HIGH ALTITUDE FLIGHTS USING AERIAL SURVEY CAMERA SYSTEMS

Oliver Koepke, aerial-survey-base, Bad Homburg

Commonly unpressurized survey aircrafts performing photo flights at high altitudes. In some cases, pressurized Turboprop or Jet driven airplanes are in use. Flights executed at high altitudes producing small scale aerial photography images. Technical problems in the entire workflow show up commonly at high altitudes. Not only caused operating an aircraft in FL150 and higher, also related to the image quality (haze and atmospheric influences) and image accuracies later on in processing.

Most image accuracy related problems are cause in air pressure and temperature.

Air Pressure and Camera Temperature

- **pressurized aircraft**
  Cabin air pressure in a pressurized aircraft is maintained by the aircraft systems at an (cabin) altitude of around 6.500 ft or 2.000 meters or 800 mbar. The temperature inside the cabin will be adjusted by the aircraft systems at around 20...25 °C in order to deliver excellent environmental conditions to the crew.
  Inside the camera, the temperatures are about 5...10 °C higher than the cabin temperature, because the motors, vacuum unit and electronic units creating some heat. These general environmental conditions are defined by the aircraft pressurization and climate control systems.

  The camera window in a pressurized aircraft is usually covered by an optical grade glass plate. In case of a high altitude flight, the glass plate will be deformed and distorted, caused by the difference between cabin and outside air pressure. The glass plate will be deformed in direction "into" the cabin.

Measurements made by Dr.-Ing. H.K. Meier and Dr. rer. nat. Zuegge (Carl Zeiss, Oberkochen) the glass plate must have these dimensions in order to avoid distortions caused by a "twisting" of the glass plate:

Dimensions of glass window in order to minimize the twisting effect		
Lens type	**Diameter of glass [mm]**	**Thickness of glass [mm]**
85 mm	720	45
153 mm	420	30
305 mm	256	20
120 mm (DMC)	400	30

These dimensions ensure a distortion of less than 2 µm.

- **Unpressurized aircraft**
  In an unpressurized aircraft, the most common kind of photo airplane, the camera window is not covered by an optical grade glass. Therefore the camera is influenced by the environment conditions of the aircraft cabin and the outside conditions.
  Inside the cabin, most often heater systems will be used in order to create acceptable conditions to the crew, especially at high altitudes. The cabin heater is only influencing a part of the camera, let say the film magazine and some parts of the camera body and lens. But other parts, as main parts of the lens system, shutter, aperture and also the filters are under the direct influence of the atmospheric conditions outside of the aircraft. Most time, cabin parts are temperature in a range of 0…7 °C, all other parts are around -12 … -30 °C, depending on altitude (up to minus 30°C!)
  The air pressure ranges from 480 mbar at 6.000 meter and 200 mbar at 12.000 meter flight altitude (standard pressure at Mean Sea Level is 1013 mbar.)

The aerial lens is made from several high performance single lenses made from different types of glass, consolidated to lens groups and mounted using high sophisticated assembly kits and "glue". The optical and thermal characteristics (refraction index, expansion coefficient etc.) are selected by the manufacturer in order to archive best optical performance. (Good to know, that most glass comes from SCHOTT, Germany, a company of Carl Zeiss, even if the glass will be used later in Heerbrugg.)
Between the lenses and lens groups are plain air and therefore the current local air pressure.
This air pressure will influence the paring of the individual lenses and at high altitude, it will be different to the adjusted, calibrated, calculated and measured pairing at the manufacturing process or measured in the calibration laboratory.

printed: July 22, 2008

Changing of calibrated focal length

Empirical measurements made using Carl Zeiss aerial cameras [Meier & Zuegge, Carl Zeiss]:

	Pressurized Aircraft		Unpressurized aircraft			
			Constant temperature +7℃		Influenced by outside tem perature	
Lens type	6 km/20.000 ft	14 km/46.000 ft	6 km/20.000 ft	14 km/46.000 ft	6 km/20.000 ft	14 km/46.000 ft
85 mm	- 0,005	- 0,019	- 0,025	- 0,038	- 0,045	- 0,076
153 mm	- 0,020	- 0,038	- 0,036	- 0,058	- 0,047	- 0,080
305 mm	+ 0,012	- 0,017	- 0,033	- 0,033	- 0,110	- 0,172

Change of calibrated focal length according to altitude of flight and environmental conditions. (All measurements in mm)

Changing of focus

Aerial camera lenses are fixing - focus type systems. The focus was adjusted at the manufacturing process in relation to the object distance (common altitude of flight). The focus is adjusted to the film plane in order to archive the best optical performance.
Change in focusing mean change of the adjustment or calibration of the optical axis.
The most common problem at high altitude flights is the influence of the air pressure to the optical system, consisting the lenses, lens groups and the mounting assemblies between.

The focusing changes therefore according to the air pressure at certain altitudes.

	Pressurized Aircraft	Unpressurized aircraft			
		Constant temperature +7℃		Influenced by outside tem perature	
Lens type	6 km/20.000 ft (cabin altitude)	6 km/20.000 ft	14 km/46.000 ft	6 km/20.000 ft	14 km/46.000 ft
85 mm	- 0,03	- 0,04	- 0,07	- 0,01	- 0,03
153 mm	- 0,04	- 0,07	- 0,13	- 0,04	- 0,09
305 mm	+ 0,07	- 0,15	- 0,25	- 0,13	- 0,23

Change of focus according to altitude of flight and environmental conditions. (All measurements in mm)

As we can see, change of focus is an important factor. The acceptable tolerance is related to the aperture (diaphragm) of the lens and so far related to the so called “circle of confusion”.

According to common photographic praxis, a change is acceptable in a range

f/4,0 = 0,04 – 0,06 mm
f/5,6 = 0,06 – 0,09 mm

We can see that high altitude flights are far outside these tolerances.

Background:

All aerial survey camera systems are best calibrated at defined, standard conditions in a calibration laboratory (Carl Zeiss, Leica-Geosystems, USGS). All environmental influences of a practical photo flight, especially at high altitudes, are eliminated. Corrections related to distortion, calibrated focal length and focusing have been calculated for those standard conditions at the calibration lab.

In case of the focal length, the ration h/f (height to focal length) is identical to the estimated photo scale number or in case of digital camera systems, identical to the estimated Ground Sampling Distance GSD. If the absolute orientation of an aerial photograph is made by ground control points (GCP) and classic bundle block adjustment methods, the scale is also determined by the horizontal control points. At high altitudes, the calibrated focal length must be compensated by the flying height above terrain. The vertical component, related to the vertical accuracies later on, the accuracies depending on the air base (b/h ratio) and also to deviations of the calibrated focal length. A discrepancy of the calibrated focal length and the nominal focal length at the practical photo flight has a direct influence on height and horizontal accuracies, because an affine deformation of the stereo model appears on the correct photo scale in x, y and an incorrect photo scale in the vertical scale number.

E.g. a 15 µm error of a wide angle camera (using 15 cm focal length), will change the height of a point located at 100 m above the level of the control points by 10 mm. This error is usually not recognizable, but a deviation on the focal length by 15 µm will change the distance from the projection center for a flying height of 1.000 m (3.250 ft = 1:6.500 scale, ca. 13 cm GSD scanned at 20 µm) by 100 mm or 0,1 %, that means in reality 10 times of the usually allowed vertical accuracy for the project.

The focal length will be measured in a calibration laboratory at exact defined and constant environmental conditions, especially relating to the temperature. In case of the Carl Zeiss – Deutscher Kalibrierdienst – Lab, a camera will be temperature for more than 24 hours before starting the calibration process. In case of a practical photo flight, these conditions are dramatically different to the standard conditions, especially at high altitude flights.

The change of a focal length is depends on the camera type, type of lens and used glass, camera operation conditions, and the time where the camera was exposed at these conditions (flying time). Therefore these values cannot be used directly to create a "correction factor" for the calibrated focal length, because these conditions changing due to the practical photo flight, environmental conditions, times and ways of operation every day and every flight. In case of using a GPS/IMU based orientation system, a calibration field (or bore sight site) can be used to determine these and other parameters for every flight – before or after taking the project photography, These boresight information can be used to calculate not only the boresight misalignment between IMU and camera projection center, it can be also used for exact determination of calibrated focal length and other parameters related to the later achievable accuracies, e.g. computing exact flying height.

Note: factors also influencing the accuracies at high altitude flights:

- Earth curvature correction
- Rotating of projection center using drift control of the camera mount (influence of rotation of the camera to the aircraft axis, Nodal point offset using some gyro stabilized camera mounts)
- Map projections in bundle block adjustment

ACKNOWLEDGEMENTS
I am grateful like to thank Dr. rer. nat. Hanfried Zügge and Dr. Ing. Winfried Lorch, the fathers of Carl Zeiss RMK TOP, Peter Herms of Hansa Luftbild, German Air Surveys and Christoph Doerstel of Z/I Imaging for providing me always extensive support and cooperation.

Literature:
Meier, H-K.: Verzeichnung, Kammerkonstante und Fokussierung von Luftbildkammern unter dem Einfluss bildflugspezifischer Umweltbedingungen, BuL, 6/1978
Jacobsen, K.: Potential and Limitation of Direct Sensor Orientation, IAPRS, Vol. XXXIII, ISPRS Amsterdam
Heipke, C., Jacobsen, K., Wegmann, H.: OEEPE Test on Integrated Sensor Orientation, ASPRS, St. Louis, 2001
Cramer, M.: Erfahrungen mit der direkten Georeferenzierung, Zeitschrift PFG, 4/2003
Honkavaara, E.: IN-FLIGHT CAMERA CALIBRATION FOR DIRECT GEOREFERENCING, Finnish Geodetic Institute