positions is not confined to the particular flight in which they are located. Although the minimum control requirements for stereotemplet solutions are not presently established, it has been demonstrated that these needs are considerably reduced, both in amount and in location, from those required for stereotriangulation. In many areas where the existing control is not suitable for stereotriangulation, an adequate scale solution may be obtained with stereotemplets.

The method offers considerable flexibility in the use of available equipment and personnel. Any number and various kinds of stereoplotters may be used to prepare the templets for a project area. Stereotemplets provide a convenient means of combining into one simultaneous scale solution the positional information derived from photography taken at various altitudes, with cameras of different focal lengths and from vertical, low-oblique and high-oblique photography.

THE NEW AIR FORCE PHOTOALIDADE*

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ABSTRACT

This paper describes the operational characteristics and versatility of the USAF photoalidade designed for determining ground elevations from oblique photography of types being utilized in the compilation of aeronautical charts. In designing the new instrument, special consideration was given to great flexibility in format, focal length and depression angles encountered in photography used for charting. Charting with the photoalidade involves many techniques other than those of operating the instrument. A few of these techniques are briefly described.

THE new Air Force photoalidade is still in the developmental stages at the Wright Air Development Center. However, we have been using six of the experimental models in production work at the Aeronautical Chart and Information Center for the past two years.

Before specifically discussing the new Air Force model of the photoalidade, I will review briefly some of its history and development.

The photoalidade is an instrument which measures horizontal and vertical angles from photographs. The first instrument to measure horizontal and vertical angles from a photograph was designed before 1865 by a European named Porro. He called it the Photogoniometer.

Even though the photoalidade is similar to the later models of the European photogoniometer, its development in this country was independent of the European instrument. Development action before 1950 was restricted to the Geological Survey. About 1910, J. W. Bagley, a member of its staff doing reconnaissance mapping in Alaska, built a panoramic photoalidade to determine horizontal positions and elevations from panoramic photographs. With this instrument, he measured the horizontal angles to image points directly, but resorted to measuring vertical distances on the photograph in order to calculate the vertical angles and then elevations.

Nothing further was done in developing the photoalidade until 1932 when another Geological Survey man, Mr. R. M. Wilson, designed an instrument which would make possible obtaining horizontal and vertical angles directly and simultaneously. His instrument became known as the Wilson Photoalidade. It utilized a regular field theodolite in sighting on points in the photograph. The theodolite was so mounted that its center occupied the perspective center of the photograph mounted on the plate. Horizontal angles were supplied by the ruling blade which was rigidly attached to the spindle of the theodolite.

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Vertical angles were obtained from a vertical circle attached to the telescope. The instrument accommodated photographs with focal lengths from 4 to 15 inches, depression angles from 0 to approximately 60 degrees; and 360 degrees of swing. With this development the photoalidade became very much like the ordinary plane-table alidade, the difference being that the former is used to get distances and elevations from a photograph of the field rather than from measurements in the field.

The first Wilson photoalidade was designed primarily to utilize oblique photographs such as the oblique of trimetrogon aerial photography. During World War II, the U. S. Air Force was using this type of photography extensively for rapid compilation of small-scale aeronautical charts. The photoalidade proved to be very useful in compiling the hypsography for these charts. It could be used to level an oblique photograph with only three or four vertical control points that might be spaced over one hundred miles apart; it could also be used to determine the positions and elevations of a dense network of points covering an area of more than 1,000 square miles. These spot elevations were then used to sketch 1,000 foot contours with an accuracy of ± half the contour interval.

After World War II the Geological Survey decided to improve the photoalidade and in 1948 completed a new model of the Wilson design (See Figure 1).

The improvements were: a solid one-piece frame, a Wild T1 theodolite, a slow motion tangent screw for making changes in the swing orientation of the photograph, and a convenient light source.

Before 1949 almost all of the small-scale charting for the Air Force in which the photoalidade was used had been done by the Special Maps Branch of the Geological Survey. In 1949 the Air Force found a need for expanding its capabilities in small-scale charting. A few of the early type Wilson photoalidades were secured at the Aeronautical Chart and Information Center in St. Louis, and with the kind help of David Landen and a few of his experts at the Special Maps Branch, photoalidade operations at ACIC got underway.

In 1950 new specifications were inaugurated for compiling 1:250,000 scale charts. These necessitated more planimetric detail than previously shown and

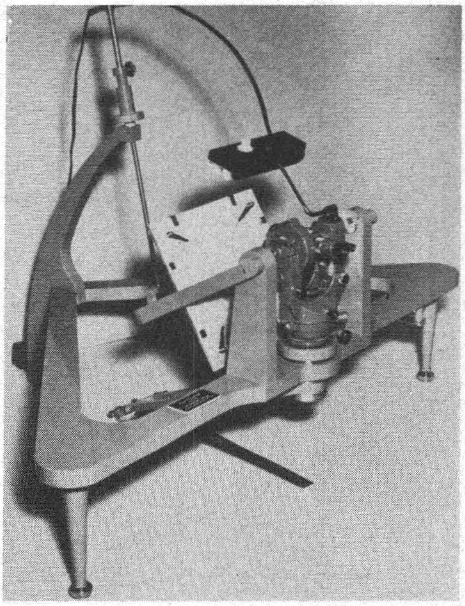

FIG. 1. The USGS 1948 model of the Wilson Photoalidade.

a much smaller contour interval (100 meters rather than 1,000 feet). The spot elevations had to be more dense and of course, more accurately determined. Also, it was expected that charting would be done with reconnaissance type photography which might have long focal lengths of 12 inches or more, and large 9×18 inch formats. These new requirements were a little too great for the old model of the Wilson photoalidade. A new instrument was needed to satisfy all of these requirements.

The Hillyer Instrument Co., of New York City, contracted with the Air Photographic Reconnaissance Laboratory at Wright Field to build a new photoalidade. It delivered the first instrument in 1952. This new instrument (shown in Figure 2) is still a Wilson photoalidade but with an entirely new appearance. It is apparent that the instrument has been designed for increased precision, versatility and convenience of operation. The 9×18 inch photoplate about which the whole instrument has been built should be noted. A heavy frame is used to give the strength and rigidity required of a precision instrument. A Wild T1 theodolite is used for obtaining a high degree of precision in sighting and reading horizontal and vertical angles.

Perhaps the greatest improvement in

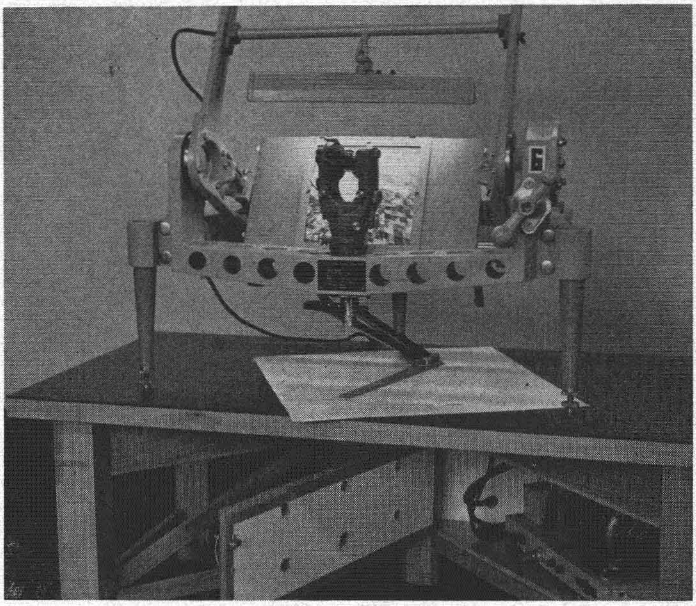

FIG. 2. The new Air Force model of the Wilson Photoalidade.

this instrument over all previous models is that it can be readily calibrated. The theodolite and the double-hinged ruling blade are mounted in a single bearing which can be moved up and down, back and forth, to either side, or tilted in any direction. This greatly facilitates locating the center of the optical and mechanical axis of the telescope at the perspective center of a photograph properly mounted on the photoplate. This adjustment is not required very often but it is a great comfort to the operator to know that he can calibrate his instrument should a periodic check reveal that calibration is necessary.

The vacuum back on the photoplate is perhaps the second greatest improvement. The operator no longer needs to place his finger on the photograph to push out the bulges and wrinkles each time he makes a reading. The vacuum pulls the most severely warped photographs down flat against the plate thus insuring the highest possible accuracy in measuring.

The operator's comfort and convenience have been considered in several ways. The table has been designed with short legs and with no obstructing brace in front so that when he sits in an armchair, the eyepiece of the telescope is at just the right height. The vacuum is for accuracy in making readings but it also makes the work a lot easier and allows the operator to make his readings many times faster. The depression adjustment is conveniently located in front so that changes in depression can be made quickly and with little effort. The crank can be removed after each setting so that it cannot be disturbed by accidental bumping.

By lowering the plate downward in the normal way, the operator can get about 32 degrees of depression with a 6 inch focal length before there is mechanical interference with the frame. Should the operator find a need for a large depression, say 40 degrees, which could not be handled in the normal way, he would mount the photograph upside down on the photoplate and raise the plate to 40 degrees inclination rather than depression. This is illustrated in Figure 3. He would then utilize the eyepiece prisms for convenient sighting at the photograph. Depression up to 90 degrees could be handled in this fashion.

The normal range of focal lengths directly accommodated in the instrument is about 4 to 12 inches. If one had a reconnaissance photograph with a 24 inch focal length and desired to use it in the photoalidade, the normal procedure would be to photographically reduce the photo so that the new equivalent focal length would be 12 inches; the angular measurements

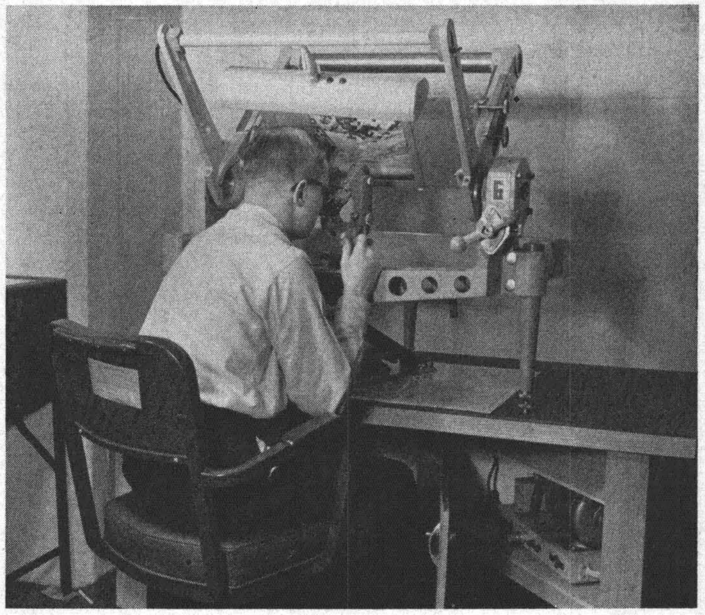

FIG. 3. Using the photoalidade for depressions greater than 32 degrees.

could then be made without trouble. That would be very satisfactory if the original print size is 9×18 inches so that the reduced size is $4\frac{1}{2}$×9 inches since this is still large enough to see something on. But suppose the focal length is 100 inches or even longer, would you still want to photographically reduce it? It would have to be reduced about 10 times and if you are lucky and have a 9×18 inch original format, the size of the reduced print will be less than 1×2 inches. This is not un-usable, but perhaps the next thing to it. A much better way is to use the original print at a substitute focal length to measure horizontal and vertical angles, and then mathematically reduce them to their true values. The equations for accomplishing this trick are:

$$(1)\ \beta = \tan^{-1}\left[\tan\beta' \frac{f'}{f} \frac{\cos VP' \cos(VP-\theta)}{\cos VP \cos(VP'-\theta)}\right]$$

$$(2)\ V = \tan^{-1}(\tan VP \cos\beta)$$

Where:

β = the true horizontal angle
β' = observed horizontal angle
V = the true vertical angle
f = true focal length
f' = substitute focal length
VP = true vertical angle projected into the principal plane
VP' = observed vertical angle projected into the principal plane
θ = depression angle

It is difficult to discuss the photoalidade strictly as an instrument without talking about some of the operating procedures and techniques employed in its use. Since the photoalidade is basically nothing more than a measuring device supplying data in the form of horizontal and vertical angles, the operator must utilize the data in such a manner as will provide useful information on the map or chart (namely spot elevations and contours). That is why the big story behind the photoalidade is really one of operational procedure and technique. When there is an error in photoalidade work, the operator knows that only he and not the instrument can be at fault. Most people are impressed with the simplicity of the photoalidade and think that operation involves no difficulty at all. Those operating it for the first time discover in short order that use is not as easy as it looked.

I will describe an ideal situation that has been worked utilizing the photoalidade. The first action by an operator is to plan the assigned area (usual chart area of approximately 6,500 square miles). He must consider all flights of photography, the availability and abundance of control, the greatest distance that he can see from any one flight, etc., so that he may be able to cover the area with the least number of setups in the shortest time with the highest possible accuracy. Next he would identify and pin prick all horizontal and vertical control in the first pair of photographs he intends to use. This usually entails some pretty tricky identification from vague descriptions or poor quality small-scale maps and at distances up to 100 miles or more. Following this he would estimate or roughly calculate the depression and swing for each photograph in the pair and with the photoalidade make what he would call control templets. These control templets are resected to the horizontal control that has been identified on a small scale map or a base compiled by a metal templet assembly. By using the ground distances from each nadir to each vertical control point and the vertical angles obtained with the photoalidade for each point, the operator can calculate the absolute orientation of the photographs. This is called "leveling" and seldom proceeds without a hitch because almost invariably bad control is mixed with the good and the operator must decide and prove which is which, after he has made certain that he himself has not made an error.

After both photographs in the set have been leveled, the operator will stereoscopically select and pin prick a dense pattern of points throughout the overlap of the two photographs. The operator will be concerned with approximately 800 to 1,000 square miles in the overlap of the two photos, and will usually require from 200 to 300 elevations at salient points on the relief, to adequately contour the area at 100 meters. The operator's next step is to obtain intersecting rays from the pair of photographs so that he may find the horizontal position for each point for which an elevation is desired. By using ground distance and vertical angles again, he will be able to calculate the elevation of each point from each photograph. (This calculation merely involves the solution of right triangles.) The two elevations he obtains for each point should agree rather closely and thus help him in checking his work.

The final stage in the photoalidade operator's job is to portray the relief with contours. During this phase he may discover that some of those elevations he so carefully computed do not make sense, and he will have to go back to find his error. He may also discover that he did not do as good a job covering the area with elevations as he thought, and will have to add a few more. The operator uses the spot elevations, the planimetric detail, and the terrain, as he stereoscopically views it in the photographs, as his guides in contouring.

These steps involved in computing elevations and contouring illustrate that the photoalidade operator's job is more largely one of procedure and technique than of operating an instrument. The conditions I have just described are far from being considered difficult by any photoalidade operator. The really difficult situations arise when there is no vertical control available, or there may be plenty of vertical control in the form of sea coasts but no horizontal control available. Such conditions call for real resourcefulness of the operator; he certainly needs a bag of tricks at his disposal to help him through. There have been many special techniques developed to cope with just such impossible situations, such as the "Butting Technique" as developed by David Landen, and many others which are in various stages of development.

The photoalidade has been found to be very reliable in running vertical control bridges or even cantilever extensions through or into areas of no control. The large overlap in oblique photographs allows getting many readings on a point as each photograph is worked in succession. This causes errors in extending vertical control to average out so that adjustments are small. Bridging or extending *horizontal* control with the photoalidade has not been fully explored as yet but I think that all photoalidade operators believe that it can be done and they will do it as soon as time will permit.