PHOTOGRAMMETRIC EQUIPMENT OF THE "GRAF ZEPPELIN" ON THE ARCTIC VOYAGE OF 1931 AND METHODS OF RESTITUTION OF OBSERVATIONAL MATERIAL OBTAINED

by

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The double apparatus for serial photographs is composed of two connected film cameras; size 12 × 12 c/m with a focal length of 13.5 c/m. The two cameras converge at an angle of 36°. The common photographic field covers an angle of 82°. Each camera has an interchangeable film carrier and 460 exposures can be made with each film. The apparatus is worked by means of an electric motor. An overlap regulator driven by variable gear allows the rapidity of the successive exposures to be adjusted to the speed and altitude of flight.

It was expected that during the Arctic voyage only relatively low heights would be attained, from 800 to 1200 metres (= 2600 to 4000 feet) above sea-level, it was necessary therefore to set the camera in a position in the ship so as to be able to photograph the horizon and to include in oblique photographs as large a surface as possible. For this reason, the lenses of the two cameras were inclined at about 18° to the horizontal and made to point outwards on the beam, forward and aft.

As each pair of photographs is taken from the same point, these can be directly transformed by photography into a panoramic picture with a single perspective; this operation is *not* strictly necessary — with this apparatus — for restitution purposes. To pass from the photographic to the cartographic representation of the land, various possibilities are offered to the operator. They depend on the two conditions fulfilled here, that, firstly, the interior orientation of the photographs is known, *i.e.*, that the relative directions of isolated points on the photos can be re-established, and, secondly, that the images have been taken with objectives free from inaccuracies so that there is a simple proportional relation between the representation of a plane surface and the plane surface itself. Hence the following possibilities may occur :—

a) Determination of the directions of isolated points;

b) Projection of the plane of the negative on to the plane of the chart;

c) Stereoscopic restitution of pairs of photographs.

The determination of the directions of isolated points may be employed for obtaining reciprocal orientation, as also for establishing a system of points, to which details can be added by one or other of the alternative methods.

The projection of the plane of the negative on to the plane of the chart can be obtained in various ways: by graphic transformation by means of perspective nets; by transformation by means of perspectographs; by optical projection; but also and above all, by the monocular use of a stereoscopic restitution apparatus. The projection of the negative plane on to the chart plane, however, does not give accurate cartographic images except in the case of plane surfaces. In the case of views taken from the Zeppelin, it was of no use except for drawing in the shape of the coast-line.

Contrary to the method of projecting the negative plane onto the plane of the chart, stereoscopic restitution not only gives the shape of the coast-line, but also all the relief of the land, and allows, if appropriate restitution apparatus is available, not only to make a photographic triangulation, but also to draw the complete chart, with indications of altitude by means of contours.

The difficulties in employing these various methods lie, in the case of photographs from a Zeppelin, in the making of the contruction sheets which are necessary to the cartography. In the first place the point from which the views were taken is not known, nor is the North direction, the inclination with regard to the vertical, the altitude above the sea, and, in the case of pairs of photographs, the distance between them (length of base), the difference of altitude of the points of exposure, the convergence of the directions of the photographs, their directions with regard to the base, the longitudinal and lateral inclination of each photograph, the azimuth of the base, and, further, the geographical latitude and longitude and altitude above the sea, of at least one of the two observation points. As a close net system of points with fixed geodetic positions is not available, data from the navigation or provided by nature herself must be utilised for the orientation of the photographs.

In the most favourable circumstances, navigation gives at any given time : approximate data as to the geographical latitude and longitude, the flying altitude above the sea as measured by barometer, and speed. With regard to the photographs themselves, their chronographical succession is determined by the action of the variable gear. Under favourable circumstances, it is possible to recognise on the photos the natural horizon, the sea-coast or the sides of lakes, the shadow of the airship or, on the water, a reflected image of the Sun.

Therefore, by means of the natural horizon, it is possible to get the position of an isolated photograph with reference to the vertical, and also, at a given time, to set the views with reference to the North from the direction of the shadow or the reflection of the Sun, and finally with the aid of the geographical coordinates of the place, or by means of the chronographic succession of the photographs, at least the difference of azimuth, *i.e.*, the convergence of the successive exposures , can be obtained. The altitude above sea-level of the point at which the exposure was made gives, at the same time, a tentative basis for the scale of the chart of the coast-line, and the length of the shadow of the airship provides a good check.

To these possibilities of setting isolated photographs may be added, for pairs of photographs having sufficient overlap, the fact that from the subject of the photograph itself, it is possible to obtain the reciprocal orientation. Therefore, each pair of photographs gives a picture of the land on which it only remains to determine the direction of North and the scale. If it is possible to recognise the coast-line on the pair of negatives, the inclination from the vertical for that pair of photographs can be found therefrom, even when the natural horizon is not distinguishable. To the determination of the scale from the altitude above sea-level and to the check provided by the shadow of the airship may be added, in the case of pairs of negatives, a check ot the scale by means of the speed of flight together with the chronographical succession or the photographs.

Under the most unfavourable circumstances, it is impossible to recognise either the horizon or the coast-line and neither the shadow of the airship, nor the reflected image of the Sun appear on the photographs and, further, the flying-altitude above the ground is unknown. In this case the restitution ot isolated photographs cannot be carried out, but the pairs of negatives will still give reciprocal orientation, and the "assumption" that water must always run in the direction of the mouth gives at least an approximate value of the inclination ot the views from the vertical. In the same way, the scale may be determined from the succession of the photos and the speed of flight, within the limits due to the uncertainty of the amount of drift in the wind.

It however happens, even with pairs of negatives, that restitution is doomed in advance to be unsuccessful, for example, when on the foreground of the views there are no identifiable points, either because the intervals between photographs are too large or because unlimited water or fog fills the picture, and neither the shadow of the airship nor the reflected image of the Sun appears on the pair of negatives.

Even under the most favourable conditions, all construction sheets are more or less inaccurate and the cartographic picture will, for this reason, be of but very limited accuracy. The greatest uncertainty in restituting isolated photographs lies in the difficulty of determining the natural horizon with sufficient accuracy. This acts the more unfavourably principally when the coast-line extends nearly to the apparent horizon. Another source of error is the uncertainty in the altitude of flight. In the case of the restitution of double negatives, conditions are generally more favourable ; this is particularly true

of photographs taken in series with a double camera owing to its large angular field. The uncertainty of restitution of double photos becomes very great when the convergence of the views can be but roughly determined owing to the lack of foreground and the lack of similar pictures of the shadow and reflection of the Sun.

The following are suitable restitution apparatus: the *Aerotopograph* (cf. *Bildmessung und Luftbildwesen*, 1928, p. 113-116), which serves for drawing up charts from photographs taken with the hand camera, and the *Stereoplanigraph* (cf. *Bildmessung und Luftbildwesen*, 1930, p. 129-139), by means of which photographs obtained with the double camera may be restituted. Both instruments can be employed equally in drawing the form of the coast-line monocularly from isolated photographs and for stereoscopic restitution.

The respective graphic transformation of isolated photographs or of pairs of negatives is extremely easily done with either of the instruments if the natural horizon can be recognised. The distance to the horizon from the most distant portion of the coast line to be restituted is determined from the lateral tilt of the camera; this allows the correction for the curve of the Earth and for refraction to be made in the inclination and altitude of flight. The graphic transformation is then begun immediately by causing the pointer to follow the outline of the coast and the drawing pencil will mark it at the same time on the desired scale.

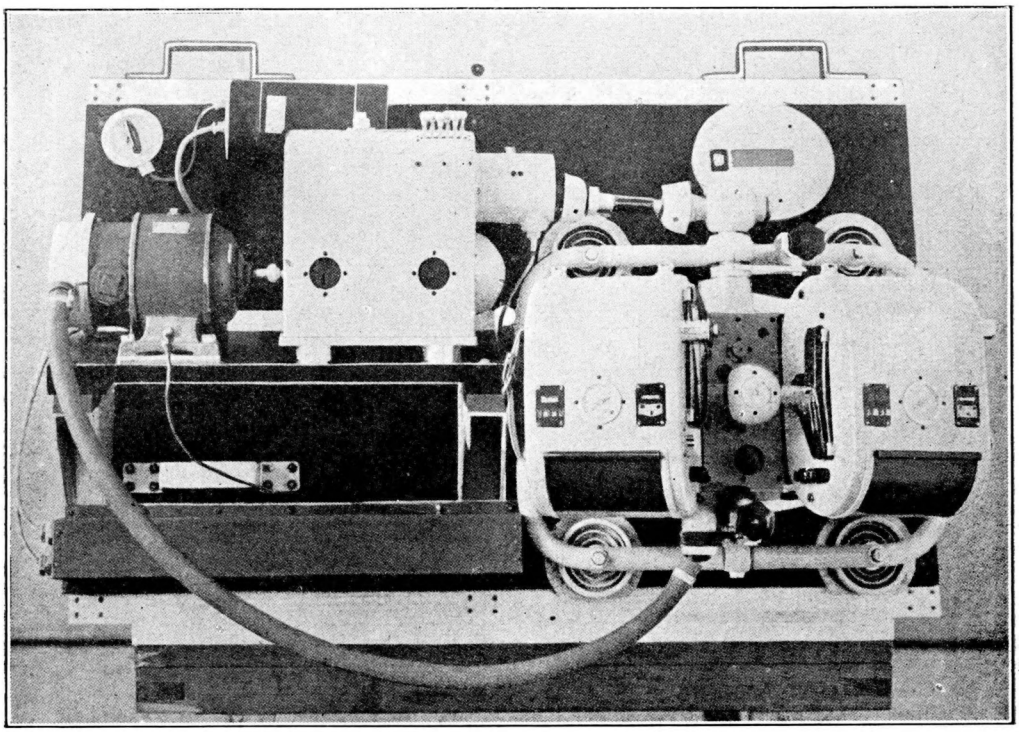
Stereoscopic restitution naturally requires very careful and accurate reciprocal setting of the pairs of negatives, and, in consequence, more or less time according to the accuracy of the available construction sheets. Once orientation is achieved, stereoscopic restitution from the aspect of the picture of the land is as easy to do as monocular restitution; owing to the effect of relief it is possible to follow not only the coast-line but also the altitude contours, and to draw them directly on the chart.

A check of all the photographs taken with the double camera for serial photographs The restishowed that only a small proportion of the views,principally those of Sievernaja Zemlja, are entirely unutilisable. In these, only distant mountain summits appear above a thick mantle of fog. It is possible to restitute all the other photographs which cover a flight about 1000 km. (= 540 naut. miles) in length, either by graphic transformation of single photos or by stereoscopic restitution. The restitution is made on scales of 1:200,000 and 1:500,000. In certain parts, interesting morphological details can be represented with sufficient accuracy on scales of 1:10,000 and 1:20,000.

The test restitutions made up to the present (parts of Mount Taimyr and Sievernaja Zemlja have also been treated) show that aerial photogrammetry, even under the most difficult conditions, is likely to provide useful results from a geographic point of view. They demonstrate also the manner in which the airship should be equipped in future expeditions, in order to increase the output and particularly to facilitate the work of restitution. It is perhaps opportune to specify the following: The installation of at least three cameras in such a manner that views may be taken by two cameras over the two sides and by the third downwards. The fields of the three cameras should overlap so that all three cover a continuous strip under the airship extending from the horizon on one side of the vessel to the horizon on the other. It is also desirable that the fields of the lateral cameras should extend as widely fore and aft as does that of the double repeating camera, for example. A suitable equipment consists of two double repeating cameras installed on each side and a ASCHENBRENNER panoramic camera downwards, as was proposed in the original plan of equipment. The greater focal length of the double repeating camera makes it better suited for taking distant views whereas, for taking the closer views downwards, the shorter focal length of the panoramic apparatus is amply sufficient; owing to its large angular field this camera is particularly well-suited for taking the near views below. The grouping of the three cameras will permit the shadow of the airship to be taken on most occasions, and possibly the reflected image of the Sun; if these two items are recorded, not only will the determination of the azimuth be facilitated, but it will be found possible to check the geographical position. As far as navigation is concerned, restitution is facilitated by maintaining, as far as possible, a steady course and a constant altitude. If the airship follows the windings of a coast, restitution is made more difficult.

Besides the elucidation of technical questions, restitution provides extremely important geographical data. The great speed of the vessel does not permit the observers to

note more than the general outlines of the region passed over ; all halts over important details were forbidden. But the photographs, when stereoscopically examined, show every detail and can be fully examined at leisure. Objects which appear doubtful during the flight or which have been wrongly interpreted, can be investigated at leisure and their dimensions and their positions determined later. Not only is the direction of mountain chains established, but also their relative altitudes, the heights of terraces and of lake surfaces ; moraines were recognised and even geological folding showed on denuded surfaces, without mentioning ice limits and glaciers. The presence of median moraines and the situation in altitude of connected snow fields reveal to the trained eye the altitude of the limits of névé. Alluvia and drifting blocks of ice show the directions of marine currents, and, in favourable conditions, the movement of the blocks during the interval between two or three successive photographs helps to determine the speed of the current. The photographs help in the determination of the height of clouds, and these latter, taken separately, even allow the velocity of the wind to be deduced, by measuring the movement of the shadow of the clouds in the interval between two successive exposures. All this shows that, on such voyages of exploration, photogrammetry is one of the most important scientific auxiliaries and that it considerably enriches geographical exploration.



Double Camera of the *Graf Zeppelin* — Appareil photographique double du *Graf Zeppelin*