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ABSTRACT

Despite their unconventional image geometry, panoramic high-altitude air photographs clearly depict forest roads and trails which may not appear on other resource photography and maps. A conventional image-transfer device, the Bausch & Lomb Zoom Transfer Scope, was able to compensate for panoramic distortion sufficiently that these secondary routes could be transferred from the photographs to base maps. A modification to allow use of roll film is described.

INTRODUCTION

Over the past five years, high-resolution medium-scale panoramic aerial photography has been increasingly available to resource managers through the U.S. Forest Service's Houston-based Nationwide Forestry Applications Program. The photography is obtained by two now-declassified items of military intelligence gear, the Itek KA-80A Optical Bar Panoramic Camera and the Lockheed U-2 aircraft, from altitudes of about 60,000 feet above ground level. The U-2 aircraft employed in resource photography missions are operated by the National Aeronautics and Space Administration's Airborne Instrumentation Research Project.

Optical bar panoramic photography is best described as very high-quality, relatively inexpensive, medium-scale transparency imagery, which can be obtained quickly over large areas, but which confronts the user with unconventional photo geometry and presents certain handling and viewing problems. The authors elsewhere (1980) describe methods of overcoming the handling and viewing difficulties without recourse to expensive specialized equipment. The geometrical idiosyncrasies of panoramic photography give trouble chiefly in measurement of ground areas and in transfer of detail from photographs to base maps. For measurement of area, users may order transparent equal-area overlay grids from the Forest Service's photogrammetry office in Washington,[1] specifying aircraft altitude, average terrain elevation, and grid cell size. These overlays match the geometry of optical bar photography and are inexpensive and reusable.

For transfer of detail, the authors have found that a standard Bausch & Lomb Zoom Transfer Scope,[2] a widely available device used in many resource management offices where air photography is employed, is capable of adequately compensating for the geometric distortion of panoramic photography over the most important portion of each frame. If flight lines are not more than 20 miles apart—a standard specification for U-2/KA-80A missions—detail can be accurately transferred to all of the area covered in a photo mission, excepting only the outermost flanks of coverage.

[1] Photogrammetry, Engineering Staff, National Forest Stystem, Forest Service—USDA, P. O. Box 2417, Washington, DC 20013.

[2] Brand names are given for reader convenience only, and no official endorsement is implied.

PHOTO GEOMETRY

The optical bar panoramic camera scans a 120-degree transverse swath as the aircraft proceeds along its flight path. If the aircraft is 60,000 feet above ground, the area scanned is almost 40 miles across. In the direction of flight, the camera's angular field of view is only 11 degrees; this subtends 2.2 miles directly beneath the aircraft, and twice that at the extreme ends of scan. Figure 1 schematically illustrates how the "bow tie"-shaped ground scan pattern is turned into a rectangular photograph with a characteristic type of distortion, termed

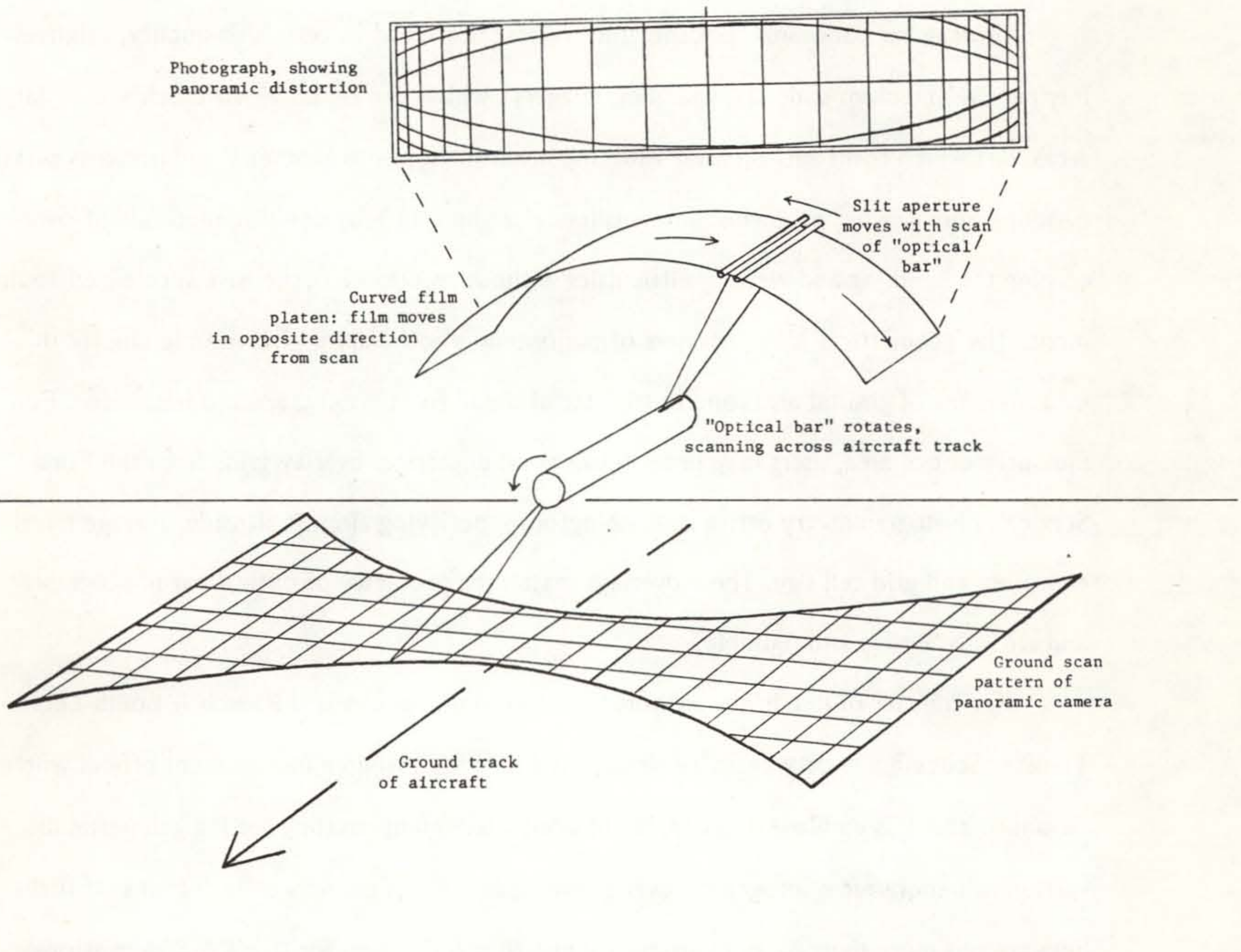

Figure 1. Panoramic photography is taken by a camera having a rotating lens assembly and a semicylindrical film platen. The rotating lens scans at right angles to the direction of flight; its ground field of view in the direction of flight is broader at the extreme ends of the scan than directly below the aircraft. This eccentrically shaped ground scan pattern is projected onto the film platen, and thus optically "compressed" into a rectangular photograph. Panoramic distortion, with convergence and foreshortening, is the result.

panoramic distortion. In the particular case of the KA-80A, the photograph is 50 inches wide (in the direction of scan) and 5 inches long (in the direction of flight). Successive photographs appear side by side in the reel of film. Scale directly beneath the aircraft is 1:30,000.

Panoramic distortion is an unavoidable feature of panoramic photography. Another type of distortion, called scan positional distortion, arises whenever a camera of this type makes photographs from a moving vehicle, since the scanning operation must take a certain length of time, during which the vehicle alters its position. Fortunately, this type of distortion can be reduced to practically negligible proportions by "forward motion compensation" mechanisms. In the KA-80A, the rotating lens head "nods" slightly to compensate for forward movement. The nodding action itself adds a third element of distortion to the photography, but this is of significance only in precision photogrammetry.

Panoramic distortion affects the scale of objects depicted in a photograph. As Figure 2 illustrates, it acts in two different directions at two different—but related—rates. These rates are functions of the transverse scan angle at which an object is photographed. The scale of an object measured in the "in-track" direction (parallel to the track of the aircraft, i.e., across the short dimension of the photograph) varies with the cosine of the scan angle, as measured from the vertical. The scale of objects measured in the "cross-track" direction (across the track of the aircraft, parallel to the direction of scan) varies with the square of the same cosine. Thus, except along the "nadir line" directly beneath the aircraft, the depicted scale of any object's cross-track dimension will always be smaller than that of its in-track dimension, which itself will vary with the angle at which it was photographed. An image-transfer device must be able to correct for this dual distortion if it is to be usable with panoramic imagery.

TRACING FOREST ROADS AND TRAILS

Optical bar panoramic transparencies have excellent color rendition and high resolution—on the order of 25 line pairs per millimeter of film, which means that objects two feet wide may be distinguished from one another at the nominal nadir scale of 1:30,000. Linear

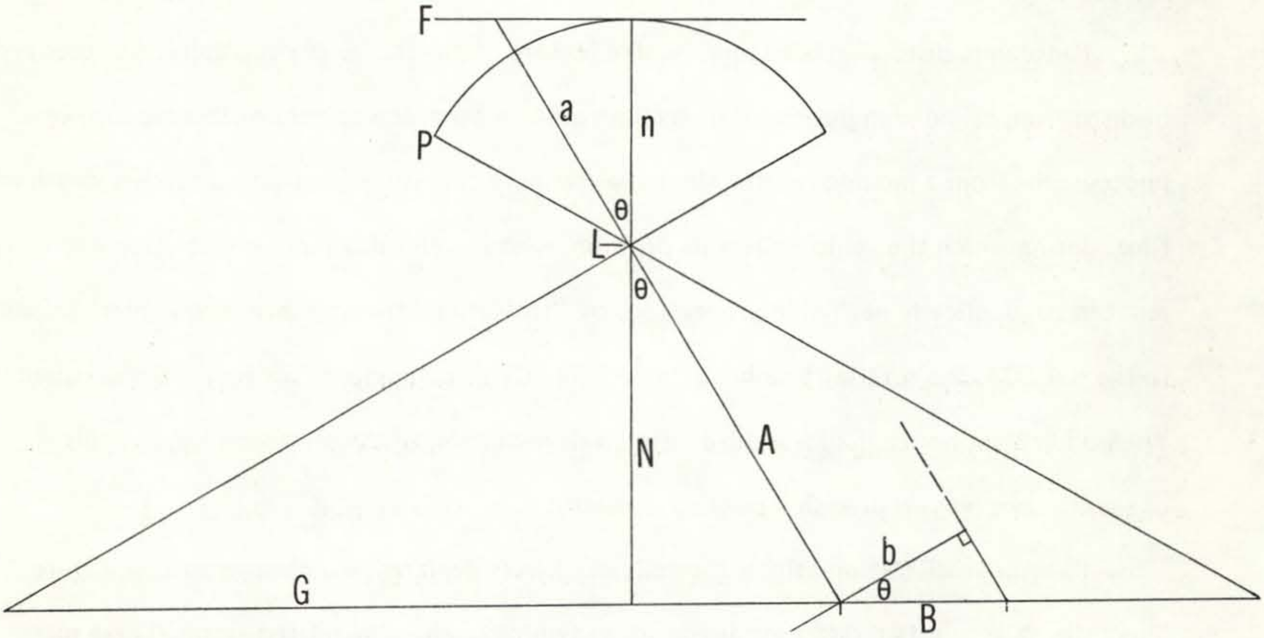

Figure 2. In general, the scale of a vertical aerial photograph is fixed by the ratio between two distances: the distance (focal length) from lens L to the film platen, and the distance from a photographed object on the ground G to the lens. Directly beneath the aircraft, the scale is thus n/N with any camera. When a conventional camera with flat platen F is used, displacement of the photographed object from the center of the picture makes no difference to its depicted scale, since the ratio a/A, by the principle of similar triangles, always equals n/N. In a panoramic camera, with an arc-shaped film platen P, distance "a" remains constant and equal to n, while A increases as the inverse of the cosine of view angle θ. Thus scale equals n/N only beneath the aircraft; elsewhere it is equal to $n/(N/\cos\theta)$. A further complication arises: this relationship holds true only for measurements made "in-track," parallel to the direction of flight. For "cross-track" measurements made in the direction of scan, image foreshortening must be taken into account as well; the camera records not line B, but line "b"—which is related to B by the cosine of θ. So for cross-track measurements, scale is $n/(N/\cos^2\theta)$.

objects may be distinguished with even greater acuity: on some frames, the authors were able to pick out high-voltage power lines near the limit of scan, where effective image scale was about 1:85,000. Users of optical bar photography have found that it lends itself well to the tracing of roads and trails that do not appear on other resource photographs or maps (Bowlin 1979, Bluestein 1980[3]).

[3] Personal communication.

The bright, raw scars of recently constructed logging roads are easily followed with the naked eye on panoramic transparencies. Other secondary routes are often more difficult to detect, being masked by vegetation to some extent on account of their age or their small size. Where they pass through heavy timber, old logging roads and hiking or horseback trails may be detectable only as occasional linear openings in the tree cover. Interpreters attempting to trace these difficult routes usually begin where the tracks cross watercourses or open areas, and work back from these to reconstruct the more problematical sections.

Stereoscopic viewing is an important aid in tracing travel routes, although the job may be done monoscopically if proper stereo equipment is not available. Optical bar photography has the conventional 50-60 percent overlap, and the entire mission area may be viewed stereoscopically. If the user has access to a split light table with take-up rollers to reduce image separation, and a stereoscope with rotatable optics to align his eyes with the flight line, stereo interpretation may be performed without cutting individual transparencies from the roll of film. Where such equipment is not available, pairs of individual exposures may be fastened to a long light table, their 50-inch sides parallel and close together, and viewed with a pocket stereoscope, mirror stereoscope, or scanning stereoscope.

Probably the best way to trace secondary routes is to view the photographs stereoscopically, marking the routes on overlay material, and then to transfer the marked routes from the overlaid photos to a map. If the user wishes to keep the film in roll form, temporary overlays with reference marks for later re-registration may be taped in place during interpretation. Users who must separate their transparencies will probably find it most satisfactory to laminate them between sheets of clear plastic (Befort, Heller, and Ulliman 1980). This greatly increases the durability of the photography and provides a permanent, reusable annotation surface.

In delineating aerial photographic detail, it is customary to demarcate an "effective area" on every photograph, or on every second photograph, in order to eliminate duplicate delineation and to ensure that the best available exposures, out of all those which might cover a given point, are used for its interpretation. The curvilinearity which results from panoramic distortion makes it difficult and laborious to rule in accurate effective areas on optical bar photography, and the photographs' unconventional size and shape complicate matters. For purposes of route tracing, the economical solution is probably to confine annotation to every second exposure, using one of the index tick-marks in the margin of the film as a sidelap boundary and accepting the possibility of a certain amount of duplication.

It was noted earlier that the ground scan pattern of the optical bar camera, assuming an altitude of 60,000 feet above terrain, is about 40 miles wide. It will be apparent that not all portions of the resulting photograph are equally useful: at the extreme edge of scan, in-track scale is 1:60,000 and cross-track scale is 1:120,000, and the view afforded is quite oblique, being only 30 degrees below horizontal. The usual practice, therefore, is to space panoramic flight lines from 17 to 20 miles apart, rather than 30-40 miles apart. With a 20-mile flight line separation, the interpreter can confine his attention to the central 35 inches of the 30-inch exposure, and need never accommodate himself to a viewing angle more than 41 degrees from the vertical; in-track scale is never smaller than 1:40,000, and the lower limit of cross-track scale is 1:53,000.

TRANSFER TO BASE MAPS

Image transfer devices allow the interpreter to see two images—a photograph and a map, ordinarily—at once, and provide some means of bringing the images into congruence by adjustment of scale and geometry. The interpreter fits the two images together and is then able to draw the photographic detail onto the map in something like its correct position. The ability to adjust geometry as well as scale is important in aerial photo work, since most airphotos are affected by topographic displacement—the distortion which arises in viewing irregular objects from a central perspective—and may also exhibit the adverse geometric effects of aircraft tip and tilt. Panoramic photographs combine these common geometric problems with their own peculiar panoramic distortion effects.

The Bausch & Lomb Zoom Transfer Scope (Fig. 3) is a desktop transfer instrument which costs about $6,000 and is in wide use for map revision. In the standard monoscopic model, a photograph is clipped to a vertical stage facing the operator, where it can be illuminated from behind if a transparency or from in front if a print. The map to be revised is placed on the table beneath the instrument, where it also is illuminated. The operator views map and photograph simultaneously, through a split optical train. He may change the magnification at which he views the map by installing "map lenses" of various powers. He has considerably more freedom as regards his view of the photograph: he may enlarge it up to 14 times, rotate it through 360 degrees, and optically "stretch" it in any direction he chooses without changing its other dimensions. By controlling, with rheostat switches, the amount of light falling on map and photograph, he can balance the strength of the two parts of the combined image, or flash rapidly from one to the other.

It is the "stretch" feature of the ZTS which adapts it well to panoramic photography, and makes it possible to correct for panoramic distortion. The operator, viewing a portion of a photograph and the corresponding section of a map, uses the enlargement control to adjust for the in-track component of photo distortion, and then stretches the photo image in the direction of scan to remove the cross-track component. Successive portions of the photograph are so registered and their detail transferred until the entire effective area has been transcribed. Because panoramic distortion proceeds at an increasing rate with scan angle, the size of the portion of photograph in which the operator is able to compensate effectively for panoramic distortion shrinks with distance from the nadir line. Topographic displacement also increases with distance from the flight line. In mountainous terrain, these two factors combine to put a practical limit to image transfer at about 10 lateral miles from the flight line, or about 40 degrees of panoramic scan as measured from the vertical. Fortunately, as we have noted, the conventional spacing of U-2/KA-80A flight lines permits achievement of full coverage within this limitation; only the imagery beyond 10 miles from the outermost flight lines of a photo project cannot be conveniently transcribed.

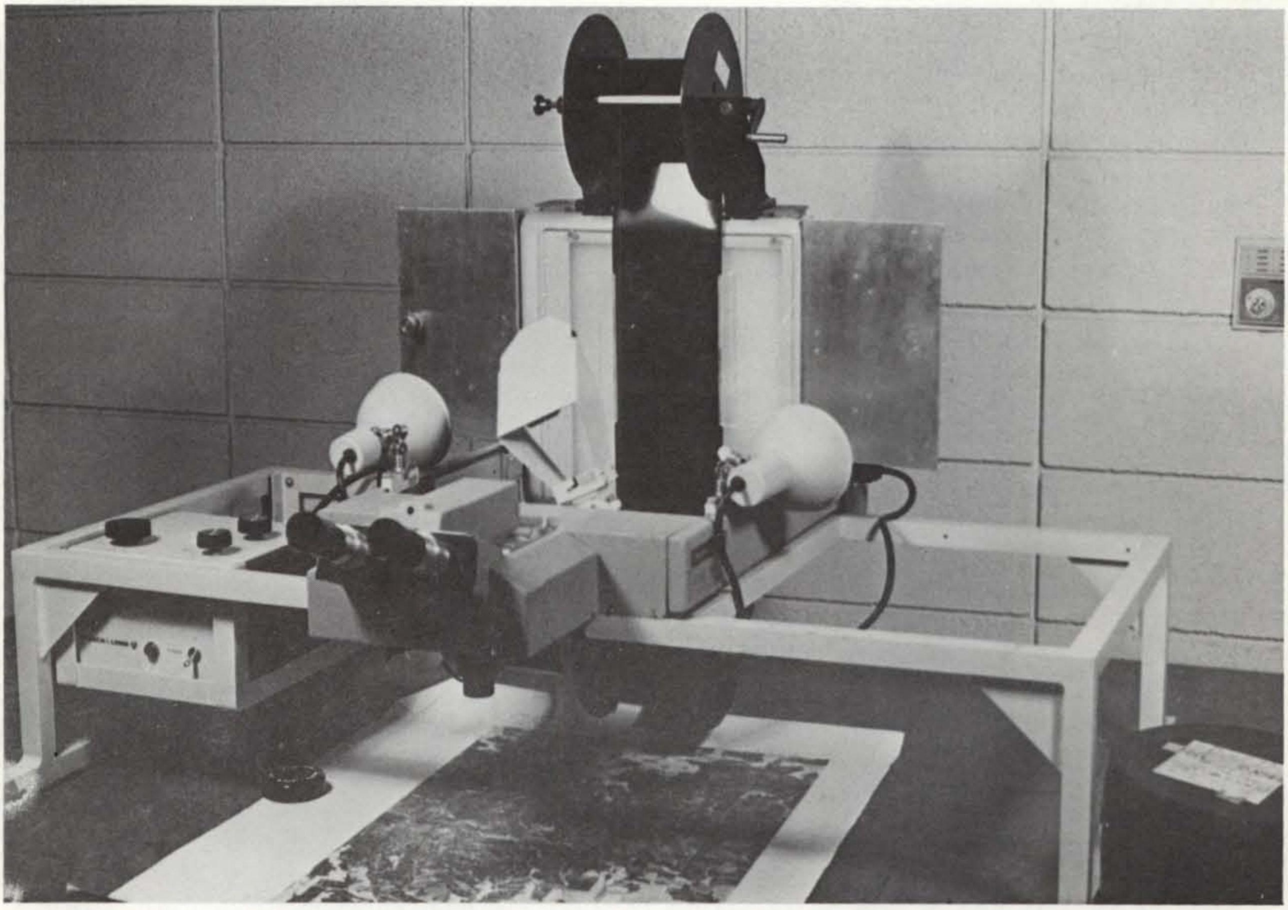

Figure 3. Zoom Transfer Scope (ZTS), modified to accept roll film. Film roll brackets slide onto plates attached to top and bottom of vertical photo stage; undercut rails on Plexiglas sheet in front of stage hold film flat. The metal "wings" on the stage are an earlier modification, unrelated to panoramic photography.

MOSCOW MOUNTAIN ROAD MAPPING PROJECT

Using an available ZTS and 10 color infrared photographs from a 1979 U-2/KA-80A flight (No. 79-087, 3 July), the principal author revised the secondary road network depicted on three 7½-minute map quadrangles: Stanford, Moscow Mountain, and Robinson Lake (Idaho). Orthophotoquads were employed as base maps; they allowed, because of their photographic detail, much more precise registration of photograph and map than would have been possible with standard topographic quadrangles. The base maps' secondary road nets had originally been mapped by the U.S. Geological Survey and had been photorevised and amplified by the University of Idaho's Cart-O-Graphics Laboratory during production of a complete set of map separations for Latah County, Idaho. Despite this recent updating, and in spite of the fact that all road interpretation was done monoscopically on the ZTS itself, rather than in a separate stereoscopic analysis, panoramic photo interpretation added 120 percent to the total length of secondary roads on the base maps. Mileage on the Moscow Mountain sheet was increased from 91 to 201. Some previously mapped roads were eliminated.

Accuracy of route tracing and classification in this exercise probably suffered from lack of stereoscopic inspection; however, the rate of production of revised maps probably benefited. After experience was gained, an operator was able to revise a 7½-minute quadrangle in less than three days' time, despite the high density of previously unmapped road. New secondary road separations were scribed for each quad; this took about the same length of time as revision itself. Transparent Ozalid masters were then constructed by Cart-O-Graphics personnel. The revised orthophotoquads will be field-checked in summer 1980 by University of Idaho Experimental Forest crews, for whom they will serve as working tools in forest management.

In operating the ZTS with panoramic film, it was found that a map-scale enlargement of two diameters gave the most generally satisfactory results. The 2-power map lens has a circular field of view about 4.3 inches in diameter on the map, which is large enough for orientation and small enough that an adequate distortion adjustment can be obtained over most of the visible area. However, delineation is best confined to the central 2 or 2½-inch portion of the field of view. Near the nadir line, the 1-power map lens with its broader (7.4-inch diameter) field of view on the map may be brought into play, since panoramic distortion is at a minimum here; with this lens, interpretation should be confined to the central 4 or 5 inches of the field of view, and the instrument readjusted when it is necessary to move beyond this circle. At the edge of the effective area, 10 miles from the flight line (about 17 inches from the center of the photograph), nearly two-thirds of the available 2X stretch adjustment is needed to compensate for cross-track distortion and topographic displacement. Here some experimentation with direction of stretch may be needed before a satisfactory accommodation can be reached.

The vertical photo stage of the ZTS was placed in its rearward position, and the .5-power attachment lens was used. Photo enlargement adjustments ranged from 1.25X at the nadir with the 1-power map lens in place, to 3X at the edge of the effective area with the 2-power map lens in use. At any position on the photograph, the "zoom" feature of the ZTS served as an important interpretation aid, enabling the operator to take a close look at a doubtful road or trail without disturbing his other settings.

ROLL-FILM MODIFICATION

Minor alterations were made to allow optical bar film to be used in roll form on the ZTS, as illustrated in Figure 3. Two pairs of film roll brackets were taken from a light table, and mounting plates were made from mild steel to fit them. These plates were bolted to the top and bottom of the vertical photo stage. Rectangles of quarter-inch Plexiglas went between the plates and the stage as spacers. The bottom plate had to be short enough to allow mounting and dismounting of the roll brackets.

The sheet of eighth-inch Plexiglas in front of the vertical stage was replaced by another, which had undercut plastic rails glued to it to serve as film guides. The top and bottom edges of this sheet were carefully rounded and sanded to avoid scratching the film. Most optical bar photography comes to the user in the form of duplicate transparencies which read correctly from the emulsion side; the film emulsion faces away from the stage and is in no danger of being damaged by friction. Where it is found desirable to keep optical bar photography in roll form, this arrangement will allow satisfactory use of the transfer instrument.

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