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High Altitude Photography: Aspects and Results

Large area coverage, combined with the use of high resolution cameras and precision stereoplotters, provides for economical mapping procedures.

Abstract: *Cameras equipped with the most recently developed lenses from Wild Heerbrugg Ltd. were used to take aerial photographs from small jet aircraft over the test range at Casa Grande, Arizona. Aircraft, flying height, field angle, and photographic emulsion were varied in the tests. Numerous stereopairs were evaluated in a precision plotter and under a P.I. microscope. The height accuracy obtained from 15 cm (6") focal length lenses was 0.004 percent of the flying height or one part in 25 000, which is a new achievement in analog photogrammetry. Systematic effects varying with altitude were detected, and a method for compensation was developed. Ground resolution was better than 2.5 m on the ground for the maximum flying height of 13.4 km (44 000 ft.).*

The enormous area coverage, combined with high geometric accuracy and ground resolution of high altitude photography, permit the use of new procedures in aerotriangulation, and in small-scale line and ortho-photo mapping. Some proposals for new procedures in these fields of application are made. Other aspects of high-altitude photography, such as automatic navigation, semi-automatic operation of a dual camera system, camera performance, and installation requirements, are discussed as well. The four photographic airplanes tested are now in use in South America.

Introduction

In practical photogrammetry a single photograph is used to cover as large an area as possible while maintaining recognition of detail and geometric accuracy necessary for topographic mapping. Small jet aircraft enable the photogrammetrist to attain image scales of up to 1:150 000. Both of the authors have installed camera systems and participated in jet test flights. Numerous photographs were taken by D. Gut over a test field. The image material was analyzed with regard to geometric accuracy and image quality. The purpose of this paper is to show the unique characteristics of jet photography and to determine the potential for map production with modern instruments on the basis of the results obtained from the test field photographs.

General Aspects of High Altitude Photography

Photographic Aircraft

Recently, very high flying small jet aircraft with pressurized cabins have been used repeatedly by civil organizations and private companies for aerial photography. The Learjet of the Gates Learjet Company (USA), for example, has a service ceiling up to 13.7 km along with other advantages important for photogrammetric application. The high rate-of-climb performance (in less than 20

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minutes up to 12 km), the high velocity (about 800 km/h), and the range of about 3000 km rapidly bring the camera system to the target area at high flying heights. Large areas may be flown over at equal illumination and weather conditions. For photography at lower flying heights the maximum velocity can be reduced to a third. The flight altitude is stable and vibrations are slight. Consequently, there are only small tilts and the image quality is primarily determined by the lens. The working conditions in the pressurized cabin are very comfortable for the operator. The camera is no longer exposed to extreme changes of pressure and temperature. The necessary floor closing glass, however, is part of the image system. Its quality also determines the quality of the photograph.

INSTALLATION OF THE CAMERA SYSTEMS

First of all the installation of a window is necessary in pressurized aircraft. Its dimensions are determined by the field angle of the lenses used, the position of the entrance pupil, and especially by the security regulations. In the Gates Learjet Model 25 C, for example, $508 \times 584 \times 38$ mm^3 windows are installed for the RC-10 equipped with a super-wide-angle lens. The optical quality of the windows must be adapted to that of the lenses and filters in order to keep geometric and optical errors small. The two surfaces must be parallel. Deflection of the glass plate causes distortion. The cameras have different lenses, suspensions, viewfinders, and navigation telescopes. For installation in a jet the most favorable components have to be chosen and special measures have to be taken. For the Aviophot System of Wild the following general aspects are of importance:

- The window dimensions are to be fixed for the lens with the largest image angle. If lenses with a smaller image angle are also used, a spacer has to be used in order to clear the lens cone from the window.
- The rotation of the camera for the purpose of the drift, tip, and tilt correction and its tilting for the change of filters require special distances to the side walls and inside setups.
- For the exclusive use of the super-wide-angle lens a suspension of low height can be used. The entrance pupil of the lens thus comes as near as possible to the window; its size can then be kept smaller than when using the standard suspension.
- For navigation, drift, and overlap control, the viewfinder telescope can be installed behind a window. It also can be prepared for simultaneous control of a second camera (slave camera).

In the Learjet the door of the airplane has been modified for a single camera and can rapidly be exchanged against the standard door.[1] For the double camera two windows lying side by side have been installed (compare Figure 1).

Often navigation of a jetplane is no longer performed with the viewfinder or navigation telescope, which merely control overlap. The Inertial Navigation System, e.g., the INS-61B of Collins Radio Company or the LTN-51 of Litton Industry, and its coupling with the autopilot hold the aircraft automatically at a very stable altitude along the desired flight path. Only the coordinates of the wing points of the flying pattern have to be keyed into the computer of the INS. Moreover, the drift angle of the aircraft is indicated and can be transferred to the camera manually.

PHOTOGRAPHIC PROBLEMS IN HIGH-ALTITUDE PHOTOGRAPHY

Systematic errors affect photographs taken through a window at high altitudes. These errors are named and estimated according to their size and their consequences.

Earth curvature. Elevations determined by geodetic surveying relate to the roughly spherical plane of mean sea level. Consequently, the photogrammetric instrument also must have a spherical reference plane or other means of compensation. If no provisions for compensation are incorporated in the stereoplotter, the photogrammetric models will be warped. Warping depends on the flying height and the focal length of the camera. The errors are high, as illustrated in Figures 2 and 3.

Atmospheric refraction. The index of refraction of air decreases with increasing al-

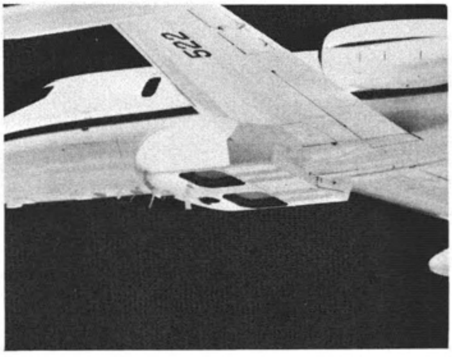


FIG. 1. Dual camera installation in the Learjet.

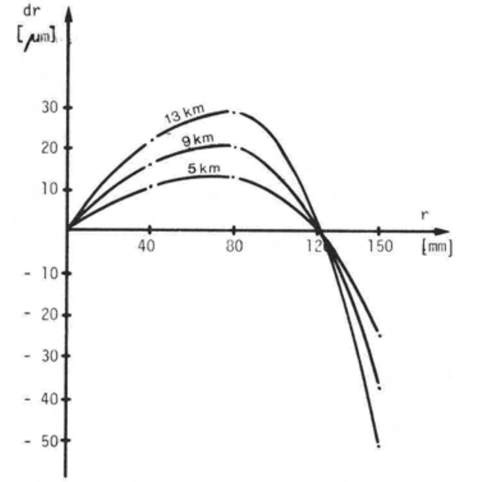


FIG. 2. Influence of earth curvature on the image position of a wide angle photograph (f = 153 mm) as a function of the flying height. The linear portion (scale) has been removed in that presentation as distortion.

titude due to changes in temperature and pressure. The imaging ray will be bent and the image point displaced towards the image edge. However, the errors are very small and of opposite sign to that of the earth curvature (Figures 4 and 5).

Window flexure and change of refraction index of air. At high altitudes temperature and pressure are very different on the two sides of the window. The resultant flexure of the window and difference in the refraction index of air produce a displacement of the image. However, the amount of the displacement is very small if the window is manufactured and installed properly (Figures 6 and 7).

Change in focus and calibrated focal length. In general, lenses with longer focal lengths (f=305 mm, f=213 mm) are focused by the manufacturer to finite object distances, for example, to 850 m at the Wild Aviotar At II. If the lenses are used at high altitudes, the resolving power may decrease under certain conditions. Especially the 305 mm lens is critical when maximum aperture and black-and-white films of high resolving power (e.g., Kodak Plus X) are used at altitudes above 4 km. In this case the use of smaller apertures or special focusing on longer object distances is recommended. The above-mentioned image displacements due to window flexure and atmospheric refraction lead to a change of the calibrated focal length. These values are smaller than 0.02 mm and can be neglected in most cases.

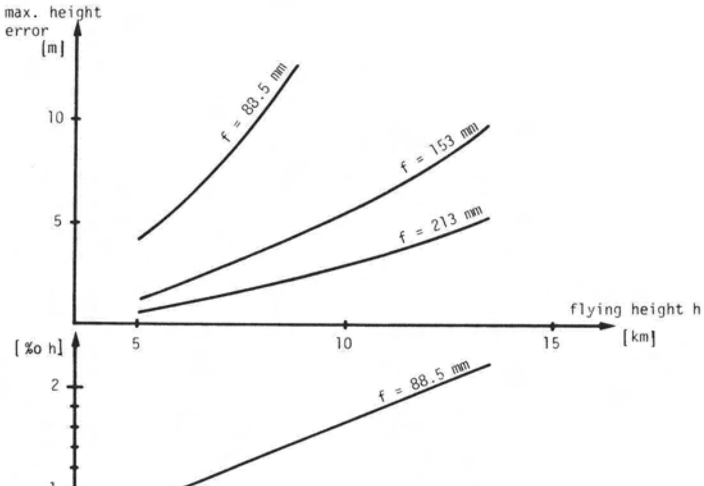


FIG. 3. Maximum vertical errors in the middle of the neat model due to earth curvature as a function of flying height and focal length. Forward lap 50 percent, sidelap 0 percent, control points in the four corners of the model.

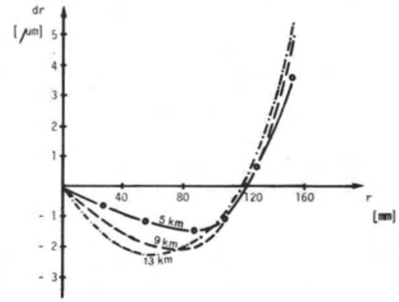


FIG. 4. Displacement of the image due to atmospheric refraction as a function of the image radius and the flying height. Values are based on a wide-angle photograph (f = 153 mm).

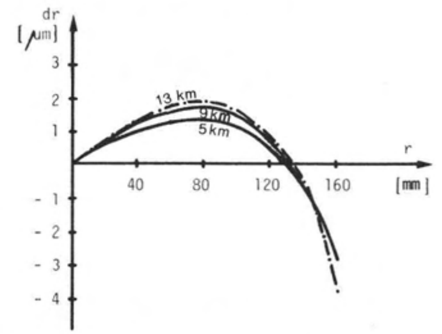


FIG. 6. Displacement of the image due to window flexure and difference of the refraction index of air at both sides of the window. (Calculation with the following parameters according to reference 2: Index of refraction of glass n = 1.517, temperature inside cabin T = 20°C, pressure inside cabin corresponding to an altitude of 2 km, window dimension 58 × 51 × 3.8 cm^3, Elasticity Modul of glass $0.7 \cdot 10^6$ kp/cm^2, focal length of lens f = 153 mm, position of entrance pupil of the lens above window 150 mm)

PRACTICAL TESTS

The functional tests of the Learjet photographic aircraft, which are carried out on a routine basis, include taking photography over a test range. In the last two-and-one-half years several tests have been performed in which aircraft, camera, lens, altitude, and season were varied. Numerous stereopairs have been evaluated with respect to geometric accuracy and image quality. From this experience the current procedures in mapping at small and medium scales shall be examined. The conditions during the tests shall first be explained.

PHOTOGRAPHIC AIRCRAFTS

The Learjet models 24 D, 25 B, 25 C, and 35 C were used. A single camera was installed in the interchangeable door or a double camera in the fuselage. In the latter case a sliding door protected the windows during take off and landing. The window was a 51 cm × 58 cm × 3.8 cm Schott BK 7 glass plate. The pressure inside the cabin corresponded to the pressure at an altitude of 2 km.

TEST RANGE

The 25 km × 25 km Casa Grande test range near Phoenix, Arizona was used. Its density of control points, one target per 2.6 km^2, and the shape of the panels allow measurements with photography of varying and extremely small scales. The target (see Figure 8) has four quadrilateral "pointers," the parallel sides of which measure between 0.8 m and 4.9 m. The smallest visible image distance in the photograph can be determined approximately with the help of this panel by a simple procedure (see Figure 15).

Camera system. For photography, the Wild Heerbrugg Aviophot System was used. The main part of the system is the RC 10 camera, in which six lens cones can be introduced. In the tests the following lens cones were used:

- the super-wide-angle lens 8.8SAG II, f = 88.5 mm, A_{max} = 5.6
- the wide-angle lens 15UAG I, f = 153 mm, A_{max} = 5.6

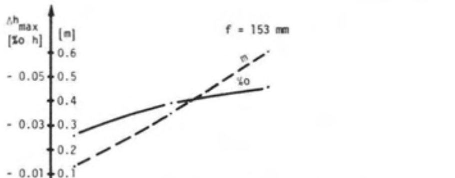


FIG. 5. Maximum vertical error within the neat model of wide-angle photographs (f = 153 mm) due to atmospheric refraction.

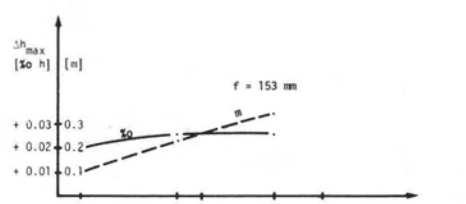


FIG. 7. Maximum vertical error within the neat model of wide-angle photographs (f = 153 mm) due to window flexure and change in the refractive index of air.

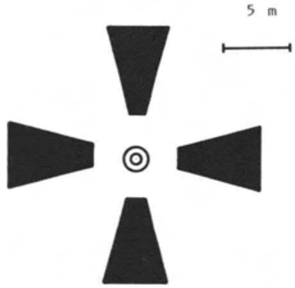
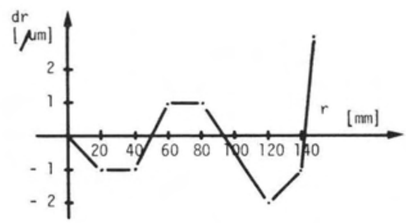


FIG. 8. Target of the Casa Grande Test Range. Its size and shape are suitable for photography of high-altitude and of varying photo scales.

- the wide-angle lens 15UAG II, f = 153 mm, A_{max} = 4
- the normal angle lens 21NAG II, f = 213 mm, A_{max} = 4

The last three lenses have been put on the market just recently. The lenses have a very small distortion which causes a correspondingly small deformation of the stereomodel (see, for example, Figure 9). The single cameras were controlled either by a navigation sight or a viewfinder in a separate mount. The double camera used is shown in Figure 10.

Both of the cameras are controlled by one navigation sight; they work simultaneously or independently with different lenses, overlap, and film. Using a dark yellow filter, two types of films, the panchromatic film Kodak Plus X and the false color film Kodak Aerochrome Infrared, were exposed. Exposure was automatically controlled.



mm	0	30	60	90 mm
100	-3	-2	-2	-3
80	-3	0	0	-3
60	-2	1	1	-2
40	0	2	2	-1
20	0	0	0	0
0	0	0	0	1
20	0	0	0	0
40	0	2	2	-1
60	-2	1	1	-2
80	-3	0	0	-3
100	-3	-2	-2	-3

FIG. 9. Radial distortion of the wide-angle lens UAg II and the resulting height deformation (values in micrometers and related to the photograph, overlap 61 percent). 3 μm = 0.02 ‰ h.

PHOTOGRAPHIC FLIGHTS

Test flights were carried out over the Casa Grande test range with four Learjets for general installation and camera tests and in order to determine the geometric accuracy. Photographs of the test range were taken from altitudes of 5 km, 8.9 km, 11.9 km, and 13.4 km on four different dates. Because the lens cones were exchanged during the tests, image scales between 1:33 000 and 1:150 000 were obtained. Navigation was carried out with the Inertial Navigation System, with the help of which the drift angle was obtained and manually transferred to the camera-controlling navigation sight. This method proved to be very practical and accurate. The overlap, however, was controlled in the usual way. For manual navigation the forward view of the navigation sight did not have to be used at these altitudes. Therefore, the camera's viewfinder, installed in a separate mount, may be used as well. Its installation and use behind a window pose no problems.

MEASUREMENT OF PHOTOGRAPHY

The measurement of single models was carried out on a precision stereocomparator and on two precision stereoplotters, the Wild STK 1 and the Wild A 10, respectively. The average elevation accuracy of the two analog instruments used in the measurements is m_h

FIG. 10. Learjet dual camera installation. From left to right: master camera with 15 cm lens and spacer, navigation telescope with overlap regulator, slave camera with 8.8 cm lens, circuitry unit, control unit, and exposure meter.

= ± 0.021 ‰ of the flying height.* The photographs are observed at 8× magnification. The instrument features a compensation device for the influence of earth curvature. A sphere built in the model space is continuously scanned so that the reference in height will change with the position in the model. The sensed value will be exaggerated by a factor corresponding to the flying height or the model scale denominator.

If systematic errors of a spherical nature remain, the compensating effect can be increased or decreased by changing the model scale denominator. In this way systematic errors in the stereo model, e.g., those due to atmospheric refraction, lens distortion, and flexure of the camera's pressure platen or the aircraft window, may be approximately compensated.

The revised model scale denominator, which is set in the correction device for earth curvature, has to be determined empirically.

The stereoplotter was equipped with a data acquisition device, the Wild EK 22, with connected desk calculator HP 9820. The coordinates and the elevations of each point were measured three times. The averaged model coordinates were immediately transformed into ground coordinates at the side of the analog instrument. A simple spatial transformation over four control points eliminates the small errors frequently arising in manual absolute orientation. The number and arrangement of control points varied.

The stereocomparator STK 1 is an even more accurate measuring instrument ($m_{x,y}$ = ± 1 μm). The measurement is done in a model affected with parallaxes. The continuous removal of vertical parallaxes at each point calls for a high quality of the imaged targets if the high accuracy of the comparator is to be exploited. Systematic image errors such as lens distortion, earth curvature, refraction, etc., are compensated for by calculation. Determination of the coordinates of the test field was done with the help of a computer.

The photointerpretation stereomicroscope Wild M 5 with parallel guided and illuminated picture carriages was used for a comparing examination of the image quality. The chosen enlargement of viewing was 12.5 ×. The ocular was equipped with a rotatable measuring scale.

* Parameters of the instrument test are measurement of 66 grid points, f = 150 mm, z = 450 mm, bx = 300 mm, and M_M = 1:100 000.

Results

Geometric Accuracy

In Table 1 the measuring results of ten single models obtained by the precision stereoplotter are shown. They comprise the errors of planimetry and elevation on the ground and in the image.

Let us first discuss the results with the eight wide-angle stereopairs. The average RMSE in elevation of ± 0.034 ‰ of the flying height, or 1:33 000, is remarkably small. This is almost the limit of performance for measurement with an analog instrument. The mean errors of planimetry average $m_{x,y}$ = ± 10 μm in the photograph. Consequently, the accuracy of planimetry is inferior to the accuracy of elevation. The reason for this may be the partially bad quality of the signals and the resulting insecurity in setting the measuring mark. Elevation setting could always be done in the horizontal neighborhood of the target. The influence of the flying height on the vertical error is shown in Figure 11.

The accuracy in elevation is best at the lowest flying height (m_h = ± 0.026 o/oo of the flying height). At flying heights of 9 km and more the accuracy of elevation is about the same (0.038 ‰ of h). The elevation accuracy of the measured normal angle and super-wide-angle stereopairs is inferior to that of the wide-angle stereopairs; it amounts to an average of m_h = ± 0.07 ‰ of the flying height. Better results for the super-wide-angle photographs can be obtained if compensation plates for lens distortion are used. When measuring the stereopairs, systematic model deformations up to about 0.2 ‰ of the flying height were found. This error, however, could largely be corrected by increasing the model scale number to be set in the compensation device for the earth curvature. The magnification factors K, empirically found for the wide angle stereopairs, are shown in Figure 12; a linear dependence on the flying height exists. Some stereopairs also were evaluated analytically in order to detect the reason for the systematic errors. The model deformation was found to be of the same size (see in Figure 13). This fact proves the good adjustment for the stereoplotter used and for its compensation device for earth curvature. The reason for the deformation is very likely a higher flexure of the window during the flight than theoretically expected.

TABLE 1. ACCURACY OF HIGH-ALTITUDE PHOTOGRAPHY

Aircraft / Lens Cone	Date / Flying Height[1]	Photo Scale / Photo No.	Control Pts.	RMSE[2] Terrain[3]	RMSE[2] Photograph[4]
25C 15 UAgII No. 3035	Sept. 74 5 000 m (16 400′)	1:33 000 1345/46	8	$m_E = \pm 0.24$ $m_N = \pm 0.39$ $m_H = \pm 0.13$	$m_x = \pm 7$ $m_y = \pm 12$ $m_z = \pm 0.026$
25C 15 UAgII No. 3035	Sept. 74 5 000 m (16 400′)	1:33 000 1341/42	8	$m_E = \pm 0.23$ $m_N = \pm 0.37$ $m_H = \pm 0.13$	$m_x = \pm 7$ $m_y = \pm 11$ $m_z = \pm 0.026$
25B 8.8 SAgII No. 2073	Aug. 75 5 000 m (16 400′)	1:56 500 180/81	10	$m_E = \pm 0.75$ $m_N = \pm 0.54$ $m_H = \pm 0.36$	$m_x = \pm 13$ $m_y = \pm 10$ $m_z = \pm 0.072$
25C 15 UAgII No. 3035	Sept. 74 8 800 m (29 000′)	1:58 000 1356/57	28	$m_H = \pm 0.37$ ± 0.47[5]	$m_z = \pm 0.042$ ± 0.053[5]
24D 15 UAgII No. 3047	Jan. 75 8 400 m (27 750′)	1:57 000 79/80	26	$m_H = \pm 0.30$	$m_z = \pm 0.036$
25B 15 UAgI No. 6034	Aug. 75 8 900 m (29 000′)	1:58 000 118/19	28	$m_H = \pm 0.33$ ± 0.66[5]	$m_z = \pm 0.037$ ± 0.074[5]
25B 15 UAgI	Aug. 75 8 900 m (29 000′)	1:58 000 119/20	28	$m_E = \pm 0.66$ $m_N = \pm 0.70$	$m_x = \pm 11$ $m_y = \pm 12$ $m_z = \pm 0.034$
25C 15 UAgII No. 3035	Sept. 74 13 400 m (44 000′)	1:88 000 1273/74	11	$m_E = \pm 0.54$ $m_N = \pm 0.92$ $m_H = \pm 0.52$	$m_x = \pm 6$ $m_y = \pm 11$ $m_z = \pm 0.039$
25C 21 NAgII	Sept. 74 13 400 m (44 000′)	1:63 000 56/57	10	$m_E = \pm 0.54$ $m_N = \pm 0.82$ $m_H = \pm 0.78$	$m_x = \pm 9$ $m_y = \pm 13$ $m_z = \pm 0.060$
35C 15 UAgII No. 3078	May 76 11 900 m (39 000′)	1:78 000 68/69	44	$m_H = \pm 0.41$	$m_z = \pm 0.035$

[1] Above mean ground level
[2] Root-mean-square error
[3] m_E, m_N, m_H in meters
[4] m_x, m_y in the micrometers, m_z in ‰ of the flying height.
[5] analytical evaluation

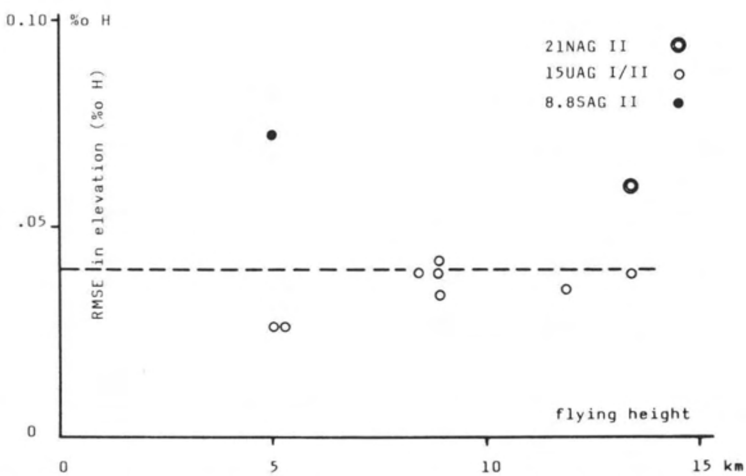


FIG. 11. Elevation errors as a function of the flying height and the lens.

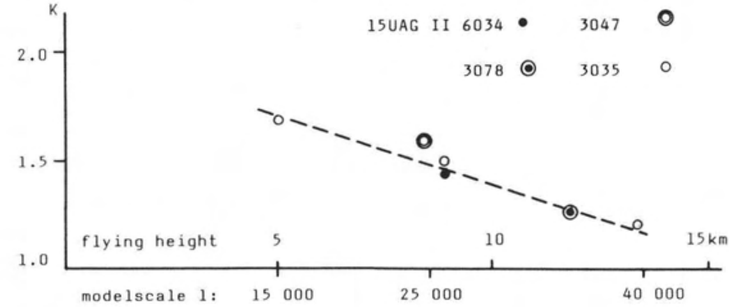


FIG. 12. Systematic errors in high-altitude photography can be compensated by using an increased altitude or model scale number used in earth curvature correction. The factor of enlargement *K* varies with the altitude. The circles in the diagram indicate empirically derived values for four wide-angle lenses in four different Learjet photographic aircraft.

IMAGE QUALITY

The procedure and the results of the image quality evaluation are shown in Figures 15 and 16. The smallest visible image distance is influenced by many factors, e.g., the contrast of the target to its neighborhood, the location in the image, the type of lens and the photographic emulsion, and others. Five different panels named S, R, D, H, and W were measured on 14 photographs at scales between 1:56 000 and 1:99 000. Their location in the image was up to 130 mm from the center. This fact, however, influenced the results only slightly.

Considering the measurements first, one can see that in 75 percent of the cases the smallest imaged distances are less than 30 μm, that is, 1.8 m (6 ft) at the 1: 60 000 photo scale. At the extremely small image scale of 1:150 000 the panels with good contrast of

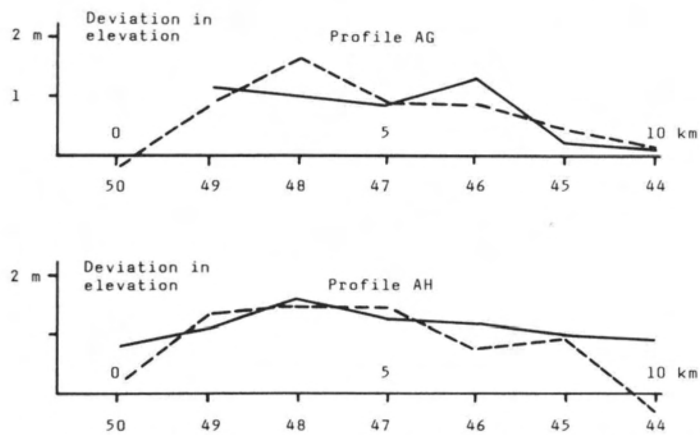


FIG. 13. Example of the deformation of a high-altitude stereo model.

Data:	Photographic aircraft	Learjet 25-C
	Flying altitude	8900 m
	Camera	RC 10 with UAg II No. 3035
	Stereopair	1356/57
	Overlap	55 percent
	Measurement in	A 10 (dashed line) and STK 1 (solid line) by D. Gut
	Revised altitude for correcting earth curvature will be	13 200 m

The positions of the profiles are shown in Figure 14.

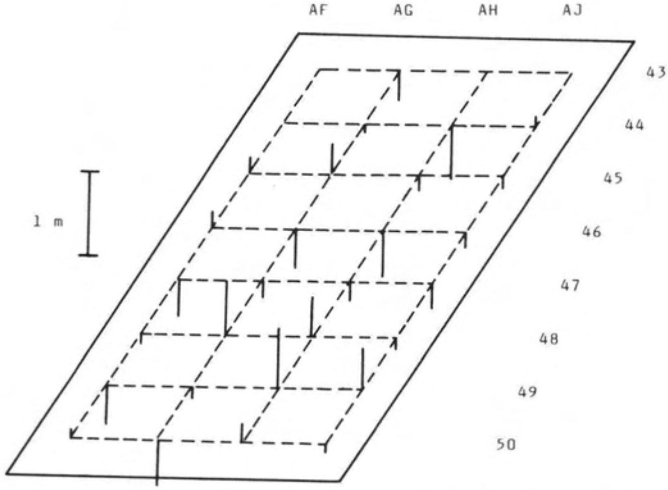


FIG. 14. Residual errors in elevation of a high-altitude stereo model. Data in Figure 13. Measurement in the A 10 stereoplotter

the Casa Grande test range (width b = 4.9 m) were still visible. Comparing the lens types, no difference can be detected for the three lenses. False color film shows equally good results as the panchromatic film. However, a greater percentage of targets were visible on the false color film. Obviously, the lower resolution of false color film is compensated by the higher contrast of this film.

Inflight camera tilt. Camera tilt at the moment of exposure was determined during measurement in the stereoplotter. For seven stereomodels the maximum range of tilt was between

-0.55^g to $+1.65^g$ for lateral tilt (ω)
-0.30^g to $+ 1.06^g$ for longitudinal tilt (ϕ)

These values are relatively small. This fact proves the stable flying altitude of jet aircraft. Small camera tilts will favorably influence the measurements in analog stereoplotters.

APPLICATION OF HIGH-ALTITUDE PHOTOGRAPHY IN TOPOGRAPHIC MAPPING

The enormous area coverage, combined with high geometric accuracy and ground resolution of high-altitude photography, permits the use of new procedures in aerotriangulation, and in small-scale line and orthophoto mapping. As early as 1969 the potential of high-altitude aircraft for topographic mapping was impressively documented by R. E. Altenhofen with the help of practical examples.[3] In the meantime, new instrumentation for picture-taking and measurements became available, e.g., handwheel and freehand driven precision stereoplotters and digitally controlled orthophoto printers of high resolution and high enlargement capability. With the help of this new instrumentation and the experience gained from the evaluation of the photog-

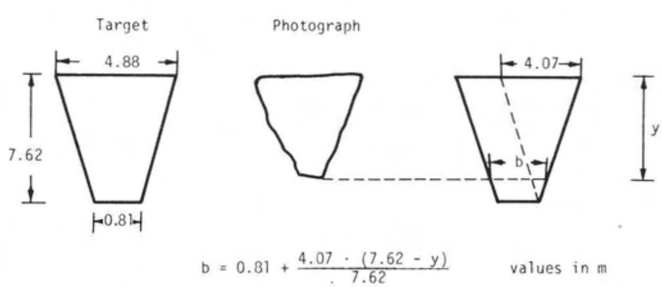


FIG. 15. Determination of the smallest visible image distance by means of a quadrilateral target. The length y of the imaged target will be measured, the width b will be determined by calculation. Values in m.

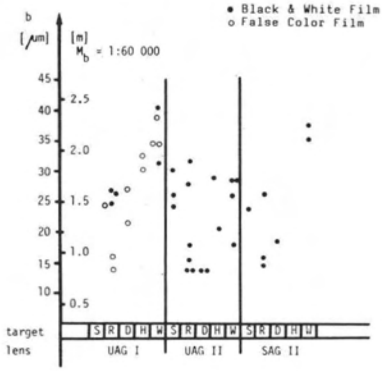


FIG. 16. Smallest visible image distance determined for three types of lenses and two photographic emulsions with the help of five different panels on 14 photographs of scales between 1:56 000 and 1:99 000. The panels measured were up to 130 mm from photograph center. The values are the mean from the four target pointers.

raphy over the Casa Grande test range, the current procedures in small-scale mapping will again require discussion.

AEROTRIANGULATION

With maximum flying height and super-wide-angle lenses, the distance between field control points may be increased. When using wide-angle photographs of 1:80 000 scale, precision stereoplotters or comparators, and modern computational methods, a distance of about 60 km can be bridged.[4] The errors in planimetry and elevation of the control points should be smaller than 2 m. Maintaining this accuracy, the bridging distance can be extended to about 100 km when using super-wide-angle photographs taken from maximum flying height. Similarly, the number of photographs is considerably reduced. An area of 100×100 km^2, e.g., may be covered by only 36 super-wide-angle photographs.

MEDIUM AND SMALL SCALE LINE MAPS

Line maps at scales between 1:50 000 and 1:25 000 had until recently been mapped from photography at scales which were smaller than or the same as the map scale. The limitations in photo scale were conditioned by the service ceiling of small aircraft and the poor working climate in unpressurized cabins. When using small jet aircraft, the scale limitations are determined by the adequacy of interpretation of small details and by the contour interval to be mapped. But with the help of precisionplotters like the A 10 or the new generation of analog stereoplotters such as the Aviomap AMH, in which

- the measuring mark is controlled by handwheels *and* freehand,
- the photograph is observed at high and changeable magnification, and
- the plotting is done with the help of an automatic table at the operator's side,

photography of smaller scales than before can be interpreted and accurately be measured. When using the new generation of wide-angle cameras and modern precision stereoplotters, the photo scales listed in Table 2 seem to be applicable for open terrain.

When using modern super-wide-angle cameras, both map scales may be produced from 1:100 000 photography (b = 3 m, Δh = 5 m).

For planning purposes with low-accuracy requirements, maps of larger scales such as 1:5 000 could be mapped efficiently from high-altitude photography as well.

Orthophoto mapping. Orthophoto maps are produced in large quantities at scales of 1:25 000 (1:24 000) and 1:10 000. Their economic production is determined by, among other things, the ratio photo-to-map scale. Modern orthophoto printers and good photography allow enlargement factors between 4× and 6×. Limitations for the factor arise from the service ceiling of the photographic aircraft and the smallest detail to be printed and recognized by the user. In addition to the wide-angle camera, the normal-angle camera with f = 21 cm is preferred in steep and wooded areas. For the map scales considered, such a camera leads to altitudes which can be reached by jet aircraft only. In open and hilly terrain, super-wide-angle

TABLE 2. PROPOSED PHOTOSCALES FOR MEDIUM- AND SMALL-SCALE LINE MAPPING. THESE SCALES WILL BE ACHIEVED FROM ALTITUDES OF 9 AND 12 km ABOVE TERRAIN, RESPECTIVELY. IN THE LATTER CASE THE TERRAIN MAY STILL BE UP TO 1.5 km ABOVE SEA LEVEL.

Map Scale	Photo Scale	Smallest Visible Image Distance b	Smallest Contour Interval Δh
1:25 000	1:60 000 – 80 000	2.0 – 2.5 m	4 – 5 m
1:50 000	80 000	2.5 m	5 m

TABLE 3. PROPOSED PHOTO SCALES FOR MEDIUM- AND SMALL-SCALE ORTHOPHOTO MAPPING.

m_k	f = 88.5 mm	f = 153 mm	f = 213 mm
1:10 000	30 000 – 50 000	40 000 – 60 000	60 000
1:25 000	100 000	80 000	60 000

photographs can be utilized provided that the orthophoto printer accepts such photographs and compensates for slope across the direction of scanning. For the photomaps considered, the photo scales at optimal field angle listed in Table 3 seem to be practicable.

The camera should be selected according to the terrain. The scales were based on the assumption that the smallest detail to be recognized in the photomap has a width of 2 m for 1:10 000 and 3 m for 1:25 000. The planimetric accuracy required for the maps will easily be met by modern orthophoto printers.

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Articles for Next Month

U. V. Helava, The Analytical Plotter—Its Future.
Gottfried Konecny, Software Aspects of Analytical Plotters.
Dr. Bernard L. Y. Dubuisson, Why Analytical Plotters?
Dr.-Ing. D. Hobbie, C-100 PLANICOMP, the Analytical Stereoplotting System from Carl Zeiss.
Christian Vigneron, TRASTER 77: Matra Analytical Stereoplotter.
Richard H. Seymour, The US-1 Universal Stereoplotter.
R. E. Kelly, P. R. H. McConnell, and *S. J. Mildenberger*, The Gestalt Photomapping System.
S. Jack Friedman, The OMI Analytical Stereoplotter Model AP/C4.
Prof. Giuseppe Inghilleri, The D.S.-Type Galileo Analytical Plotters.