SUMMARY

Acquiring thermal-IR imagery of large areas requires a mosaic flight pattern which must be carefully planned and navigated. Flight planning includes selection of time-of-day, flight altitude, and orientation and spacing of flight lines. Charts of image scale and lateral coverage as related to flight elevation above terrain are a practical guide to flight planning. Information content of imagery is related to contrast and spatial resolution. Resolution decreases with increasing altitude, but contrast does not seem to decrease. For many requirements an acceptable tradeoff between image quality and operation economy is provided by parallel flight lines at 6,000 ft above terrain spaced at 3-mile intervals. The resulting image scale is 1 inch equals 1.6 miles. Each image strip has a 4-mile swath width on the ground with 1 mile of sidelap on adjacent strips.

For geologic purposes, flight lines should be oriented so that scan lines are not parallel with the structural strike or grain, as this tends to obscure linear features. To avoi the effects of differential solar heating, nigh is the optimum time for most image flight introducing navigation problems. Exper ence has shown the limitations of conve tional nighttime navigation methods. Th newly developed VLF navigation syste produces satisfactory guidance for nighttim mosaic flights and has advantages over othe methods.

ACKNOWLEDGEMENTS

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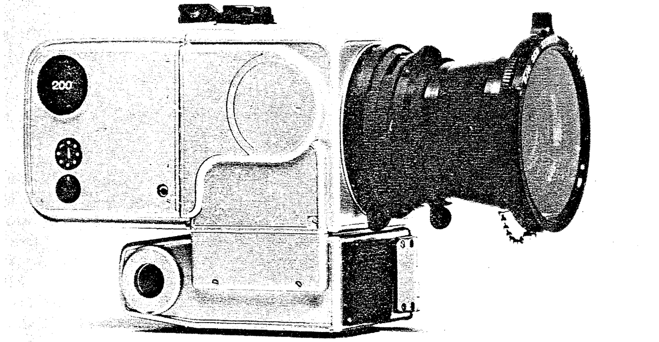

FIG. 1. The Hasselblad 500 EL Data model is a metric camera.

DR. JOACHIM KAMMERER
Paillard Incorporated
Linden, New Jersey 07036

The Moon Camera and Its Lenses

A popular professional camera was converted into a metric version for space studies.

(*Abstract on page 61*)

INTRODUCTION

A HASSELBLAD camera has been used during all NASA lunar landings from Apollo 11 through Apollo 16. A few basic changes make it different from Hasselblad equipment used in previous space flights. (Figure 1)

This camera, Hasselblad 500 EL Data camera, allows for the first time photogrammetric measurements of all photographs taken in space and particularly on the moon.

The following is a report about this lunar camera as well as the optics developed for it, including the test and calibration work necessary to establish the inner orientation of the metric camera.

HASSELBLAD EL DATA CAMERA

The basis of the Data camera is the commercial Hasselblad 500 EL in which unnecessary camera parts, such as the mirror reflex viewfinder and the auxiliary shutter, have been omitted to reduce weight. NASA needed a relatively light-weight and handy camera with universal lens and film interchangeability to photograph the lunar landing program both for documentary photography and for the exploitation of photogrammetric applications.

NASA gave Hasselblad and Carl Zeiss the task of developing a Data camera with a special line of optics from the previously space-tested Hasselblad.

The main new feature of the Data camera consists of the installation of a reseau plate situated immediately before the film plane. The high-precision reseau plate is a glass plate which has a number of measuring crosses on the side facing the film. These crosses are used as reference points in the photogrammetric exploitation.

As can be seen from Figure 2, the plate has 25 reseau crosses located in five horizontal lines and five vertical lines at a distance of 10 mm from one another. These crosses are etched into the plate. The length of the cross arms is (with the exception of the center cross, which is double the size) 1 ± 0.1 mm,

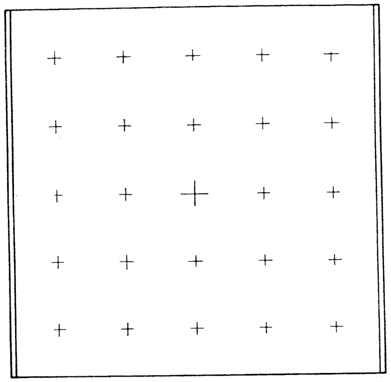

FIG. 2. A reseau plate was added to previous non-metric models.

and the width of the lines of the crosses is 0.02 mm. The distance between the neighboring reseau crosses varies from the basic distance of 10 mm less than 0.005 mm.

The reseau plate has an anti-reflection coating on both sides. Furthermore, the plate has on its reseau side an antistatic coating which is connected to the camera housing to avoid electrical discharges between plate and film with its disagreeable consequences (blackening of film). The vertical sides of the reseau plate are built to form film guides. They extend over the reseau plate 0.08 mm and prevent direct contact between plate and film, which could lead to scratching of plate or film.

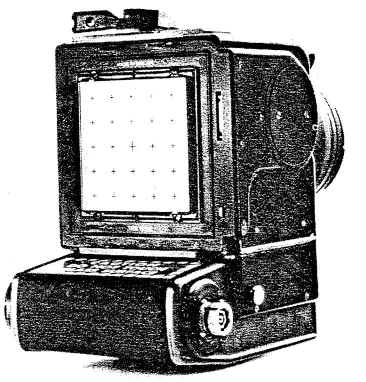

FIG. 3. The reseau plate in position in the Hasselblad 500 EL.

The reseau plate was manufactured by Carl Zeiss. Figure 3 shows a Hasselblad EL Data camera with the built-in reseau plate.

Lenses

The line of lenses for the Data camera consists of a Biogon 1:5.6 $f = 60$ mm, a Planar 1:2.8 $f = 80$ mm, and a Planar 1:3.5 $f = 100$ mm (Figure 4). Of these lenses, the Biogon 5.6 $f = 60$ mm and the Planar 3.5 $f = 100$ mm were designed specifically for the Data camera. The Planar 2.8 $f = 80$ mm practically corresponds to the well-known 80 mm Planar available for the commercial Hasselblad camera.

All optics are equipped with a Syncro-Compur shutter by the Compur Werke in Munich, fulfilling the demand for operating dependability under conditions of space flights.

BIOGON 1:5.6 $f = 60$ mm

For the lunar landing program, NASA was particularly interested in a wide-angle lens with the largest possible field angle and absolute minimum distortion for photogrammetric applications. By omitting the mirror reflex finder in the Data camera the Biogon type could be considered. The Biogon is well known for its high resolution and superb distortion characteristics.

The Biogon 5.6/60 (Figure 5) developed for the Data camera consists of eight lens elements in five components plus the reseau-plate, which must be included in the lens design. The field angle of this lens is 65°.

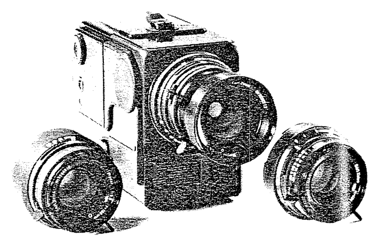

FIG. 4. The camera is furnished with three different lenses: a Planar 1:3.5, $f = 100$ mm (left); a Biogon 1:5.6, $f = 60$ mm (center); and a Planar 1:2.8 $f = 80$ mm.

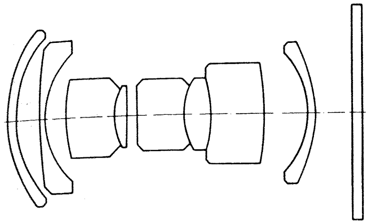

FIG. 5. The Biogon 5.6/60 has eight lens elements.

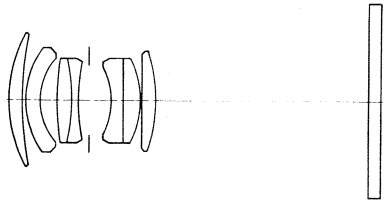

FIG. 6. The Planar 2.8/80 contains seven lens elements and has a field angle of 52°.

ABSTRACT: *The Hasselblad 500 EL Data camera is a metric version of a previous camera which was modified and calibrated to meet the special space requirements of NASA. The principal change was the addition of a reseau plate of 25 crosses in the focal plane. Three of the former lenses were included as a part of the camera equipment. But the camera-reseau-lens combinations needed to be precisely calibrated.*

This Biogon succeeded completely in fulfilling the rigid NASA demands with reference to resolution and distortion. NASA permitted only very small tolerances for the distortion symmetry which required highest precision manufacturing, particularly in lens centering. The Biogon 5.6/60 has been used in all lunar landings so far.

PLANAR 1:2.8 $f = 80$ mm

The Planar 2.8/80, which has proven successful since the beginning of NASA space flight program (the first space pictures were taken with this lens by Walter Schirra on October 3, 1962), is used on the Data camera for general purpose photography (not for photogrammetric purposes).

The Planar lens was slightly redesigned to take the reseau plate into account in correcting aberrations of the lens. The lens corresponds in its design and resolution to the existing Planar 2.8/80, consisting of seven lens elements and the reseau plate (Figure 6), and has a field angle of 52°. The adjustable focusing range extends, as with the Biogon, from three feet to infinity.

PLANAR 1:3.5 $f = 100$ mm

The Planar 3.5/100 mm lens completely fulfilled NASA'S requirement for a lens with minimum distortion and highest resolution for the evaluation of high-altitude photography taken with the Data camera. Because this lens is used only for taking photogrammetric pictures from orbital altitudes, it is focused at infinity, increasing photogrammetric measuring accuracy considerably by the elimination of movable adjusting rings.

The Planar 3.5/100 (Figure 7) consists of five lens elements that are assembled in four lens components. An integral part of the Planar is the reseau-plate. The lens has a field angle of 43°.

Calibration of the Metric Camera

The photographic image is a central perspective image of the object photographed. A photograph is a photogrammetric representation only if the light rays on the object side can be reconstructed from the picture. For this reconstruction it is necessary to know the position of the image plane in relation to the center of the perspective (projection center), the so-called *inner orientation*. Establishing the data for inner orientation is called *calibration*.

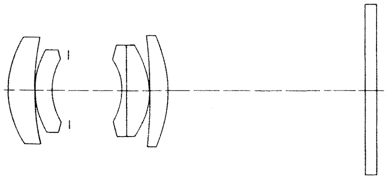

FIG. 7. The Planar 3.5/100 contains five lens elements and has a field angle of 43°.

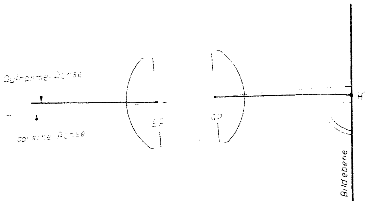

FIG. 9. The foot H' of the perpendicular from the image node to the picture plane needs to be determined for *inner orientation.* (Aufnahme Achse means photographic axis; optische Achse, optical axis; and Bildbene, picture plane.

Before the calibration of the metric camera, the position of the crosses on the reseau plate, which serves as a set of reference points for photogrammetric evaluation, are measured with a universal measuring microscope to an accuracy of ± 2 μm and the deviations are recorded on a test certificate. A test of the lens assembly is required before calibration. The contrast transfer function and distortion of lenses are measured. For both the contrast transfer function and the distortion characteristics NASA was guaranteed values whose tolerances had to be verified. Particularly rigid demands were set, as mentioned previously, on the distortion symmetry, i.e., on the optical centering of the lenses. The tolerances permitted for the distortion symmetry were 3 μm for the Planar 3.5/100 and 10 μm in the focusing mount for the Biogon 5.6/60 and the Planar 2.8/80 lenses. The spectral tramsmission characteristics of the lenses are also checked. These measuring results, together with the calibration data of the lens assembly for the metric cameras, are shown in a test report. Finally, the rear focus of the lens assembly is adjusted to the image plane of the camera.

By calibrating the camera it should be possible, as mentioned before, to reconstruct completely the light rays on the object side from the photograph. It is necessary to know the relationship between the picture angle τ measured at the projection center and the related image distances within 1 minute. (Figure 8). This formula is expressed generally as $1' = c \cdot F(\tau)$. If the taking lens is absolutely distortion free, then there is a distinct central projection, whereby $F(\tau) = tg\ \tau$. Accordingly, the following relationship exists between the image distance of 1 minute and the related picture angle $\tau : 1' = c \cdot tg\ \tau$. This relationship is corrected by the amount of distortions $\Delta 1'$ which exist in any real lens, even though to a small degree:

$$1' = (c \cdot tg\ \tau) + \Delta 1'.$$

The factor c in this formula is called the calibrated focal length (*cfl*). The *cfl* equals the distance of the center of projection from the image plane. It can, therefore, be defined only in connection with a film plane. In the first approximation it is equal to the optical focal length of the taking lens.

Besides the already mentioned data *cfl* and *distortion*, the fiducial center H' must be known in order to establish the inner orientation. The fiducial center is defined as the plumb point of the center of projection to the image plane (Figure 9). The plumb line is considered the index of angular measurements derived from the photograph. Distances of 1 minute in the image are measured from the H' point. The position of the fiducial center in the image plane is determined by its coordinates x'_H and y'_H. The zero point of this image coordinate system x, y is the center cross M of the reseau-plate (Figure 10).

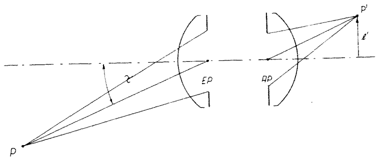

FIG. 8. Object angles, such as τ, must be reproduced in the image space to produce no distortion.

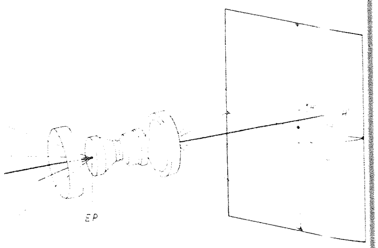

FIG. 10. The coordinates x'_H and y'_H of the poin H' define the position of the fiducial axes.

To measure the coordinates of the fiducial center, the distortion and the *cfl*, the Data camera is placed in a special goniometer (Figure 11). The goniometer contains a viewing telescope (1) and an autocollimater (2), the axis of which is parallel to the axis of the telescope. Using this Autocollimator mount, the camera is aligned with the adjustable mount (3) of the Goniometer table (4) so that the reseau plate and, therefore, the image plane, is perpendicular to the collimator axis. The optical axis of the observation telescope corresponds, then, according to the above mentioned definition, to the optical axis of the lens if the center of the crosshair of the viewing telescope is optically coincident with the fiducial center. After this calibration, the x'_H and y'_H offsets of the fiducial center from the reseau-plate center cross are determined for each lens of the metric camera with an eyepiece micrometer built into the viewing telescope. Then measurements are made with the special goniometer to determine the distortion of the lenses using the points defined by the reseau.

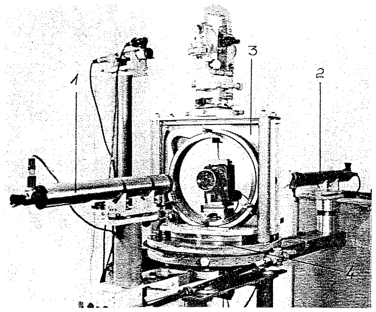

FIG. 11. A goniometer is used to determine the calibration constants of a lens.

The coordinates of the fiducial center, the distortion values, and the *cfl* derived from the distortion measurement are tabulated in the test report delivered with each camera.

During the next lunar landing, and throughout the SKYLAB program, just as on Apollo missions 11 through 17, the Hasselblad EL Data camera with its Zeiss lenses will be the photo equipment used by astronauts. Again the Data cameras will fulfill their task; that is, to deliver photographic records of exceptional value and unexcelled interpretability and, with their photographed reseau crosses, also photogrammetrically valuable.