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The performance capabilities of modern aerial camera systems

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ABSTRACT

The features of modern aerial cameras such as forward motion compensation (FMC), stabilized mounts and flight management systems, based on developments made in the seventies outside photogrammetry and taken up by camera manufactures in the eighties, have brought an enormous advancement in performance capabilities.

1. INTRODUCTION

The eighties saw a remarkable change in aerial photography systems with regard to the quality of photographs, the handling of photographic flights and a better integration of aerial photography into the overall photogrammetric process.

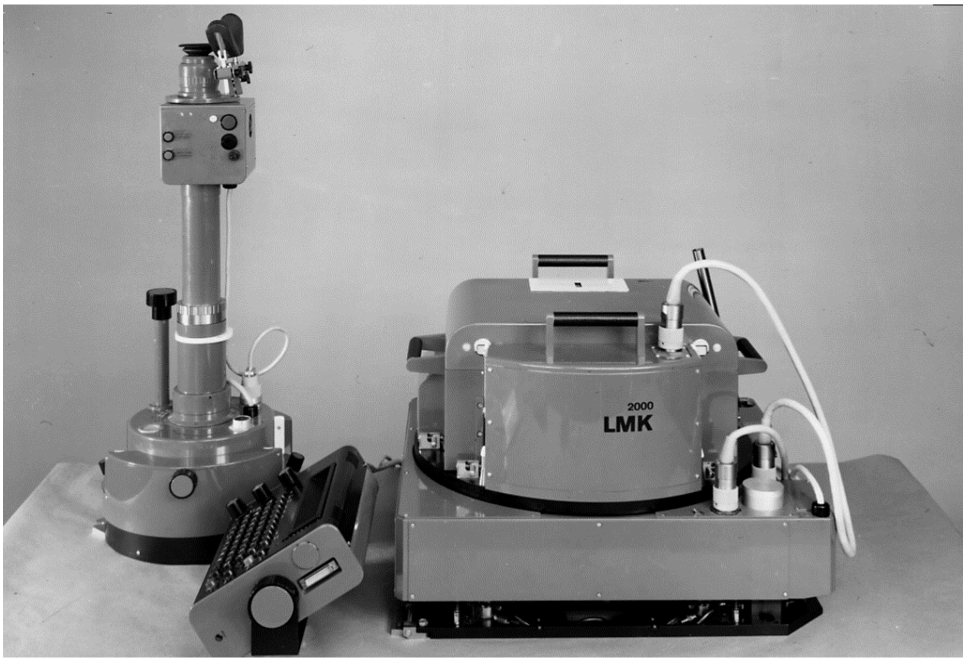

Figure 1: LMK 2000 Aerial Camera System.

The change became possible because manufacturers and users of cameras took up developments and accomplishments made in other fields during the seventies.
Examples are

- Microelectronics	- increased demands on lens quality; microprocessors, PC
- Space technology	- films of higher resolution
- Defence technology	- global positioning systems (GPS)

The development of cameras in the past decade can be outlined by the following table:

Introduction of FMC	**LMK (1982), RMK (1984)**, RC 20 (1987)
Microprocessor-controlled camera	**LMK (1982)**, RC 10A (1981)
- with flexibly installed control unit	**LMK 2000 (1989), RMK-TOP (1989)**
Introduction of stabilized mounts	**LMK 2000 (1990), RMK-TOP (1993)**
Satellite-based navigation	CCNS 4 (1990), **T-Flight for RMK-TOP and LMK 2000 (1992)**
Advanced lenses	**LMK: Lamegon D (1989)** **Lamegon E (1993)** **Superlamegon C (1993)** **RMK: Pleogon A3 (1989)** **Topar A3 (1989)** RC 10: UAG-A (1983) RC 30: UAG-S (1992)

The table plainly evidences the pioneering role of Zeiss in advancing aerial photography. Figures 1 and 2 show the two leading aerial camera systems, LMK 2000 and RMK-TOP.
This paper will be focused on the components that determine the performance level of a modern aerial photography system, i.e. **forward motion compensation**, which is fully effective only in cameras having a **stabilized mount**, and the use of **flight management systems**.

2. FORWARD MOTION COMPENSATION AND STABILIZED MOUNT

The effect of aircraft forward motion on the generation of aerial photographs is well known. However, it needed the high resolution of spaceborne photography to stimulate new efforts to find an adequate solution for airborne cameras. Given the large angular aperture of aerial cameras, the solution would have to be a rigorous one.
The basic approaches that suggested themselves were

- rotating wedges in front of the lens: no exact solution;
- tilting the camera during exposure: no exact solution;
- **moving the film pressure plate in the flight direction: exact solution.**

It is no wonder that all camera manufacturers have, from the start, used the version mentioned last. The exact timing required for an exposure cycle has become much easier to control by means of microprocessors. Nevertheless, the results of photographic flights soon showed that the potential of FMC could not be utilized in all kinds of weather. In low-altitude flights, atmospheric turbulences caused angular image motions, which now began to matter. The natural consequence of this experience was the development of stabilized mounts.
The main purpose of a stabilized mount is to keep the optical axis of the camera in a constant attitude in terms of longitudinal and lateral tilt (phi and omega) and to prevent rotation about the axis (kappa). At the same time this satisfies the objective of keeping nadir distances as small as possible.

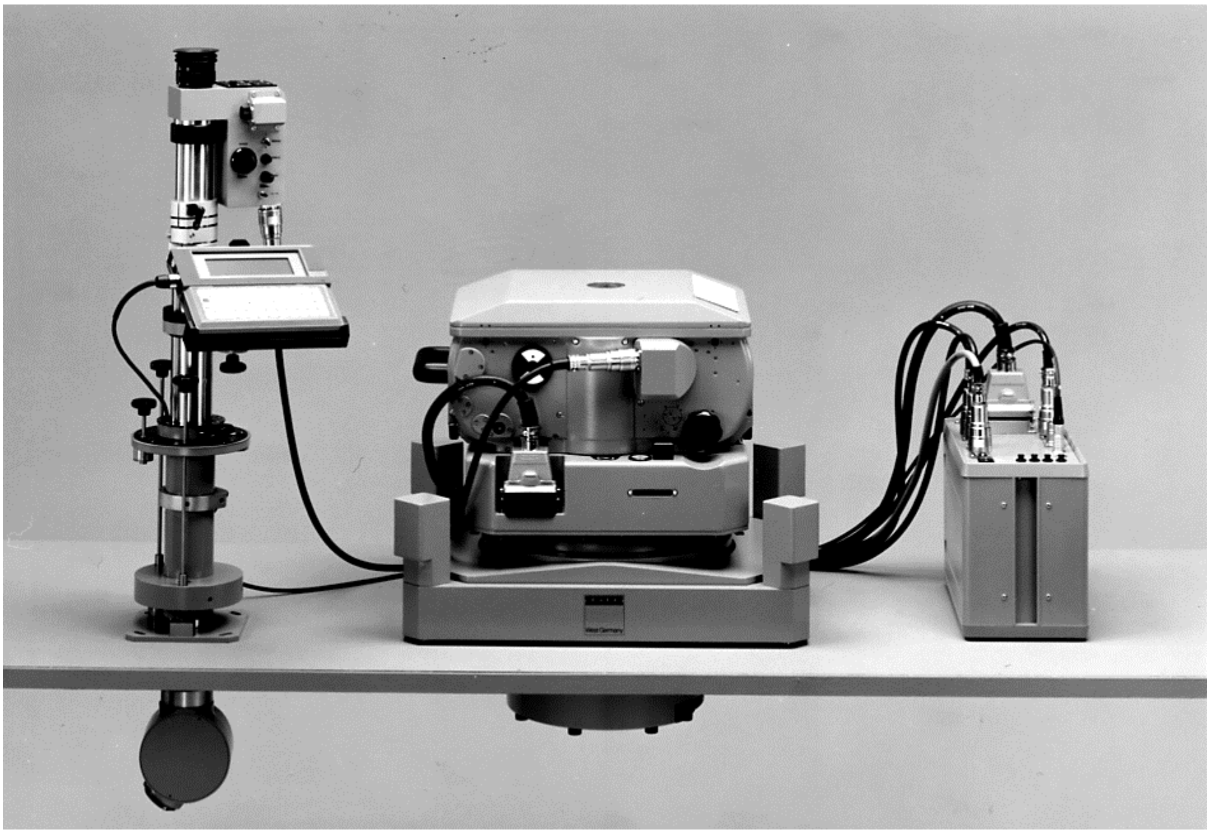

Figure 2: Aerial Survey Camera RMK TOP.

Essentially, a stabilized mount consists of a base plate and a superstructure, which have to be joined by a play-free Cardan suspension. The base plate must be rigidly fixed to the aircraft floor. The substructure carries gyroscopes, which register the angular velocities of the aircraft and release a compensating movement of the superstructure by means of servo actuators fitted to the base plate. The compensating movement stops when the deflection of the gyroscopes is zero. Electrolytic levels acting both along and across the flight direction automatically keep the mount in a horizontal position and nadir distances small. The Cardan joint between superstructure and base plate is of either of two types, viz.

hydraulic	-	SM 2000 mount of the LMK 2000 camera, or
mechanical	-	T-AS mount of the RMK-TOP camera.

Fig. 3 shows, for example, the design principle of the SM 2000.
FMC and stabilized mounts not only have immensely advanced the quality of aerial photographs, but also may have direct advantages with regard to information extraction: the small nadir distances lead to high-quality photomosaics. FMC and stabilized mounts have not, however, rendered the demands to be made on the pilot's skill in steering the aircraft less stringent. The tilt ranges and positioning speeds of stabilized mounts are limited (the former to ± 5 degrees). For good and uniform image quality, therefore, the plane should still be flown with a steady attitude, and the pilot should consider the behaviour of the mount when approaching the photographic track. GPS-based flight management systems can be a considerable help.

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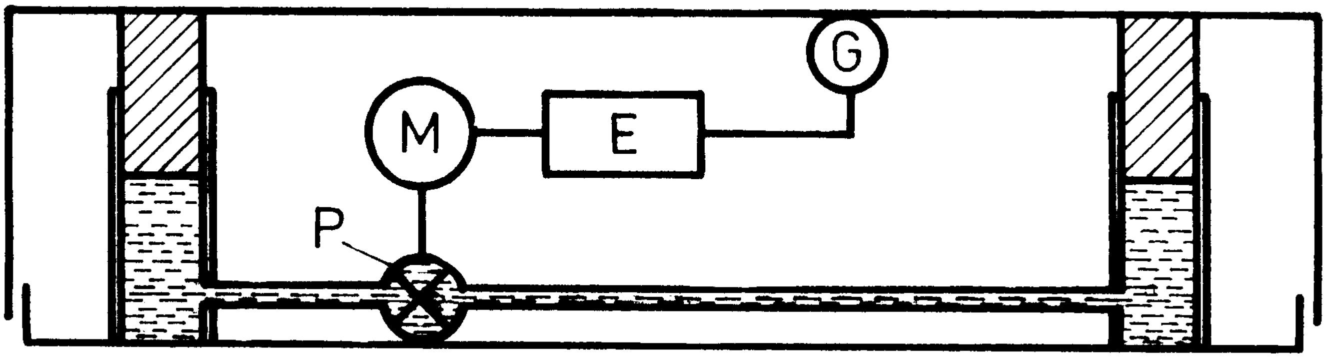

Figure 3: Design principle of the SM 2000.
(G gyro M motor P pump E control electronic)

3. GPS-BASED FLIGHT MANAGEMENT

The comprehensive management of photographic flights today should comprise

* the planning of photographic flights in a graphic compilation environment,
* flight navigation and control by a GPS in accordance with the planned strip layout,
* determination of the camera's positions at each exposure by means of GPS measurements, and
* output and analysis of flight data.

These requirements were the basis for developing the T-Flight system of photographic flight management for the LMK 2000 and RMK-TOP cameras. The system was designed in collaboration with MAPS geosystems, because of the close interrelation between camera development and practical application. Fig. 4 is a block diagram of the entire system.
The four components of T-Flight are implemented as follows:

Component	serving for	implemented by
T-PLAN	project-oriented graphic flight planning	software module for navigation computer or office PC
T-NAV	GPS-based navigation, camera control and recording of taking positions	navigation computer (PC with graphic screen, suitable for airborne use)
T-REP	analysing and recording of flight mission data and plotting of taking positions	software module for navigation computer or office PC
T-DIF	recording of differential GPS measurements at the ground station	software module for office PC

T-Flight relieves the pilot from navigation tasks, enabling him to fully concentrate on keeping the aircraft on the planned track with the aid of the system's cockpit display.

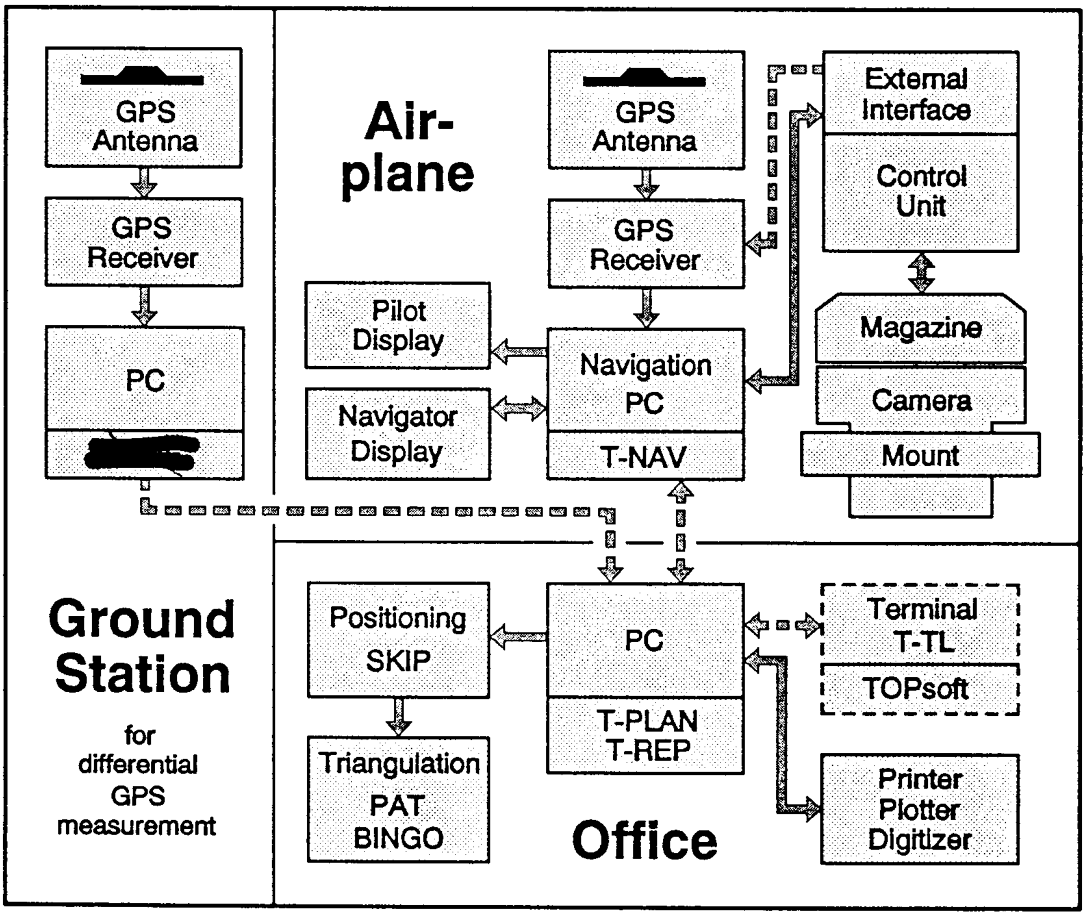

Figure 4: T-Flight Photoflight Management System with GPS.

If the camera position at the moment of exposure is to be determined to a high accuracy, the GPS system should be a so-called geodetic receiver, which is suitable for both kinematic measurements abourd the aircraft and differential measurements at a stationary reference station. If the GPS is to be used for flight navigation only, a non-geodetic receiver will do.
Photographic flights are today carried out by one of two methods, viz.

* exposures made at pre-computed camera positions ("pin-point photography"), or
* serial exposures made in accordance with the desired longitudinal overlap and measured v/H values; the serial exposure function is switched on by T-NAV at the beginning of a strip and off at the strip end.

Although the RMK-TOP and LMK 2000 cameras differ by a number of conceptual details, both connect readily and without restrictions to GPS-based flight management systems and produce similar results in practice. The table below lists some important properties relevant to GPS-assisted aerial photography.

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Properties	RMK-TOP	LMK 2000
GPS interface	universal	universal
Recording of exposure moments	max. error 0.1 ms	max. error 0.1 ms
Data exposure	provided	provided
Shutter	pulsed rotating discs constant access time (50ms)	rotating discs
v/H determination	NA automatic navigator	laser altimeter installable in lens cone
	Navigation telescope	Navigation telescope
Antenna offset	output of attidude	
Cloud observation		video camera in lens cone

The T-Flight management system is complemented by the **SKIP** program (**S**tatic and **Ki**nematic **P**ositioning with GPS), which computes the geographic coordinates of the antenna positions and transforms them into the desired geodetic system, allowing for the eccentricity between antenna and camera. Knowledge of these coordinates reduces the number of control points required for aerotriangulation and increases the profitability of the photogrammetric method.

4. CONCLUSION

The decisive features determining the performance of modern aerial cameras are forward motion compensation, stabilized mount and GPS-based flight management. Besides these features, the Zeiss LMK 2000 and RMK-TOP cameras are outstanding also for the high resolution and low distortion of their lenses and the centralized control and operation from flexibly installable control units.