about ten millions if the job were done wholesale.

Most of the overlooked opportunities, the mistakes and failures of this world, are due to making assumptions and generalizations from half truths and inaccurate information. For nearly three quarters of the United States, the best available maps are but generalized compilations of a heterogeneous lot of poorly coordinated traverses, platts, reconnaissance surveys and sketches. Very few Americans are acquainted with accurate detailed large scale maps of the type made in all the leading countries of Europe. Although most of such maps were made by expensive ground methods and their land of comparable fertility sells for the same price as ours, these countries have found the maps excellent investments. They say they must have such maps to act intelligently and that only a country as rich as the United States could afford the waste of doing without them. The point is that wherever large scale detailed maps are available, hundreds of uses arise which combined repay the cost of such maps many times. But, like first class highways, there are few special projects extensive and important enough by themselves alone to justify their costs. Only the more advanced nations have had the time and intelligence to appreciate and secure for themselves the combined usefulness of adequate maps. We who are working in photogrammetry in 1936 look forward to the day when any man may sit at his desk and visualize, with the aid of accurate detailed large scale maps and aerial photographs, any part of this country in which he may be interested; to the day when he may plan his actions precisely in accordance with the basic facts about the land and move with speed and certainty instead of being compelled to wait for expensive special surveys or muddle through with generalized half truths on many of his maps as at present.

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LENS REQUIREMENTS FOR PHOTOGRAMMETRY

by

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Aerial photography serves the single purpose of obtaining and conveying information. It had its origin and early development during the World War wherein its application was of course purely military. Since the close of the war the possibilities of aerial photography in the field of mapping have been widely recognized and the development of equipment such as cameras, lenses, etc. has been guided by the needs both of the military establishments and the surveyors.

The first aerial photographs were naturally made with such ordinary hand cameras as were available but it immediately became apparent that such equipment was far from satisfactory. In military operations planes were forced to fly higher and higher as the effectiveness of anti-aircraft artillery was improved, and as the altitude of the flight was increased lenses of longer and longer focal length became necessary.

During the war the allied forces found it difficult to obtain lens equipment suitable for their needs, in part because of a lack of optical glass of suitable quality in sufficiently large pieces and in part because of special requirements as to image quality or lens performance that had not, prior to that time, been of sufficient importance to lead to suitable lens designs.

Since the war reasonably satisfactory lenses have become available but with the development of the practice of photogrammetry and a better realization of its possibilities, there has arisen the need for a lens surpassing anything yet achieved by the lens designer.

The main properties of photographic lenses in which we are interested are focal length, relative aperture, angular field of view and image quality. The factors that combine to determine the specifications of a lens are the altitude of the flight, the ground speed of the plane, the degree of fineness of detail that must be recognized in the photographs, the amount of territory to be covered by a single exposure, the vibration of the plane, the characteristics of the photographic emulsion and the character of the illumination.

It is difficult to mention any one particular factor as a starting point for there are limits to all of them. In military operations there is a lower limit for altitude set by the effectiveness of the enemy's guns. In both military and civilian applications there is an upper limit set by the difficulty encountered in reaching it and operating in it after it has been reached. A photographer can operate at an altitude of 18,000 feet without oxygen, but it is alleged that he experiences bad after-effects if he stays for any length of time at that elevation without extra oxygen. At the present time from 18-20,000 feet may be regarded as an upper limit. In civilian applications the lower limit is rather determined by lens considerations instead of the reverse.

The next controlling factor to which attention naturally turns is the size of the plate. During the war a good deal of photography was done on 4 x 5 plates. I believe that all plates are now larger than this and that there has been a good deal of progress in standardizing in plate sizes. If one should set definite specifications for the size of the smallest detail he wishes to read from the photograph, to the size of the plate, and to the area to be covered in a single exposure at a given altitude, it is quite likely that it will be found impossible to meet all requirements simultaneously. At a given altitude, if size of plate and area to be covered are specified the focal length follows. At the same time, focal length is determined by specifying the altitude of flight and the minimum size of detail required so that it is obvious that the focal length of the lens must be determined by compromising between different requirements.

The relative aperture of the lens must also be chosen as a compromise between conflicting and opposing requirements. Because planes travel at a high rate of speed and because they are subject to violent vibration, exposure times must necessarily be short. They cannot exceed 1/50 second and in most cases probably should be less. Exposure time depends on illumination, emulsion speed and relative aperture. In peacetime operations practically all work is done in full sunshine. Little photography can be accomplished on cloudy days for the plane flies at an altitude that is above the usual cloud level. The emulsions used are high-speed panchromatic. With such emulsions and working in full sunshine, it would seem as if lenses of pretty low relative aperture would suffice, even though the exposure time is 1/50 or 1/100 of a second. But another fact operates to increase the required relative aperture, namely the need for filtering the light to cut out the blue end of the spectrum in order to decrease the effect of atmospheric haze. At best, the surface of the earth, viewed from a height of 10,000 - 20,000 feet, presents but little contrast and it is very seldom that the horizon can be seen because of the interposition of haze. Yellow and red filters are employed effectively to reduce the effect of haze and to improve contrast. For civilian mapping work exposures can be made with a relative aperture of f:8 and sometimes even less by confining the work to the most favorable hours of the day. In military operations, of course, it is important to confine the flying to conditions most favorable for photography, and pictures have to be obtained at all times of the day during which the equipment available will actually produce a picture, so that for military operations speeds as high as f:3.5 have been employed.

Anyone who has had experience with photographic lenses knows that as the relative aperture increases, it becomes more and more difficult to obtain critical definition and a field of view of substantial size so that relative aperture must be a compromise between the requirements of short exposure and ability to work under unfavorable light conditions, on the one hand, and image quality and size of field of view on the other hand.

In ordinary photography, relative aperture is also dependent on the depth of focus required. Aerial photography differs in this respect inasmuch as the lens is so far from the object plane that depth of focus is no problem.

Field of view is of fundamental importance inasmuch as it controls the amount of territory that can be covered at a single exposure for an image of prescribed scale of reduction. The limits are here set by lens performance which in turn depends on the skill or good fortune of the lens designer and on the optical glasses available to him. It is obvious that if the scale of reduction is not prescribed, the amount of area covered by a single exposure on a given plate can be increased at will by increasing the altitude of the flight. As pointed out before, there is a practical limit to the height at which the plane can operate and there is a limit to the scale of reduction that is acceptable so that the photographer is here quite completely at the mercy of the lens designer.

Inasmuch as the value of an aerial photograph is directly proportional to the amount of information that can be obtained from it, it is obvious that the utmost refinement of definition is essential. Here is no place for soft focus, pictorial quality. The lenses operate under two conditions not commonly encountered in ordinary photography: First, in order to reduce haze, they are used with strong yellow or red filters so that no blue light reaches the plate and the ordinary chromatic correction employed in photographic lenses is no longer appropriate. Attention should be confined to achieving the best possible union for light in the upper end of the visible spectrum from the green to the red.

The other condition is the necessity for the most complete freedom from distortion. In a lens that is afflicted with distortion linear dimensions in the image are not geometrically similar to the corresponding dimensions in the object plane in all parts of the field. Measurements made from photographs taken from lenses that exhibit distortion are in error unless the exact amount of distortion is known and allowance made for it. This would be a tedious operation and is regarded as impractical. Therefore every effort has been devoted to the design of lenses in which distortion is reduced to a vanishingly small amount over an extended field.

Distortion is a variation in magnification with distance of the object from the center of the field and this variation may be expressed in terms of percent. If a lens has o.5 percent distortion at 30° from the center of the field, it means that the distance from the center of the image to the point corresponding to the 30° angle will be 0.5%, too large or too small depending on the sign of the distortion. In ordinary photography, distortion that does not exceed 1% usually escapes notice and distortion less than 0.5% requires careful inspection to detect. Lenses have been designed for aerial photography, however, in which over a total field of 60 or more degrees the distortion nowhere exceeds 0.02%.

The desire to cover an extended territory with a minimum of flying time has led to the development of multiple lens cameras in which simultaneous exposures are made through one lens pointing vertically and a multiplicity of lenses pointing obliquely Other cameras are single lens cameras. The multiple lens cameras are, for the most part, equipped with lenses of the order of 6 or 6-1/2 inches focal length; the single lens camera, lenses of 10, 12 and 24 inches, the latter being intended more particularly for military operations where small detail must be detected from great altitudes. Reference was made a little while ago to the desire on the part of the aerial photographer for another lens surpassing anything that he so far had. This should be a lens of 6-1/2 inch focal length that would cover a plate 9 inches square representing an angular field of view of nearly 95° with no distortion, excellent definition and not too much decrease in illumination in passing from the center of the picture to the edge. This is the problem now before ambitious lens designers.

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