THE EMPLOYMENT OF A HOT-AIR SHIP FOR THE STEREOPHOTOGRAMMETRIC DOCUMENTATION OF ANTIQUE RUINS

HOLGER WANZKE

Research Project MOHENJO-DARO
Department for History of Architecture and Architectural Preservation RWTH Aachen

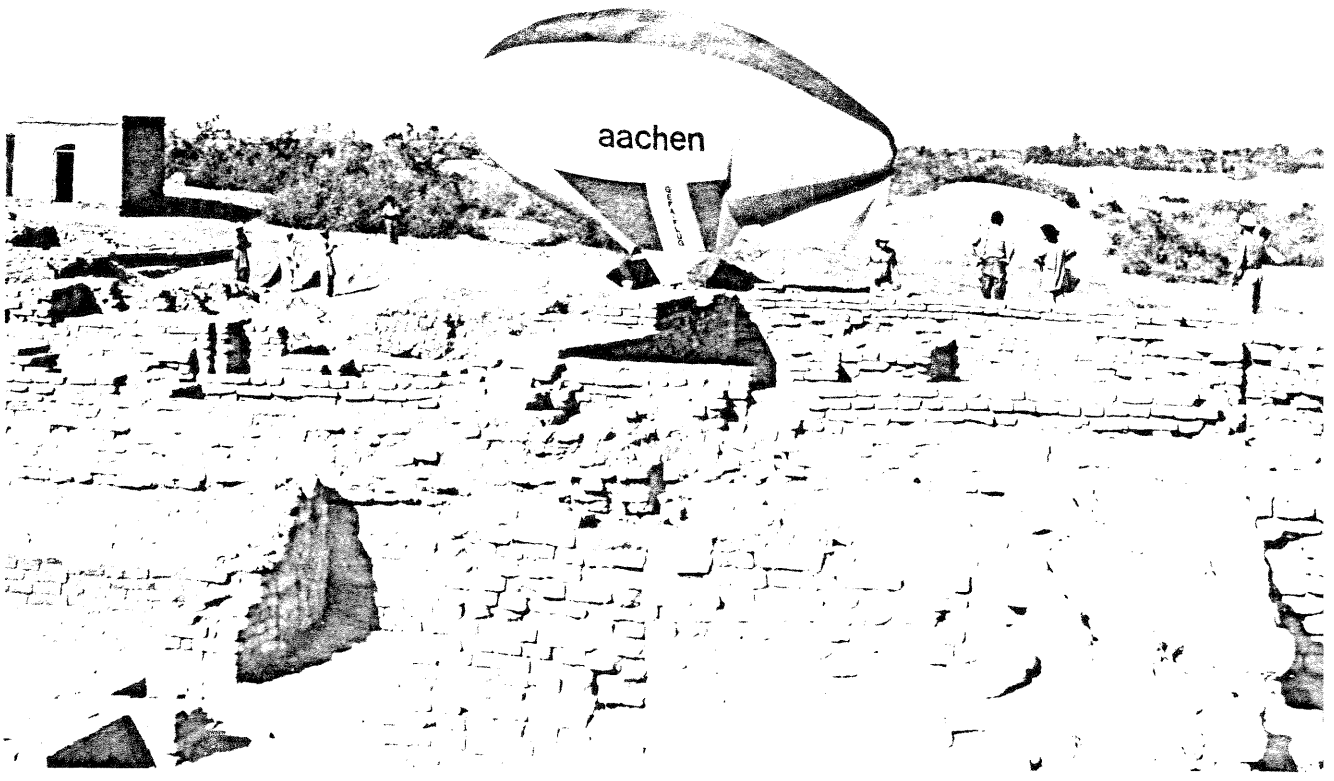
Germany (FRG)

Comission V

Since 1979 a Research Project has been running in the Department for History of Architecture and Architectural Preservation of the RWTH Aachen, whose aim is the architectural documentation of the 5000 year old town MOHENJO-DARO, situated on the Indus river in Pakistan.
MOHENJO-DARO is one of the main finding places for the Harappa culture, a material culture of the 2nd and 3rd millenium B.C..
In its significance as regards the phenomenon of the urbanization process of the Neolithic Revolution, this culture is on the same level as those already known in Egypt and Mesopotamia.
The architectural finds discovered up to the present show extraordinary features in relation to the stage of development.

A characteristic feature of MOHENJO-DARO is the construction using fired bricks and a settlement structure of small componental members, with houses ranging from 100-150sq.m. in size. The town shows signs of a differentiated development system, with 9m wide main streets and narrow alleys.
Interesting for such an early culture is the highly developed water supply. Each house is situated at most only 20m from a well, many are equiped with bath and toilet facilities, which are connected to an extensive sewerage system.

Monumental buildings such as temples or palaces have so far not been discovered, the only notable large construction being the ''Great Bath'', a water reservoir with a possible ritual function. The hitherto architectural description of MOHENJO-DARO is totally unsatisfactory, being dependent on extensive, but incompletely understood excavations in the twenties. Thus the aim of research work should be, in the first place, to include the whole of the site in a documentation survey, and in the second phase, to begin a reliable reconstruction, interpretation and functional analysis of the architectural remains on the base of this.
The Project, sponsored by the German Research Society (DFG), runs from 1979 to 1985, with an annual 4-5 month field-work phase in the winter in Pakistan. The team usually consists of 10-15 members, drawn from the spheres of archaeology, architecture, town-planning and geodesy. But within the framework of inter-disciplinary research, geo-physicists, geologists, paleo-biologists and geographers occasionally work on the project as well.



The main function of the documentation is above all the survey of the 84 hectare large area, i.e. the three-dimensional registration of separate structures and their classification in the overall system, as well as a reproduction in plans of a scale of 1:200. After the first year, when terrestrial methods were used, it became clear that a quick, complete and exact documentation would only be possible with the aid of large-scale aerial photos. Conventional camera carriers such as aircraft and helicopters could be ruled out from the start on the basis of technical, economical and political limitations. It was thus decided, in collaboration with the appropriate experts, to construct a hot-air ship which could be used for photogrammetry.
The design and construction of the balloon system was placed in the hands of the Aachen firm GEFA-Flug, under the direction of K.L. Busemeyer. The archaeological-photogrammetric points were discussed in close cooperation, and the concept for exposure technique, navigation and interpretation drawn up.

Objectives

A hot-air balloon should achieve the following, taken from the Research Projects list of objectives:

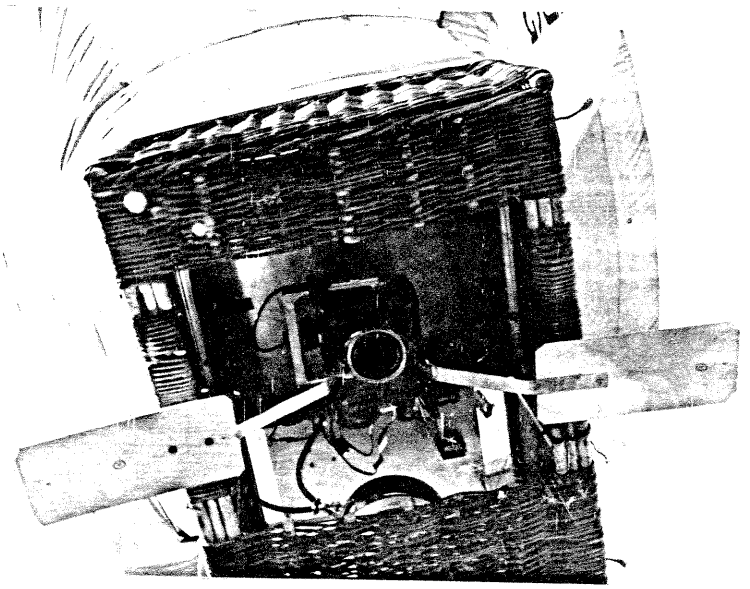
- the production of a documentation of the excavation areas with the aid of blocks of stereooverlapped photograms, which covers the present day state of MOHENJO-DARO and can act as the basis for further research work (aerial photo archive)
- the production of ground-plans and isometric block diagrams on a scale of 1:200, through photogrammetric interpretation, of certain excavated areas which, because of high walls, are difficult to survey from the ground
- to assist the surface analysis during the 1982 field-work phase through the production of detailed colour aerial photos from differing altitudes, and using black & white photos to produce rectified photomaps
- to enable a visual interpretation of the surface through colour stereo-photos.

The requirements and construction principles of the balloon resulting from these objectives have been described in the article from K.L. Busemeyer.

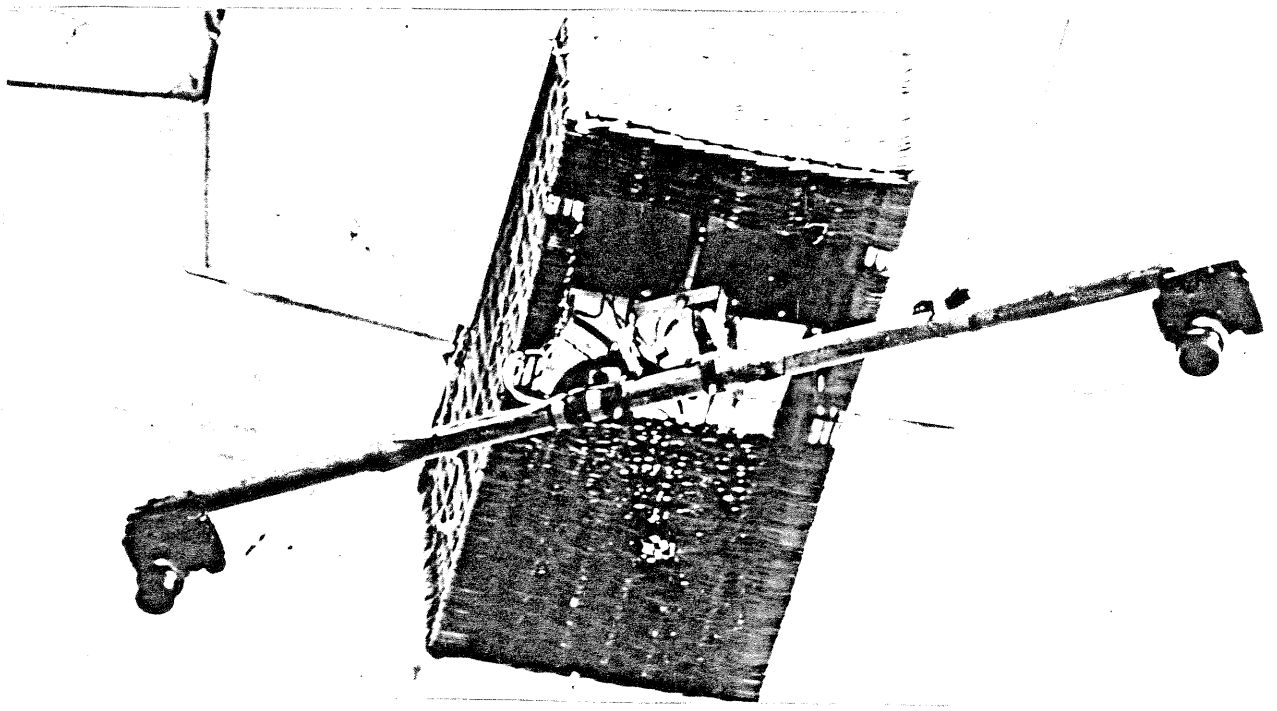
It was important in the photogrammetric concept that, for any exposure, the elements of exterior orientation should be kept within narrow bounds.

This was made possible through:

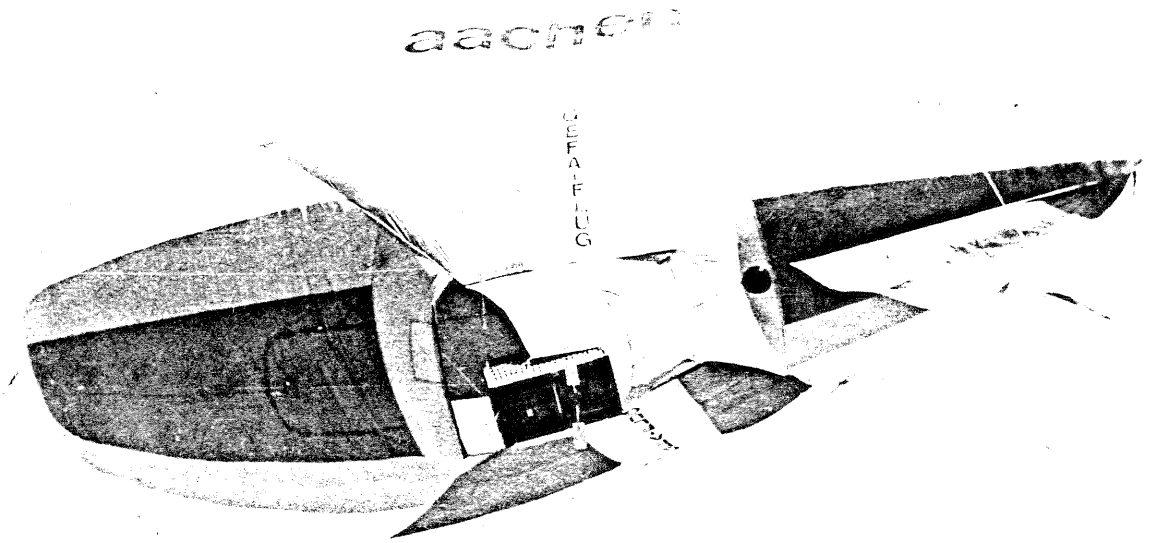
- the captivation of the balloon for exact positioning (Xo,Yo)
- the Cardanic suspension of the camera ($\omega \sim 0, \varphi \sim 0$)
- rotational ability of the camera along the vertical axis ($\varkappa$)
- altitude control through a measuring tape hanging down (Zo).



Rolleiflex SLX with reseau in cardanic suspension



Two NIKON motorcameras for stereophotos with fixed base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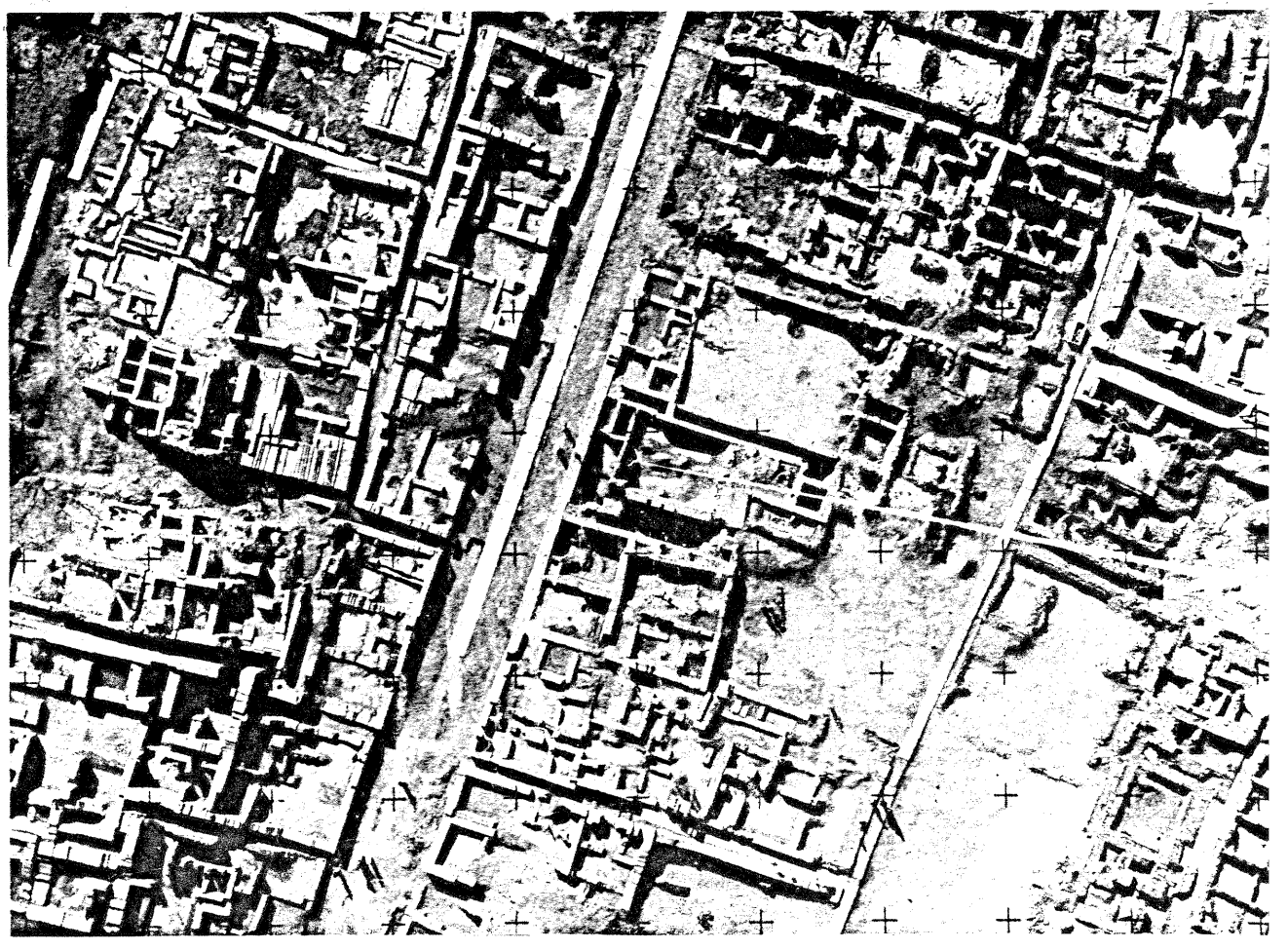


The Photogrammetric Concept

The aim of using the hot-air ship was to obtain a surface-covering, stereoscopically overlapped registration of the excavation area through blocks of aerial photos. The plans to be drawn up from these were to be on a scale of 1:200; thus the photographic scale was set at 1:1000.
The camera used was a WESTER-EBINGHAUS model of the Rolleiflex SLX, developed as a semi-calibrated camera. To adapt for the different surface categories, two lenses were used:

DISTAGON 50mm for flat surfaces
S-PLANAR 120mm for excavation areas with high walls to reduce dead ground.

In detail the following aerial photo-flights were recorded:

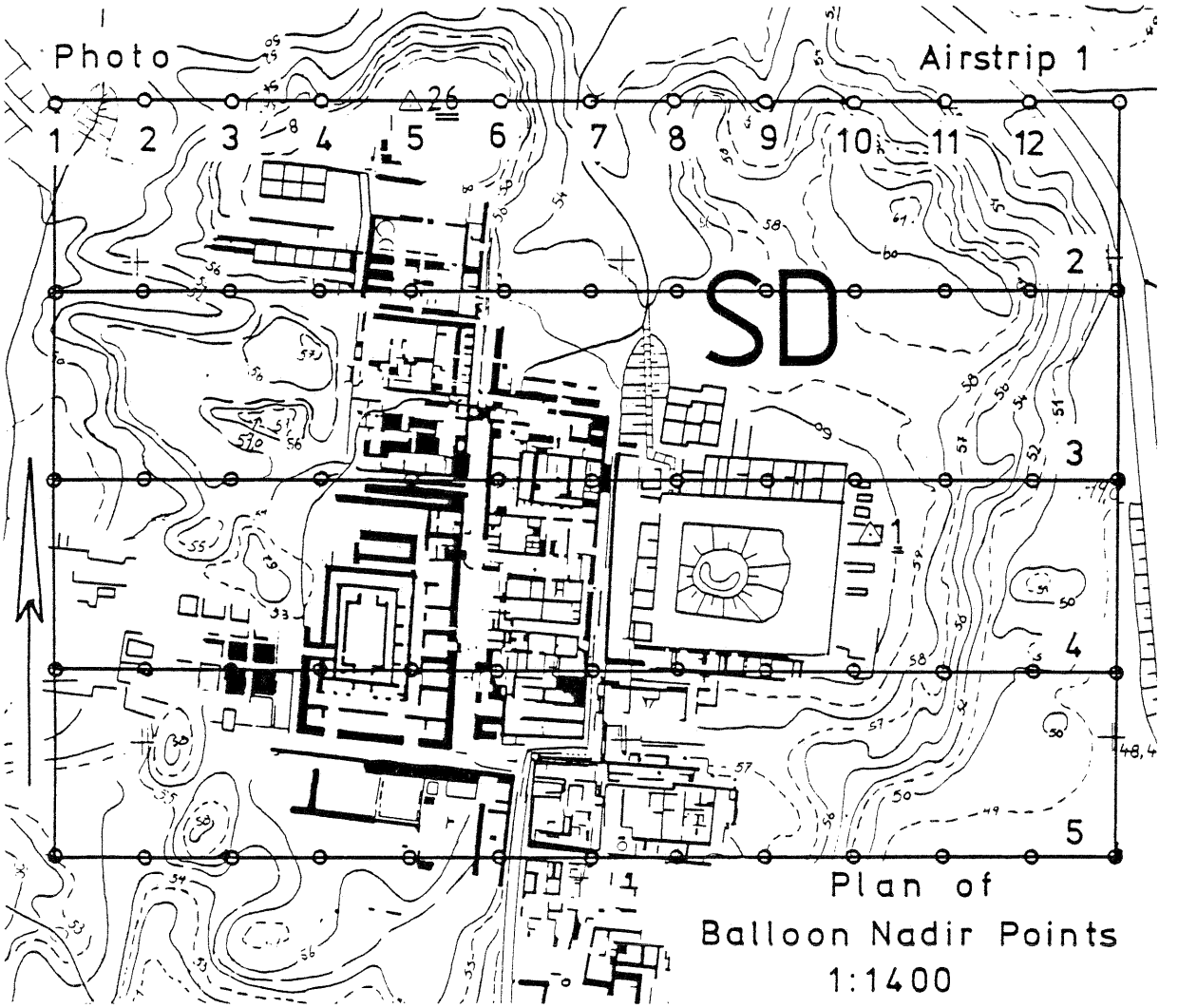
Distagon 50mm		S-Planar 120mm
75^{0}	Angle of field	36^{0}
$55 \times 55 mm^{2}$	Size of film	$55 \times 55 mm^{2}$
61.5m	Altitude	101.2m
60%	Longitudinal overlap	60%
10%	Lateral overlap	13%
26.40m	Topographic lower plane	18.33m
59.40m	Strip interval (of aerial photo)	39.85m
$4356 m^{2}$	Area per photo	$2100 m^{2}$
$1568 m^{2}$	Stereooverlapped area	$730 m^{2}$
1:2.5	Base-height ratio	1:5
1:1200	Photographic scale	1:833

Navigation

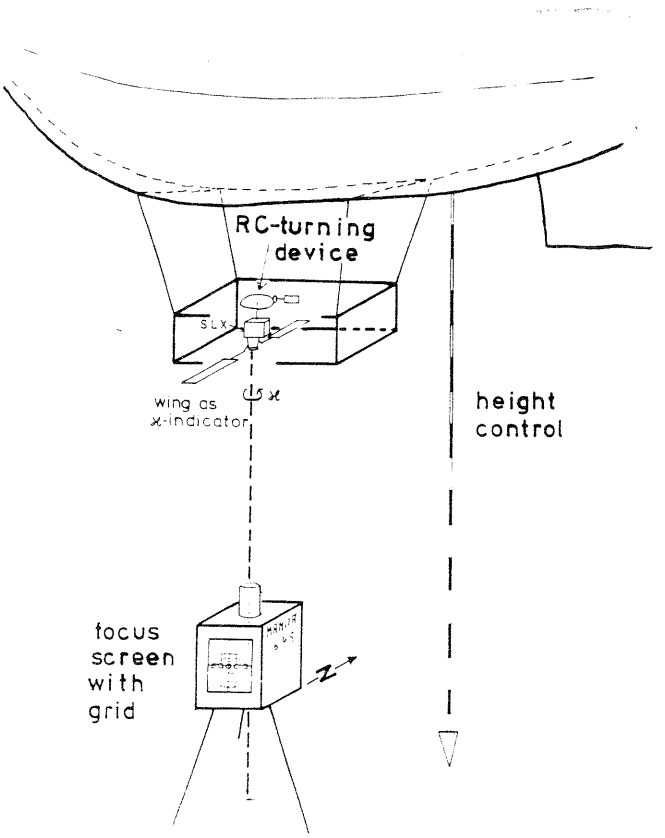
In order to produce blocks of aerial photos with definite overlapping, the navigation must make sure that:

- the airship can be positioned exactly over a previously marked point
- the altitude is maintained
- the camera can be positioned in the direction of the air strip.

The navigational basis is the balloon grid, made up of calculated and marked points. Each point (Balloon Nadir Point=BNP) is the target position for the airship in the aerial photo block



For the exposure a Mamiya 645 reflex camera was set up on a tripod over each BNP, aligned, with the optical axis in strict vertical, and orientated on a N-S axis by means of a compass. A cross-hair focusing screen was used as viewfinder.
To position the equipment, the balloon was towed by guide-lines into the cross-hair viewfinder and the camera rotated by remote control so that the sails on the Rolleiflex camera lens were aligned with the cross-hair.
At the same time the altitude was controlled by a measuring tape hanging down from the airship.
After training the system functioned well, time needed per BNP was approx. 10mins. Problems were encountered with gusty winds from differing directions, because the airship tended to turn its nose into the wind. The typical phenomenon of a tethered, spherical hot-air balloon,i.e. that in wind the envelope becomes deformed, thus the balloon decreases in volume and descends, never occured with the Zeppelin-shaped airship.
The operational limits in wind were conditioned by the materials stability.

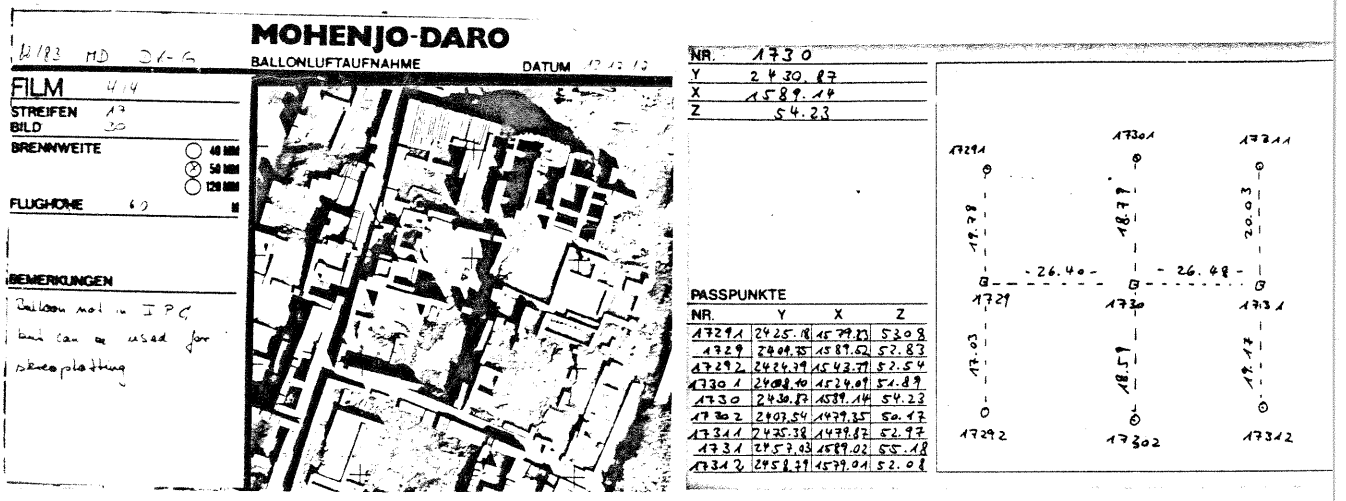


The accuracy with which the airship could be positioned by this method worked out at 1-2m in its position, the angle of swing could be kept down to 5 gon.

Documentation

The aerial photos were developed, enlarged and controlled for overlapping, blurredness through movement etc. all on the same day. Because of the large amount of photographic material obtained, an exact documentation was obligatory.
A file-card was prepared for each interpretable aerial photogram. This contained:

- contact print of the aerial photo
- identification number for film and photo
- index for localization on the surface
- photographic parameter
- control points co-ordinates



Using this system, it is possible to hand the aerial photos on to other authorities for interpretation.

Interpretation

The surveying of control points is a requirement for a clear geometric classification of stereo models and topography. The density of control points depends then upon the plotting technique. For interpretation purposes, the Research Project has the use of the PLANIMAT analogue stereoplotter in the Geodetic Institute of the RWTH Aachen. So many control points were marked and surveyed for a proportion of the photos (120mm S-PLANAR), that, using this, six can be seen in each stereo model. As practice has shown, although the technique takes time, it is exact enough for a clear plotting of the planimetry.
For most of the aerial photo material, control points were plotted on the ground only on the edges of the blocks, further density is due to aerial triangulation. The photo coordinate surveys were carried out with a PLANICOMP C100 at the GERMAN MINING MUSEUM (Bochum), the calculations and diagrams at the Institute for Photogrammetry, Bonn University.
Complimentary to the line maps, rectified photo maps were produced for some excavation areas on the SEG V.

Summary

Using the described aerial photo system, the excavated town of MOHENJO-DARO could be completely documented in the winter of 1982 in three blocks of aerial photos containing 150 photograms as well as several hundred genaral survey photos and detailed colour photos from altitudes of between 10 and 150m. Thus, not only could the research work at MOHENJO-DARO be effectively assisted, but at the same time an aerial photo archive has been acheived which, because of the rapid decay of the walls, will be of enormous value in the future.
The photogrammetric system proved itself to be robust, ready to hand and universally applicable. The hope remains that it will, in further employment, prove itself useful in other areas of close-range photogrammetry.