haze aiding the ship.

An apparatus for neutralizing the effect of the camouflage might be devised. This machine as previously mentioned

would probably consist of a series of revolving color screens which would enable the effect of all but black and white to be eliminated from the ship. Actually the ship would assume a flat gray aspect. The time element in observations is very important, and any equipment for discovering the camouflage would have to be adjusted and operated within a few seconds to be successful.

The day of camouflaging ships in war time has passed with the passing of the submarine as an effective weapon of naval operations. It is unfortunate that so very little was accomplished during the progress of hostilities, for the results might have prevented the loss of many ships, whereas camouflage had no more than a ten percent tendency towards safety.