FROM THE BALLOON CAMERA TO THE MICROPROCESSOR-CONTROLLED LMK AERIAL SURVEY CAMERA SYSTEM

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Commission VI/2

GENERAL

When in 1982 the international photogrammetric community learned about the LMK, the world's first commercial aerial mapping camera to have a facility for compensating linear image motion, its Jena manufacturers looked back on a seventy years tradition in the design of equipment for the metric, photographic sensing of the earth's surface. Aerial cameras have always been one of the main product lines within the photogrammetric equipment range, which started in Jena with the Stereocomparator developed by C. Pulfrich in 1901. In the beginning the development of aerial cameras was almost synchronous with that of aviation engineering.
This article will trace the constant efforts, right from the beginning, of the Jena works towards the improvement of aerial photogrammetric equipment. This is evidenced by the almost confusing succession of product models that have left the workshops between 1910 and now, to be used all over the world.

From the very start, the success of aerial photography was principally due to the excellent conditions existing at Jena with regard to the designing and manufacture of high-quality optics and precise mechanical systems. A third component being incorporated in an growing measure is microprocessor engineering, which Jena scientists and designers have been utilized with great success in recent years for a substantial increase in camera performance; this ist impressively proved by the technical features of the LMK and LMK-1000 camera systems.

1. THE DEVELOPMENT OF AERIAL CAMERAS FROM 1910 TILL 1945

The idea of using the new medium of photography for the purpose of a pictoral representation of the earth's surface features dates back to first practical experiments in the middle of the 19th century (C.F. Tournachon, also known by the name of NADAR, 1858). But it took some substantial advances in aviation engineering as well as the creation of better performing camera lenses before Jena developed and produced the Model 18/1318 Balloon Camera (Fig. 1) in 1910, for which again Pulfrich deserved a major part of the credit. This camera had a frame size of 130 mm x 180 mm, a fast lens of 180 mm focal length, and a plate locating frame provided with four marker holes, which served to establish the positions of the optical axis and the plate horizon. The camera was designed for being

cardanically mounted to the basket ring of a free balloon. Inclinations of the optical axis between 0° and 30° from the vertical were possible by means of a sector arc divided into 5° intervals. A box level and a magnetic needle were exposed together with the ground image on every photoplate for better orientation.
The subsequent years saw the development of further plate cameras, conceived primarily for taking aimed single photographs of particular objects from aeroplanes and airships:

- 1911 aeroplane camera, focal lengths f=250 mm, f=300 mm and f=700 mm
- 1912 aeroplane hand camera (Fig. 2), focal length f = 250 mm, relative aperture f/3.5, plate size 90 mm x 120 mm, focal-plane shutter, changing magazine for 12 plates
- 1914 balloon camera, focal legth f = 1200 mm
- 1914 aeroplane cameras with tilt and swing measuring facilities.

Regarding further technical details, Schumann /1/ cites from the literature that the aeroplane cameras employed lenses such as the 250 mm f/4.5 Tessar and the 500 mm f/4.8 and 700 mm f/5 triplets. The focal-plane shutters allowed shutter speeds between 1/50 and 1/800 second. Facilities for exposing tilt and swing angles on the photoplates were provided, as already mentioned.
The cameras mentioned above served, without exception, for the taking of single photographs and thus had only a limited usability for the aerophotogrammetric recording of extended ground areas.
In contrast to these, the large camera developed in 1917 (Fig. 3), which hat a frame size of 240 mm x 300 mm, was capable of exposing series of photos onto film. The film cassette accommodated 60 m of film, which lasted for about 200 exposures. The optical data were characterized by the 500 mm f/5 triplet and the cloth focal-plane shutter. No fixed orientation being provided, the camera was not a metric camera in the strict sense.
Remarkably, however, both film advance and shutter operation were performed by electric motors. In an upgraded version of the camera, the film was held flat against a perforated, ground and polished platen by vacuum action.
Substantial advances were achieved with the RMK C/1, a serial metric camera (Fig.4) built in Jena in 1922. Its frame size was 130 mm x 180 mm, and the lens was an 180 mm f/6.3 Tessar, with a four-blade between-the-lens shutter. A cassette load of 60 m film allowed about 420 exposures. Shutter cocking and film advance could be operated either manually or by motors powered from a propeller-driven generator with multistep reduction gear. A speed controller was provided for controlling

the frame sequence and, thus, overlap. Film flattening was effected by the action of the dynamic pressure built up in an outboard tube.
The camera mount, consisting of a tubular steel frame, permitted both drift correction and tilting up to 47° from the horizontal.
The advancements made in the following years were principally directed at automating the operating cycle and improving optical performence. The latter was mainly achieved by the designing of special lenses having, by the standards of the time, low distortion and low field curvature. In addition, the RMK C/2 developed in 1925 already had a detachable finder scope. Other improvements over the earlier model were the 210mm f/4.5 lens, selectable shutter speeds of 1/75, 1/100, 1/130 and 1/160 s, and a frame counter.
The RMK C/3 manufactured in 1926 already had a square image frame of 180 mm x 180 mm, which later became the standard international format. The lens was a 210mm f/4.5 Orthometar.

In parallel with the continuous improvement of the serial cameras, Jena also advanced its manually operated single-shot cameras, with both plate and film magazines. Mentioning each and every model here would, however, exceed the scope of this report.
Another essential innovation was introduced in 1928 with the RMK C/5-Perseus (Fig.5). It was the first camera to have a control unit for drift correction and overlap control by means of a travelling grid and a course line visible together with the ground image on a ground-glass screen. An upgraded version designated C/5a (Spica) was driven by a 12V, 100W d.c. motor.
From 1928, the Jena works designed and built various models of two-channel mapping cameras as well a four-channel one, the 4xRMK C/1. Their internal parameters were based on those of the respective single-lens cameras from which they were derived. For their technical data see ref. /1/.
The continuous advancements were frequently stimulated by the practical requirements of the users. One such requirement, the free selection (within certain limits) of the flying height at a given photoscale, led to an innovation in the first half of the thirties automatic high-precision cameras with interchangeable lens cones of different focal lengths.
The RMK S 1818 (Fig. 6) with the standard 180mm x 180 mm frame size, for example, was available with 135mm, 210mm, 300mm and 500mm lens cones. An electric drive module with multistep gear, finder scope or ground-glass viewfinder could be fitted.
The development of peripheral modules such as the horizon chamber (for the 210mm lens cone) for determining photo tilt, and the statoscope recording chamber aimed at a further enhancement of performance capabilities and operating convenience.
The introduction of the travelling grid, which moved acrosss the ground-glass viewfinder at infinitely controllable speeds,

substantially improved overlap control. Further, very useful improvements resulted from the data records that could be exposed on to the frame corners, comprising frame number, time of day, and a box level for tilt information. The development of wide- and superwide-angle lens cones (f = 100 mm or 75 mm, respectively) complemented the existing range of focal lengths to great advantage.

Let the great number of camera versions, which left the Jena works between 1930 and 1940 and which differed mainly by their frame sizes and focal lengths, be exemplified here by the RMK 20/3030 Wide-Angle Mapping Camera produced in 1936. It had a 200mm f/6.3 Topogon lens designed in 1933 by R.Richter. This first wide-angle aerial lens marked a new stage in the development of aerial photography. The angular coverage was 105 gon, corresponding to a frame size of 300 mm x 300 mm, Compared to the normal-angle lenses which by that time had been the only available aerial photolenses, the Topogon brought a remarkable progress with regard to capturing a larger ground area from the same flying height. The RMK 20 had a between-the-lens leaf shutter, with selectable speeds between 1/25 and 1/250 s. Selectable f-stops were 6.3, 9 and 12.5.

Convenient operation, by the standards of the time, of all aerial camera models was possible by means of the IRU Universal Control Unit (Fig.7), which provided stepless control of frame and, thus, of overlaps between 10% and 90%. The unit also contained a drift meter, ground-glass viewfinder, pulse transmitter, switches and pilot lamps. Connection between the IRU and the camera was by cable, which afforded a welcome freedom of arrangement within the aircraft.

2. THE DEVELOPMENT OF AERIAL PHOTOGRAPHIC EQUIPMENT IN JENA AFTER 1960

The first MRB 21/1818 Aerial Survey Camera (Fig.8) that left the Jena plant in 1961 marked the beginning of a new epoch of aerial camera design in Jena. Its designers had, from the start of their post-war efforts, oriented themselves by international standards and requirements. The MRB 21/1818 reflected both the requirements and possibilities of the time. It was a normal-angle camera with a frame size of 180 mm x 180 mm and a 210mm f/4 Pinatar lens. The outfit comprised four units, viz. mount, camera proper, magazine and control unit. The control unit contained all control and monitoring elements of the system and enabled its remote operation.

The rotary blade shutter had a high efficiency and steplessly controllable speeds between 1/100 and 1/1000 s. The optical specialists at Jena met the grown demands for high-performance lenses by designing in 1962 special lens testing devices such as a distortion tester, an image quality tester and a flatness tester. These new facilities had a favourable effect on the development of high-performance lenses such as the 115mm f/4 Lamegon (1964), which formed part of the wide-angle MRB 11.5/1818 camera. The Lamegon was the first wide-angle lens to have a relative aperture of 1:4. Yellow and orange filters were provided with it, allowing the user to eliminate atmospheric stray light, which otherwise reduced contrast and definition. The control unit, which was identical for both MRB models them existing, offered greater operating convenience than its predecessors.

Camera operation was facilitated also with regard to objectivated exposure metering, thanks to the AEROLUX, a photoelectric exposure meter (1964). It directly indicated shutter speeds after f-stop, film speed etc. had been set, as a function of brightness values registered by a selenium photocell. Another peripheral unit, launched in 1965, was the REGISCOP, a recording statoscope which continuously recorded changes in the plane's altitude during a photographic flight.

1968 saw the introduction of new wide- and superwide-angle cameras, the MRB 15/2323 and MRB 9/2323. The high-performance 150mm f/4.5 Lamegon PI and 90mm f/5.6 Superlamegon PI lenses were corrected for the visible and infrared spectral range to make them useful for both topographic mapping and photo-interpretation.

These new cameras heralded the change-over to the larger standard format of 230 mm x 230 mm still in use today.

The range of peripheral equipment was completed by the AEROSCOP Navigation Sight. Its 20mm f/5.6 Flektogon lens had an angular coverage of 100^g, of which 90^g looked in front of and 10^g behind the vertical.

In the light of practical requirements, the MRB's control unit was substantially improved in 1975. Its field angle was increased from 30° to 50°, and the speed control range for the travelling grid doubled. The resulting advantages included a broader range of possible photoscales and a better cost-to-benefit ratio for photographic flights.

The range of available focal lengths was supplemented in 1976 by the MRB 30/2323 with its 300mm f/5.6 Lamegor PI lens. The new camera unit was fully compatible with the existing system. The Lamegor, a high-performance lens, had an area-weighted average resolution (AWAR) of 55 l/mm with high object contrast, and a distortion of less than $\pm$ 3 µm (tested on Kodak Plus X film). Now an efficient camera for large-scale surveys was available.

Another highlight in the development of metric cameras in Jena was the MKF-6 Multispectral Camera launched in 1976, with the corporation entered the field of space technology. The camera, which excellently stood its acid test in its first practical mission aboard the Soviet Soyuz 22 space probe, was an efficient, six-channel multiband camera for remote sensing from an air or space platform. Each of the six component cameras was fitted with a 125mm f/4 Pinatar lens and a narrow-band metal-dielectric interference filter. The filters had centroid wavelengths from 450 to 840 nm, with a half-peak width of 40 nm. The camera had a facility for compensating the forward motion of the space probe or aircraft

during exposure. The MKF-6M model turned out two years after was a special modification for long-time space missions.
In 1984 another multispectral camera was added to Jena's photogrammetric and remote sensing camera range- the MSK-4, a four-channel camera specially designed for aircraft use. Into its design went the experience gained with the MKF-6 and MKF-6M cameras.
The Double Camera Adapter introduced in 1978 provided a possibility for the simultaneous of two aerial cameras of identical or different focal lengths.
In 1980, the wide-angle lens cone was upgraded. The 150mm f/4.5 Lamegon B lens duplicated its predecessor in focal length, angular coverage and lens speed, while considerably surpassing it in imaging quality. At f-stop 5.6 it yielded an AWAR of 61 l/mm for high contrast and 31 l/mm for low contrast (on Kodak Plus X). Standard distortion throughout the frame area was 3 µm or better.
An entirely new generation of aerial cameras emerged from Jena in 1982 - the LMK Aerial Survey Camera System
The system completely differs from the MRB concept, with new substantial performance features thanks to the incorporation of modern microprocessor technology. Camera weight has been substantially reduced (to about 30% of the MRB); exposure control has been automated, based on differential exposure metering, and aircraft forward motion. The camera's new control unit offers a maximum in a lucid user-friendly arrangement, including the indication of current operating variables (f-stop, shutter speed etc.), gamma recommendation and the amount of image motion (if the motion compensator is switched off). Levelling-up and drift corrections are automatically transferred from the control unit to the camera.
The system comprises the following modules, viz.

- mount,
- lens cone,
- drive unit,
- magazine, and
- control unit.

The splitting of the camera unit (as exemplified by the MRB) into two components, i.e. lens cone and drive unit, contributes to the previously mentioned weight reduction and especially decreases the weight to be lifted in case of lens cone change during a flight. Supplementary developments as well experience gained in the successful practical use of the camera led to an upgraded system, now designated LMK-1000. A new high-performance lens, the 210mm f/5.6 Lamegoron P was added to the system's range of lens cones, and the range of forward motion speeds that can be compensated was extended from a maximum of 32 mm/s to 64 mm/s.
Another improvement is the data projector incorporated in the magazine, with with camera data (shutter speed, f-stop, forward motion amount, frame number) and external data can

be exposed on to the film. Thanks to the introduction of intermediate f-stops, the sensitivity of the automatic exposure control has been increased. The latest addition to Jena's aerial photography equipment is the NCU 2000 Navigation & Control Unit developed in 1987, which now permits the camera system to be operated by a single person. The standard control unit and the NCU fit the same mount, so that conversion between the two modes of operation can be effected quickly and easily.

3. SUMMARY

Since 1911, the Jena optical works have made outstanding contributions to the development of aerial photography. The Jena scientists and engineers have always been guided by the most advanced international standards, not seldom setting new standards themselves.
The Jena optical works today live up to that tradition, which is made evident by such extraordinary products as the MKF-6 or the LMK. This report, without claiming completeness, outlines the history of aerial camera design at Jena by way of significant product developments - from the balloon camera to the LMK-1000. This is, at the same time, part of the history of photogrammetry.

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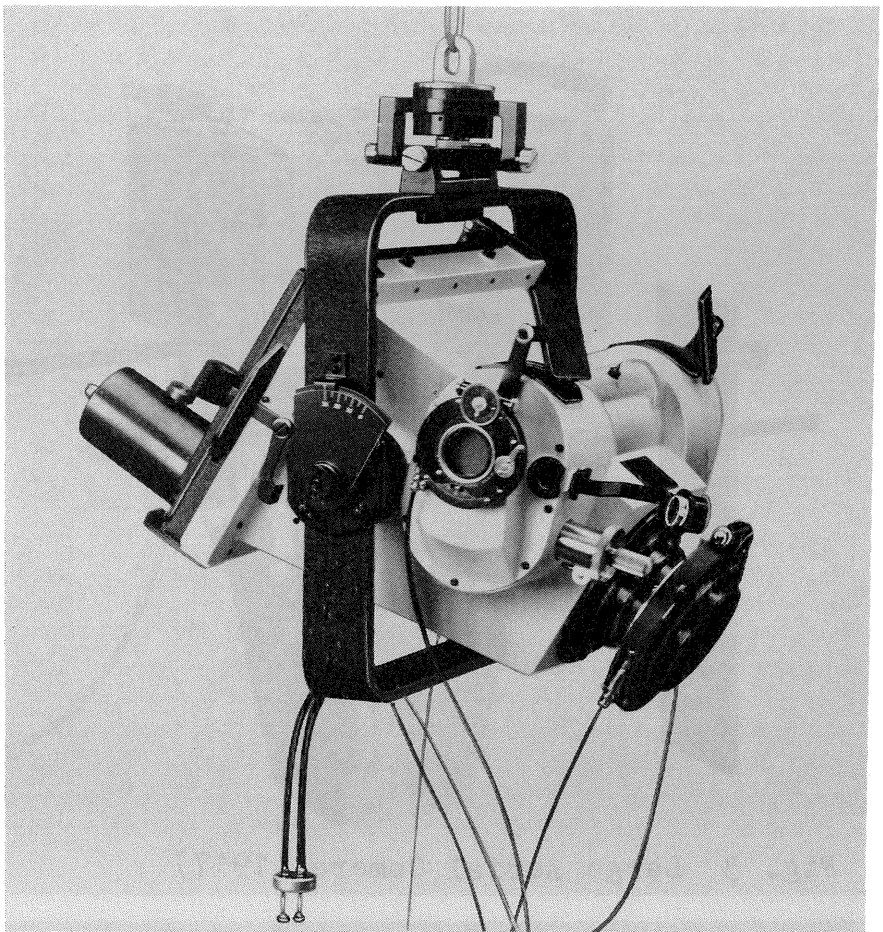

Fig. 1 Balloon Camera 18/1318 (1910)

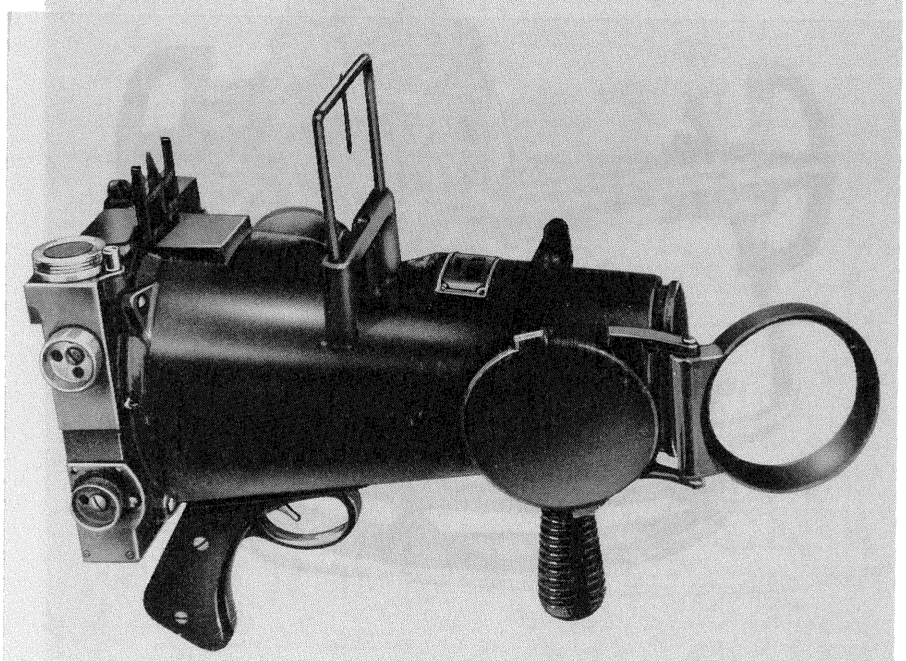

Fig. 2 Manual Aerial Camera (1912)

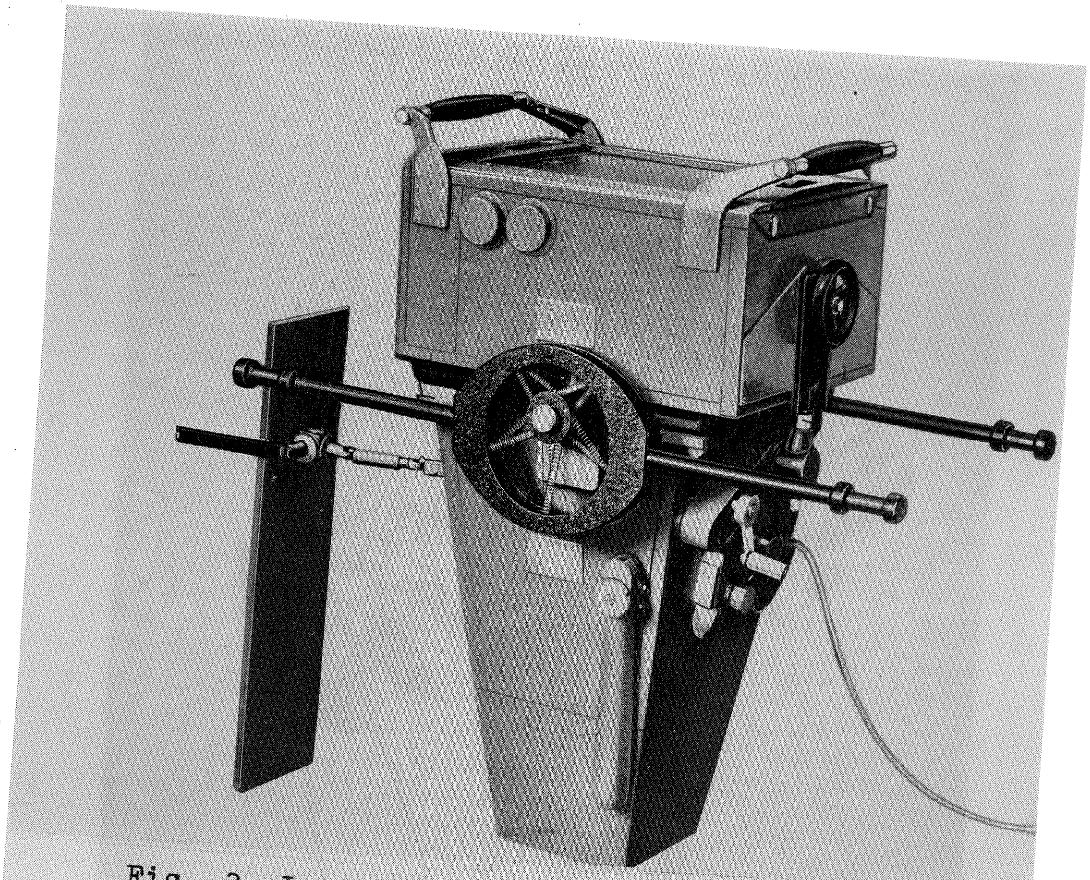

Fig. 3 Large Aerial Camera (1917)

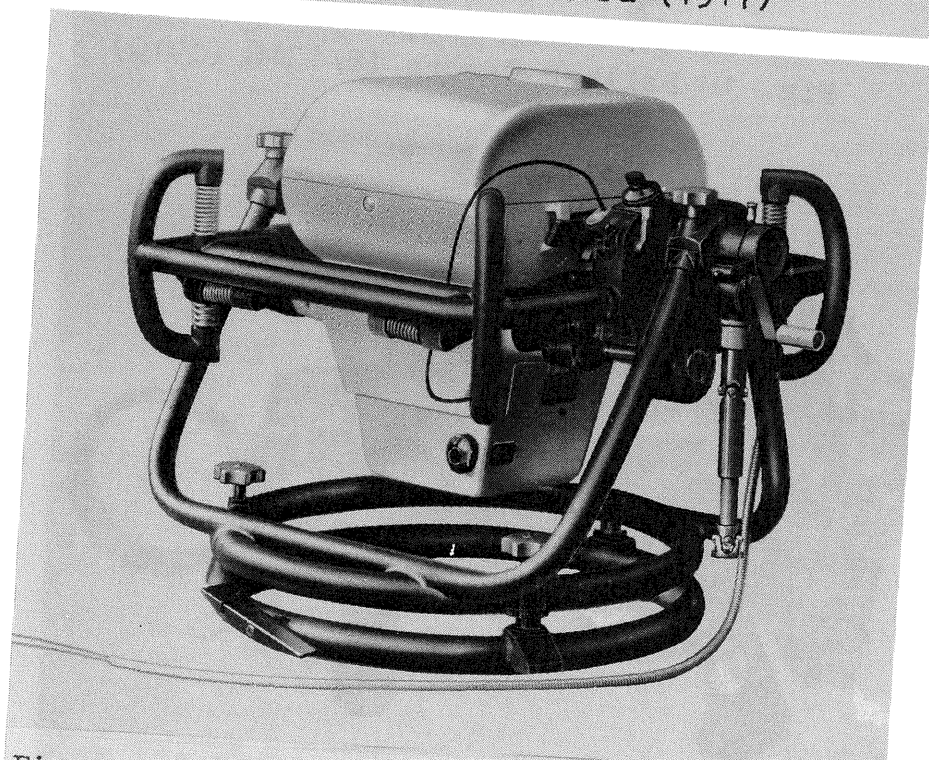

Fig. 4 RMK C/1 Aerial Camera (1922), the first aerial exposure camera

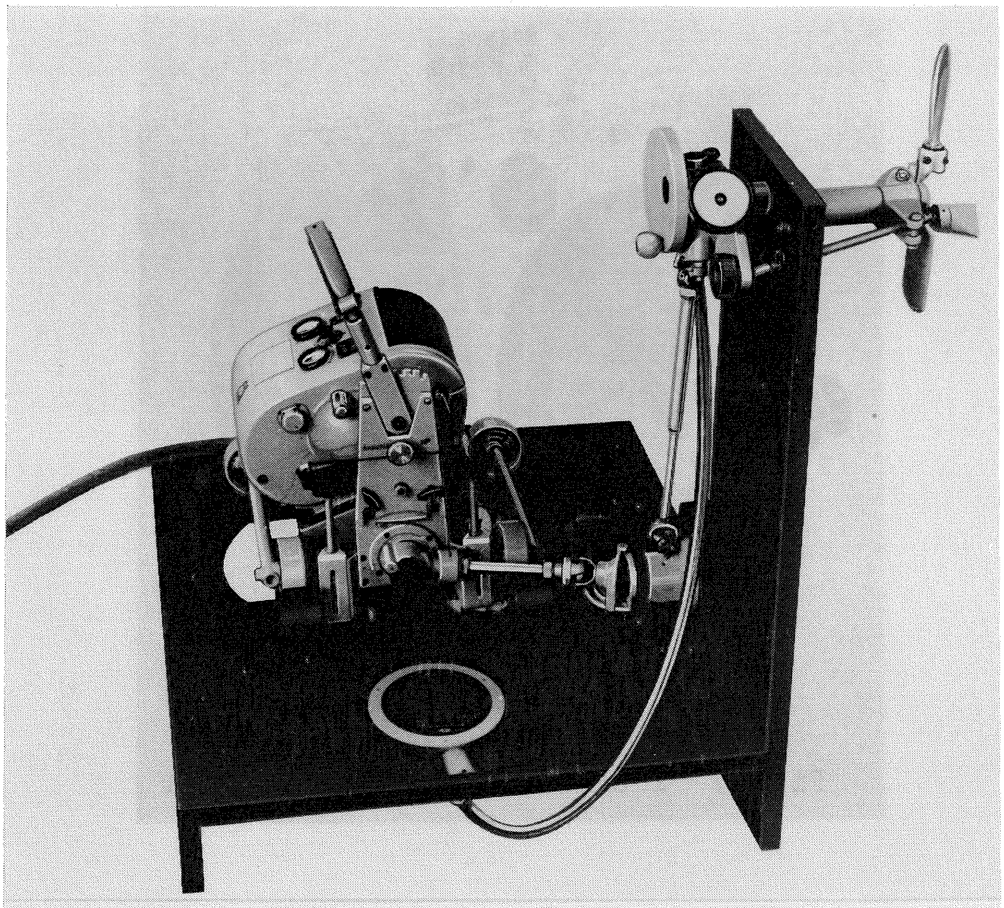

Fig. 5 RMK C/5 - Perseus Aerial Camera

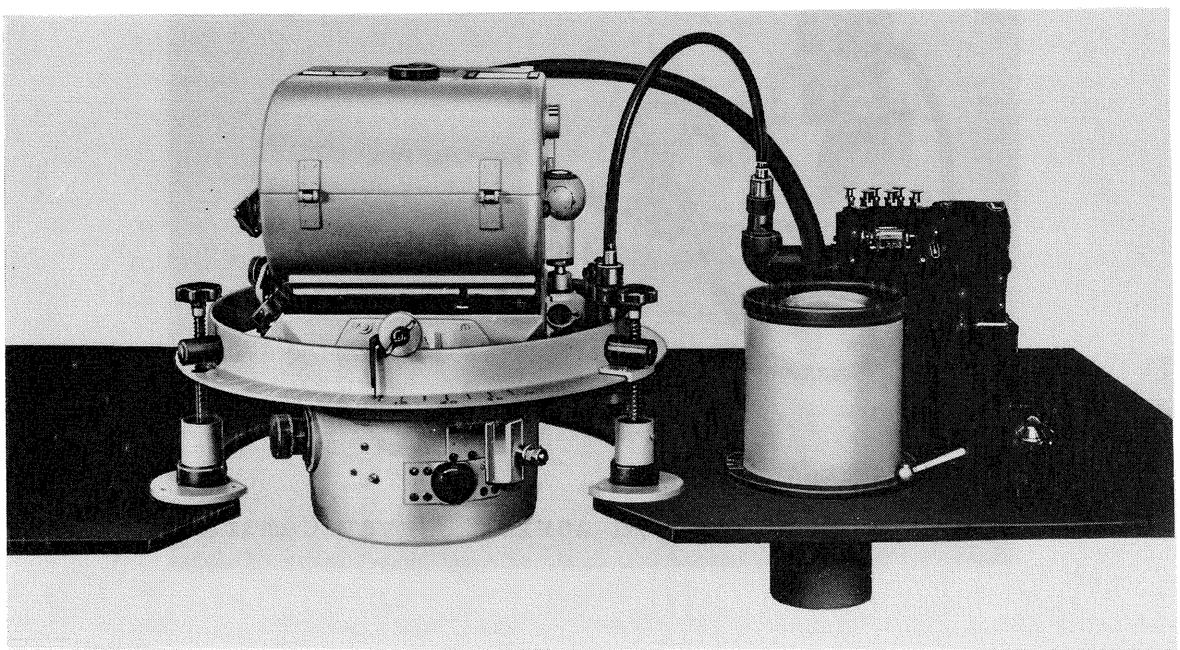

Fig. 6 RMK S 1818 with 210 mm lens cone, multistep transmission gears

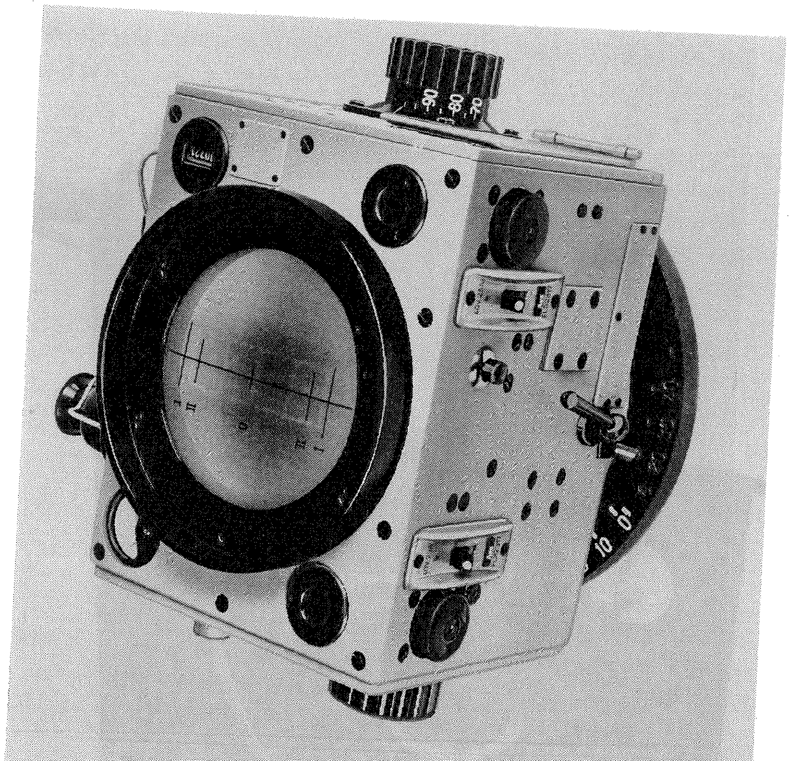

Fig. 7 IRU Universal Control Unit

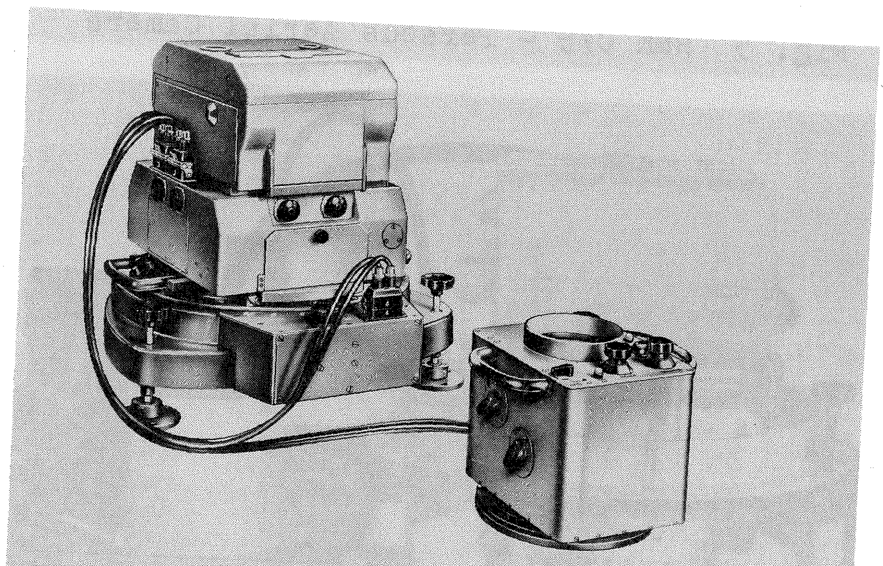

Fig. 8 MRB 21/1818 Aerial Survey Camera