Some of you who have heard me on previous occasions in the past know that I have some very fixed and rigid points of view which might tend to be associated with the Canadian position. But we would be very glad to relax those or compromise in any way if we could get down to a general International basis whereby we know what each of us is talking about when we talk about lens resolution and lens calibration.

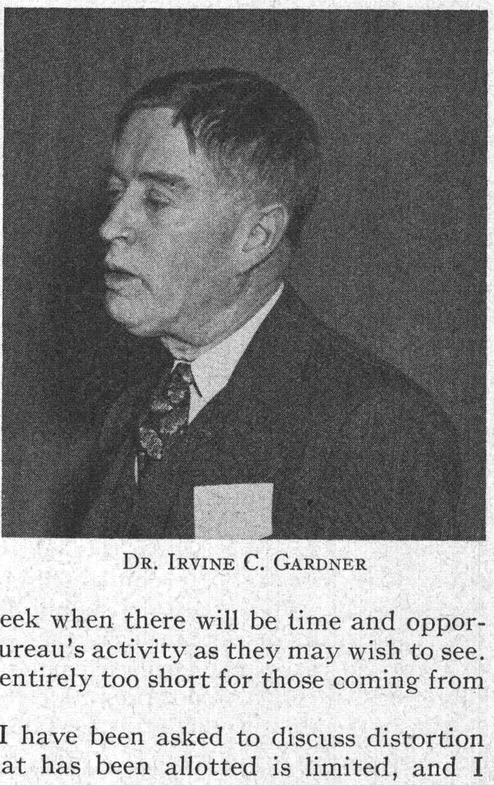
I suggest we all have that in mind as we hear the various points of view that will be brought forward this afternoon. It is not a matter of defending individual points of view, but of seeing how many times we can reconcile different points of view, one with the other, with a compromise here and a compromise there. We can then arrive at a working agreement, which may not be ideal, but at least will be a foundation for something worth while to come later.

I will now ask Dr. Irvine Gardner, Chief, Optics and Metrology Division, National Bureau of Standards, to present his paper. He is so well known to all of you that a long introduction is unnecessary. In fact, I propose to conserve our time and not read any long biographies.

THE SPECIFICATION OF RESOLVING POWER TESTS

Dr. Irvine C. Gardner, National Bureau of Standards

AS A preparation for the 1952 International Assembly of the Photogrammetric Societies in this city, it is interesting and desirable to discuss resolving power tests at the present meeting. In view of this, I wish to congratulate Dr. Howlett, for the success that he has achieved in persuading representatives from the societies of the European countries to visit and join us in this discussion. And, as a digression, in addition to the welcome that they have received from the Photogrammetry Society, I wish to extend a personal welcome and the official welcome of the National Bureau of Standards. It has been my good fortune to visit Europe on many occasions during times of prosperity, of economic difficulty, and of war, and I have always been delighted and surprised by the courtesy and cordiality that has been uniformly extended to me by scientist and layman. This meeting of the Society makes the present week a very busy one, and I sincerely hope that our distinguished foreign visitors can remain in Washington over the week end and visit the Bureau again next week when there will be time and opportunity to show as many phases of the Bureau's activity as they may wish to see. I feel that the scheduled tour has been entirely too short for those coming from great distances.



DR. IRVINE C. GARDNER

To return to the subject at hand, I have been asked to discuss distortion and resolution. However, the time that has been allotted is limited, and I consider that there is considerably more room for differences of opinion concerning resolving power than distortion. Consequently, it may be that I shall use all of my time for general and personal views bearing upon resolution tests, and leave the simpler questions concerning distortion to be adjusted by correspondence.

It is unfortunate that we do not have an adequate or complete formulation of the manner in which the different parameters that control resolution interact. Consequently, any prescribed resolving power test formulated at the present time must be arbitrary in some respects. In making the arbitrary decisions, it is of course necessary to have in mind the purpose of the resolving power tests under consideration, if the best decisions are made. In making any of these arbitrary decisions, however, we must bear in mind that arbitrary decisions, under any condition, are distasteful and that we look forward to the time when this subject will be more thoroughly engineered, and all that is arbitrary can be eliminated.

There are at least two tenable assumptions regarding the purpose of a resolving power test. But because they have not often been explicitly stated and precisely formulated, it seems to me that we have not always adhered either to the one or the other, when specifying our resolving power test of the future. According to the assumption which I shall consider first, the purpose might be to formulate a test such that the result will correlate in the most direct manner possible with the results one obtains in actual airplane photography. In accordance with this theory it may be inferred that the resolving power obtained in the laboratory ought not to appreciably exceed the value obtained in mapping photography. It follows that all details of the test must simulate as closely as possible actual mapping experience. This is an argument that should be used with caution. It is very unlikely that we shall finally obtain a test which gives a resolving power in lines per millimeter which can be transferred directly to the ground, to give the dimensions of the smallest detail that will be just discernible in the airplane photograph. It is unlikely that this can be done because the resolving power test does not introduce a sufficient number of parameters. Furthermore, it is not the purpose for which resolving power tests are being formulated. After a standardized resolution test has been agreed upon, it will then be desirable and useful to correlate such tests with the amount of detail upon the ground that can be recorded upon the negative. Such work is particularly valuable, difficult, and time consuming. Dr. Macdonald at the Boston University Optical Research Laboratory has inaugurated experimentation designed to obtain this correlation for some of the better known resolving power tests that are now in use.

I do not believe in the simulation basis for formulating a test for several other reasons. Such a test becomes a "go" and "not go" test and yields the minimum of information about the lens. But chiefly I object to this method of test because I do not believe it is the best way to accomplish the real purpose of a resolving power test. According to the second tenable assumption, the real purpose of the test that we are formulating is to sort or screen the lenses being tested, in order that the best ones may be made available for mapping purposes. For this purpose the test should be established in such a manner as to make the lens the more influential element in the test, in order that the test may provide better discrimination of lens quality. This is particularly desirable because a resolving power test is fundamentally a measurement of a threshold, and such a measurement, at best, presents great difficulties. With this viewpoint, which I believe to be the correct one, simulation of flying conditions is required only to such an extent as is necessary to prevent grading the lenses in an incorrect order of rank or merit. This subject of the real purpose of a resolving power test will be returned to, from time to time, as the different parameters are considered.

The parameters that need to be controlled to properly define a resolving power test certainly include type of test chart, choice of emulsion, exposure, development, and manner of evaluation.

The type of test chart will be considered first. The majority of test charts that have been proposed consist of mutually perpendicular patterns of parallel lines. I think there are sound reasons why we should not depart from such patterns. Considerations of symmetry, of the most fundamental character, indicate that the maximum and minimum dimensions of the image pattern of a point produced by a lens will be perpendicular to each other, and that one of them will lie along a radius extending from the center of the image field. The different line patterns that have been used make use of this property, and its validity has never been questioned. In my opinion, any lens which does not conform to this characteristic must be so badly centered or otherwise so defective that it is not likely to be considered for photogrammetric work. The groups of parallel lines give information additional to that obtained from circular or pie-shaped targets at no additional cost. If one wishes to attach a single number to the resolving power at a point, I suggest that it be the product of the resolving powers, expressed in lines per millimeter, obtained from the two perpendicular patterns. Such a value may be expected to have a correlation with the number of points per square millimeter on the test negative that it is possible to record. This is to be considered as a fortunate by-product that derives from the test pattern of parallel lines.

A remaining important characteristic of the test pattern is the contrast which it should possess, contrast being defined by the equation

$$\text{Contrast} = D_1 - D_2 \text{ (in terms of photographic density)}$$

when

$$D_1 > D_2$$

and D_1 and D_2 are the brightnesses of the dark and bright portions of the target. Much of the testing of the past has been done with high contrast targets, and there is remarkably little concrete evidence to indicate that this leads to important inversions in the grading of lenses. With the present state of our information, I should be quite willing to agree upon a test chart with a contrast as small as 0.2 which has been chosen by the English, but I believe there is no advantage in going to a lower contrast. To justify the lower contrast for tests, it should be necessary to show that important inversions of order of grading will exist when lenses are tested with the two contrasts under consideration. The use of the maximum contrast consistent with correct grading will facilitate the assessment of test negatives, and will probably make the results more precise.

The manner in which the chart is presented to the camera is important. At the National Bureau of Standards, we have used collimators to project the test chart to an infinite distance. This is quite necessary for measurements of distortion, and has worked satisfactorily for resolution measurements. However, with collimators it is not a simple matter to provide an illuminated background covering the entire field. This test characteristic, which has generally been ignored, is necessary because different individual lenses may differ in the amount of scattered light arising from difference in polish, difference in reflection reducing coating, or difference in the blacking of the interior of the lens barrel, and such differences are not distinguished by present test methods. At the National Bureau of Standards, we are giving consideration to modifications of the collimator and to other methods for providing a surrounding brightly illuminated field when the test negative is made. A rather radical innovation that is being considered is the possibility of using practicable indoor distances for testing a lens without the use of a collimator. We are using an electronic computer to trace rays through standard photogrammetric lenses, as described in patent specifications, in order to determine the practicability of making tests at distances feasible for indoor testing without the use of collimators. It would, of course, be necessary to have a standard shim for each focal length, to separate the photographic plate from the focal plane of the camera, and to bring it into a plane conjugate to the selected object distance. The purpose of our computations is to determine at how short a distance the aberrations will not differ significantly from those for an infinitely distant object. If such a method of test can be adopted, an illuminated background can be readily provided, and all effects of aberrations of the collimator objective will be avoided. It would of course be necessary to establish without any doubt the satisfactory equivalence of this test and one with the object at an infinite distance, before a test differing so radically from all others that have been contemplated could be generally accepted.

A second important decision in connection with the resolution test is the emulsion that is to be used. It has been said, and correctly, that the resolving power of a lens-emulsion combination can only be determined by testing them together. With our present state of knowledge this is probably true. However, I submit that the purpose of the resolving power tests which we are now devising is not the determination of the resolving power of a lens in combination with the photographic emulsion now in general use. The purpose is the grading of lenses in accordance with their merit. When a lens and an emulsion are used together to record an image, the resolving power of the combination is dependent upon the contributions from the two members. One can imagine a choice of lens and emulsion in which the emulsion is so coarse grained that the property of the emulsion is completely the limiting factor, and consequently one obtains no variation in performance with the different lenses that are tested. Consequently a test set up on this basis would serve no purpose in screening or grading the lenses. One might say that if such an emulsion were in actual use, there would be no necessity to screen the lenses since all would give the same result in practice. This would be true, but with such a test there would be no stimulus toward improvement of the lens for possible better emulsion, and one should not expect any advance in the art. On the other hand, if the test is made with an emulsion of a fineness of grain and resolving power greatly exceeding that of the standard emulsion, then the differences in end result on the test negatives will largely result from the differences introduced by the lens. Our threshold test then becomes more precise, because the differences of performance on the fine grain film may be expected to be greater than the differences to be realized in practice. So long as one remembers that the real purpose of the test under consideration is the screening of lenses, and not the determination of a given resolving power, it becomes apparent that the use of the fine grain film is advantageous. There is one danger that must be avoided. In introducing departures from exact simulation in our standardized test, we must be certain that such departures will not result in a changing of the order of grading of the lenses, as this would lead to incorrect conclusions and judgments. If, in the formulation a resolution test, we departed from exact simulation of service conditions by using an emulsion of the same spectral sensitivity as that used in service, processed to give the same gamma but of much finer grain, I feel there is little probability that this change will involve any inversions in the order of grading of lenses. On the other hand, it will open out the differences between lenses under test, and thus increase the precision.

There is another advantage in specifying a film for use in the resolution test that is different from the one that is actually used for photogrammetric work. Different countries have different sources of film supply and consequently, on the basis of exact simulation, different countries should logically use different film emulsions with resulting lack of uniformity. Even in one country, all services and firms do not use the same film, but for some purposes slower finer grained film with careful processing is used. Furthermore, if this procedure were followed, with every improvement in emulsion technique as superior films become available, the test procedures must be changed and the results of a large volume of completed tests representing much work become largely valueless. Consequently, it will also probably be easier to obtain agreement among the different countries upon an emulsion differing from that in regular use by any nationality, than it will be to obtain agreement upon an emulsion used by one country but not by another. In this country it would be my suggestion that an emulsion equivalent to Eastman's Panatomic be used for testing purposes. This is an all purpose emulsion with a spectral sensitivity the same as that of Super XX, and it is probable that other film and plate manufacturers produce emulsions substantially equivalent.

There remains the selection of exposure time and processing. The reciprocity law is so nearly obeyed by photographic emulsions that the brightness of the target and the length of exposure can be varied together over a considerable range in such a manner as to produce the same negative density without differing results. Consequently, instead of specifying brightness of object and exposure it is probably sufficient to say that the exposure shall not be more than, say, 1 second, and selected, in conjunction with the brightness of the target, to give an assigned background density for the negative with an assigned gamma.

Summarizing the preceding paragraphs, I have tried to emphasize the fact that the purpose of a resolution test which is now under consideration is not to obtain a measure of what the lens will accomplish when flown in a plane, but rather to grade the lenses under test in order that only the best ones will be used for photogrammetric purposes. Consequently, it is often advisable to depart from exact simulation of the conditions of use when making tests, if the tests can thereby be made more precise, and it is only necessary to simulate conditions of use when inversions in the order of grading would otherwise result.

Reference has been made to the inherent difficulty of making resolution tests because of its threshold character. At best the resolution test may be considered a stopgap test to be supplanted by a more precise test as our knowledge increases. Experiments are being made at the University of Rochester on a method of test in which the amount of luminous energy from a point object concentrated within a specially defined small area is used as a measure of performance of a lens. This is an entirely objective test and tests the lens as an entity without using a photographic emulsion. A test of this nature has much to recommend it, and as instruments for its application are improved, it is quite conceivable that it may replace the resolution test. This test has none of the disadvantages characteristic of a threshold test, and once established will not need to be altered every time that there is an important improvement in emulsions.

In discussing the arguments for and against devising a resolution test which shall exactly simulate the use of the lens in the field, it has been mentioned that simulation is required only as a result of our ignorance of the manner in which the different parameters involved act jointly to determine the final resolution. If we thoroughly understood the functional relation between the resolution of a given lens-emulsion combination and the parameters associated with the lens and the emulsion, it would probably be much preferable to determine the different parameters separately. Unfortunately the determinations of these relations is a long and tedious task, and it is only for this reason that we are still using a resolution test. The National Bureau of Standards is doing what it can to simplify this problem. We have devised a resolving power chart which consists of two patterns of parallel lines perpendicular to each other. The Bureau exhibit makes clear some of the details of these charts. Each chart consists of a large number of lines with the widths and spacing decreasing continually from the first line to the last. By this means, instead of having steps equal to the reciprocal square root of two, or reciprocal sixth root of two, one has practically a continuously varying range of frequencies.

Such a chart was developed independently at the Bureau, but it was later discovered that a similar chart is described by *Sayce*[1] at a much earlier date, and that it is now being used for some purposes at the National Physical Laboratory. With this chart the frequency varies from one end to the other. We have introduced a further modification by having the densities of the lines and spaces vary in a direction parallel to the lines, so that each point on the chart corresponds to a given frequency and contrast. From the study of the image of such a chart, it is possible to plot directly a graph showing the relation between frequency and contrast for a given lens-emulsion combination. These charts, unfortunately, are difficult to make but with our present experience we hope soon to have a limited number of charts available which can be distributed to the laboratories that are specially interested in resolution tests. As with all line charts, there are difficulties arising from the presence of pseudo-resolution. This has been present in the charts at present used by the Bureau for routine testing, and introduces no difficulty so long as there are patterns coarser than the value corresponding to the true resolving power of the lens. Because of the two dimensional characters of the new charts, it is even easier to determine which resolved pattern is the one that is truly resolved. A chart with a continually varying range of frequencies makes it easier to precisely determine the resolving power than when the steps are discrete, because one is able to select a value intermediate between the frequency certainly not resolved and the one certainly resolved. The same chart provides for a measurement at any desired contrast. The chart is also particularly convenient for an objective evaluation by means of a microdensitometer, because for any contrast it is only necessary to scan the chart along one straight line. It will be a great convenience to have a chart of such form that the test negative, without prior thought or care, will always be in condition either for a visual appraisal or a more subjective appraisal by a microdensitometer. The Bureau is making an attempt to bring this chart into condition for distribution and trial by interested laboratories well in advance of the International Meeting in 1952.

Chairman Howlett: The next talk will be given by Dr. K. Pestrecov, well known to us all for his work at Bausch and Lomb.

---

[1] *Photographic Journal, 80,* 454 (1940).