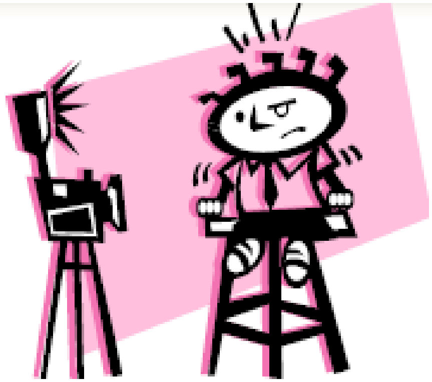
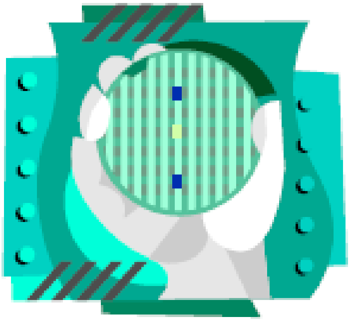
AERIAL CAMERAS

FILM-BASED CAMERAS

CAMERA

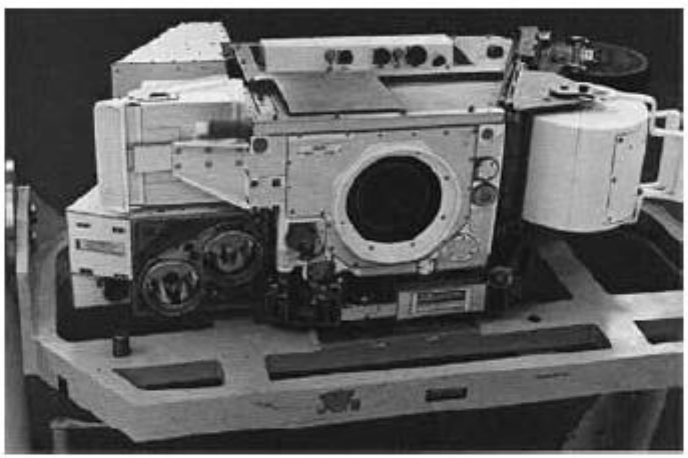


- Light-proof chamber or box in which the image of an exterior object is projected upon a sensitized plate or film, through an opening usually equipped with a lens or lenses, shutter and variable aperture
- In digital photography – use semiconductor electronics instead of film



Types of Aerial Cameras

- Frame camera (sensor)
  - Acquire image simultaneously over entire format



- The frame camera: exposes a square-shaped of ground all at the instant of time
- The continous strip:The film moves continosly past a slit in the focal plane
- The panoramic camera: operates in a direction normal to the direction of flight.It takes a sweeping picture of the ground from right to left

AERIAL MAPPING CAMERA REQUIREMENTS

- Lens of high geometric quality
- Capable of exposing large no. of photos in rapid succession to exacting specifications
- Short cycle time
- Fast lenses
- Efficient shutter
- Functional under extreme weather conditions, like temperature and humidity, in spite of aircraft vibration
- Simple to use during photo mission
- Equipped with safeguards to protect against operator blunders
- Automatic as possible
- Able to preserve elements of interior orientation and preserve internal geometric relationships

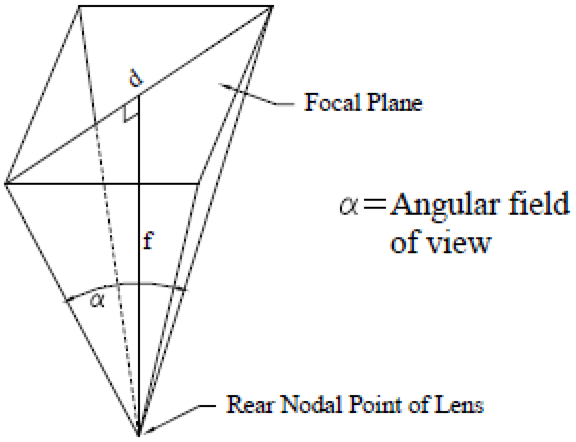
METRICAL CAMERAS

- Designed specifically for use in photogrammetry
- Precise determination of spatial positions of objects
- Traditionally use of roll film for recording images

SINGLE LENS FRAME CAMERA

- Lens held fixed relative to focal plane
- Film generally held fixed
- Classified by angular field of view
  1. Normal angle (up to 75°)
  2. Wide angle (75° – 100°)
  3. Superwide angle (> 100°)
- Angular field of view

$$\alpha = 2\tan^{-1}\left(\frac{d}{2f}\right)$$



Data of different lens assemblies

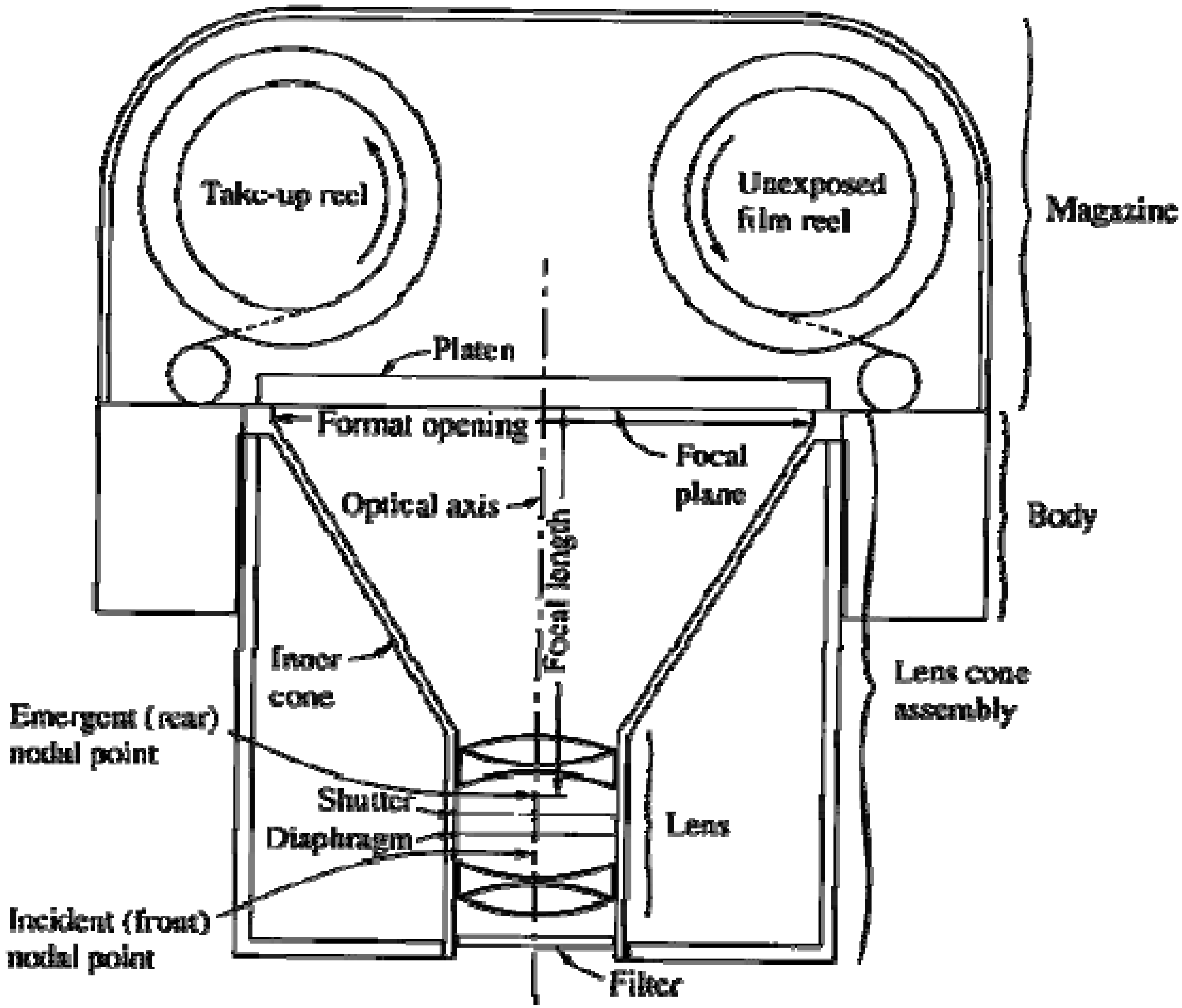
	super-wide	wide-angle	inter-mediate	normal-angle	narrow-angle
focal length [mm]	88.	153.	210.	305.	610.
field [o]	119.	82.	64.	46.	24.
photo scale	7.2	4.0	2.9	2.0	1.0
ground coverage	50.4	15.5	8.3	3.9	1.0

FRAME CAMERAS

- Used for most photogrammetric operations
- Principle parts are:

1. The lens assembly
2. The Inner cone
3. The focal plane
4. The Outer cone and body
5. The Drive Mechanism
6. The Magazine

AERIAL CAMERA PARTS



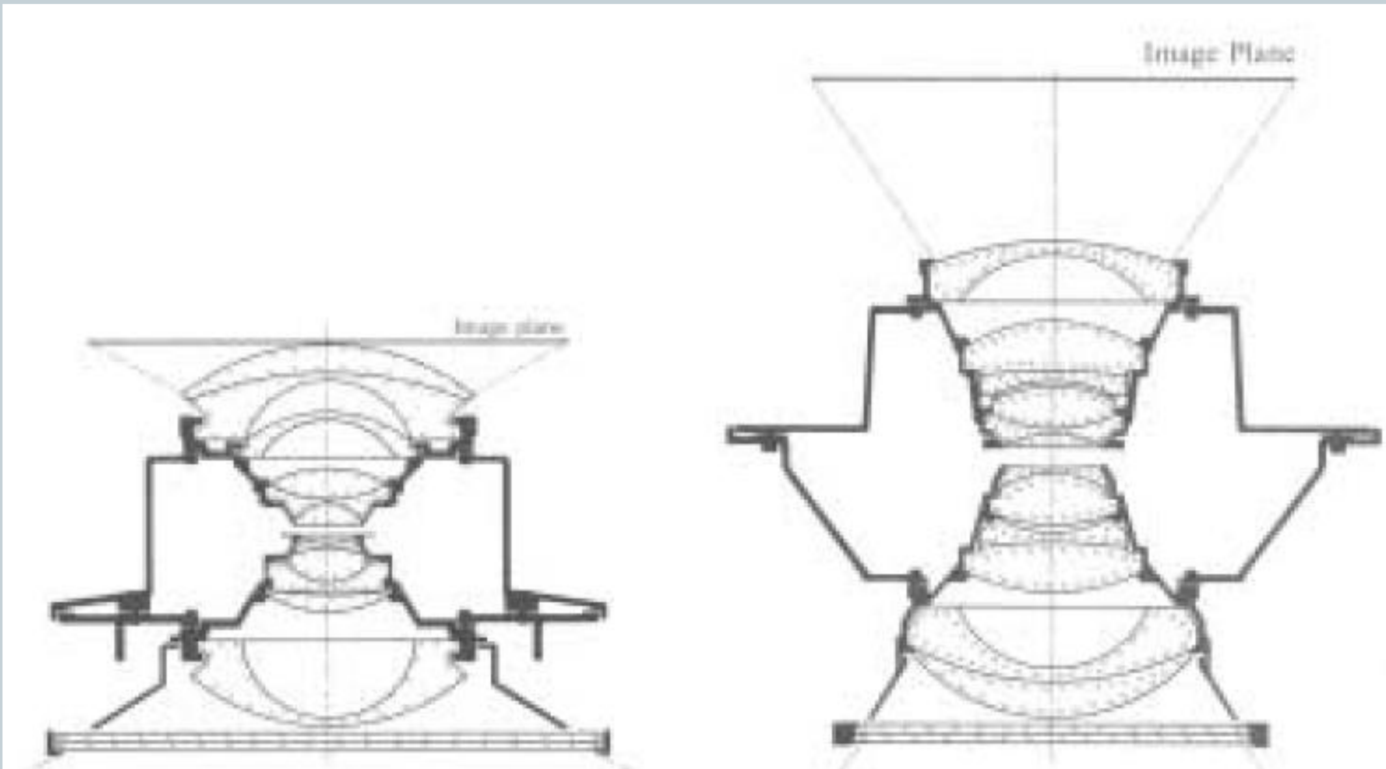
The lens assembly

- Forms the image of the ground being photographed in the focal plane
- The diaphragm and shutter control the exposure according to the amount of available light and film speed
- The Filter helps to penetrate the atmospheric haze

LENS

- Gathers light rays from object space and brings them into focus in the focal plane behind the lens
- Array of lenses aligned in lens cone

Cross-sectional view of aerial camera lenses



The Inner cone

- Holds the lens assembly fixed with respect to the upper surface (the focal plane) of the cone.
- The upper surface contains reference marks called fiducial marks which define the coordinate axes of the resulting photograph
- The relative positions of the lens axis, the focal plane and the fiducial marks fix the elements of interior orientation of the camera

FOCAL PLANE

- Plane where all incident light rays brought to focus
  - Aerial cameras have focus fixed for infinite object distance – set focal plane equal to focal length behind rear nodal point
- Defined by upper surface of focal-plane frame
  - Surface where film emulsion rests

Fiducial marks
    Index marks imaged on film
    Serve as reference photo
    coordinate system

The focal Plane

- Defined by the upper surfaces of the fiducial marks together with the upper surface of the focal plane.
- Located at such a distance (focal lenth) from the rear nodal point of the lens as to give the best overral image definition
- The focal length is determined by calibrating the camera

Outer cone and body

- To support the inner cone
- To hold the drive mechanism
- Furnish a support for the magazine

The Drive Mechanism

- Provides the motion necessary to wind and trip the shutter,flattenning the film in the focal plane and wind the film or change the plates between exposures

The Magazine

- Holds the exposed and unexposed film (or plates)
- Advances the necessary amount of film between exposures
- Houses the film flattening device
- For a 23 by 23 cm picture size, the magazine can hold up to 120m of film that is 24cm wide. This will yield as many as 475 exposures

Image Motion

- During the instance of exposure, the aircraft moves and with it the camera, including the image plane.
- Thus, a stationary object is imaged at different image locations, and the image appears to move.
- Image motion results not only from the forward movement of the aircraft but also from vibrations

Forward image motion

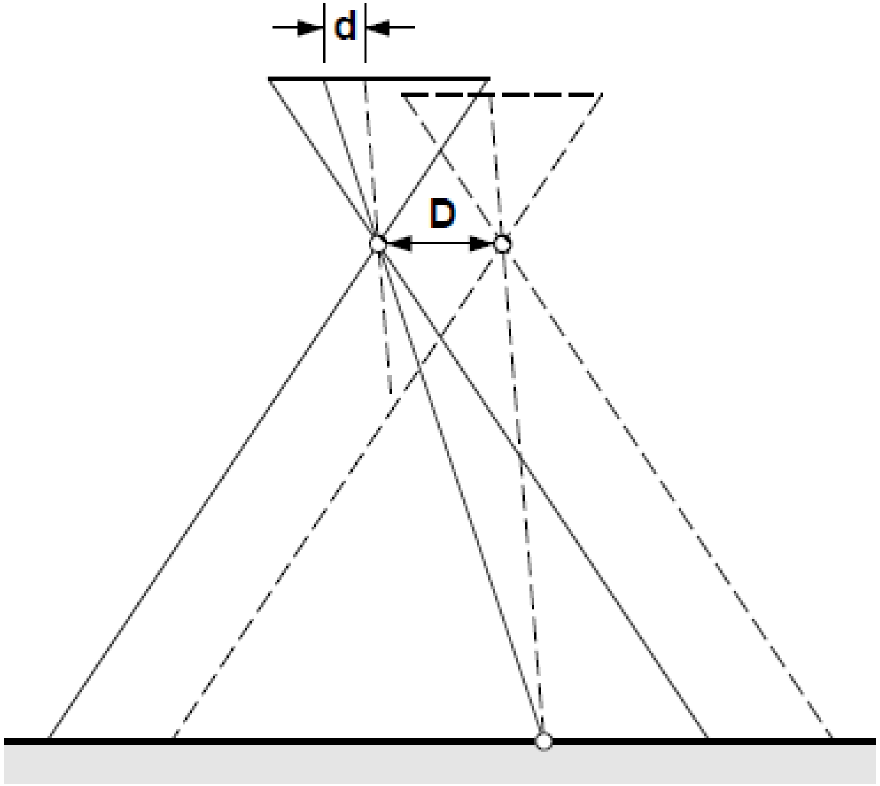


Figure 2.5: Forward image motion.

- An airplane flying with velocity *v advances by a distance D = v t during the* exposure time *t. Since the object on the ground is stationary, its image moves by a* distance *d = D/m where m is the photo scale. We have*

$$d = \frac{v\,t}{m} = \frac{v\,t\,f}{H}$$

with *f the focal length and H the flying height.*

Example: given

- exposure time $t = 1/300$ *sec*
- velocity $v = 300$ *km/h*
- focal length $f = 150$ *mm*
- flying height $H = 1500$ *m*
- **image motion $d = 28$ µm**

FORWARD MOTION COMPENSATION

- Move film slightly across focal plane during exposure in flight direction

- Example (3.1) Camera with f = 152.4 mm, airplane velocity = 200 km/hr, flying height above terrain = 3,500m, exposure time = 1/500 sec. What distance (in mm) must film move across focal plane to obtain clear image?

FORWARD MOTION COMPENSATION

- Solution:
  - Distance plane travels during exposure

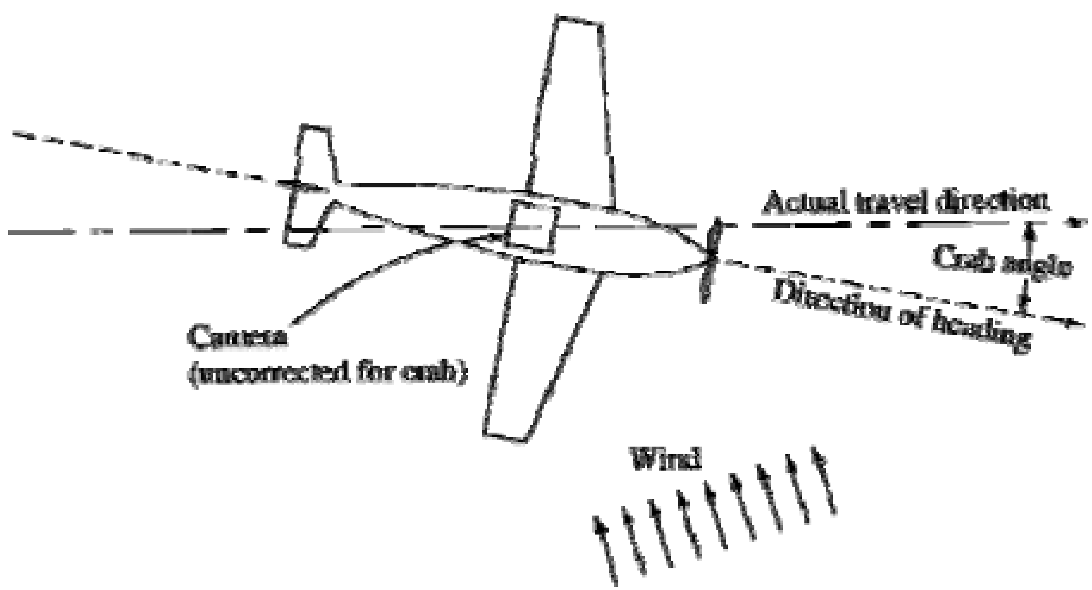
$$D = (200\ \text{km/h})\left(\frac{1}{500}\text{sec}\right)\left(\frac{1\ \text{hr}}{3600\ \text{sec}}\right)\left(\frac{1000\ \text{m}}{1\ \text{km}}\right) = 0.11\ \text{m}$$

  - Distance image moves during exposure

$$d = 0.11\ \text{m}\left(\frac{152.4\ \text{mm}}{3500\ \text{m}}\right) = 0.005\ \text{mm}$$

CAMERA MOUNTS

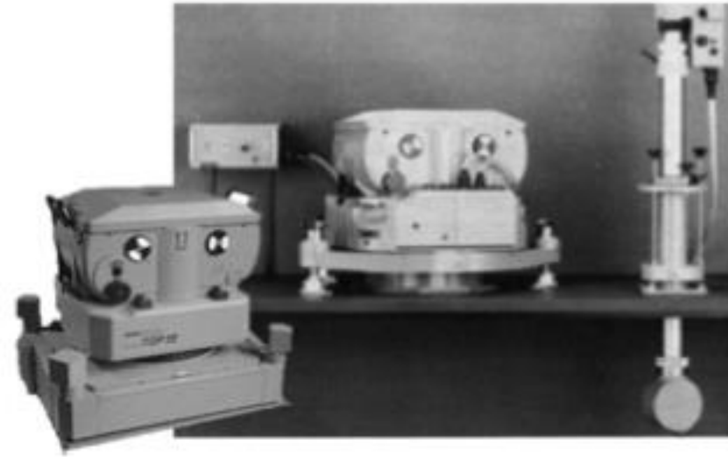
- Attaches camera to aircraft
- Constrains angular alignment of camera
- Minimum mount has dampener devices & crab correction
- Crab
  - Difference in camera orientation w.r.t. aircraft's actual travel direction



EFFECT OF CRAB

- Undesirable effect – reducing stereoscopic ground coverage of aerial photos

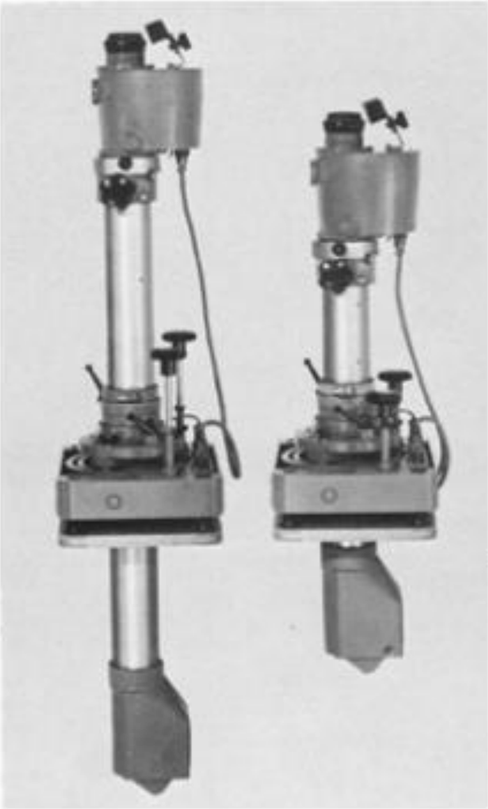
CAMERA CONTROLS



- Intervalometer
  - Device that automatically trips shutters & activates camera cycle
  - Interval depends on focal length, format size, end lap, flying height, velocity
  - Modern intervalometers – part of integrated unit incorporating GPS

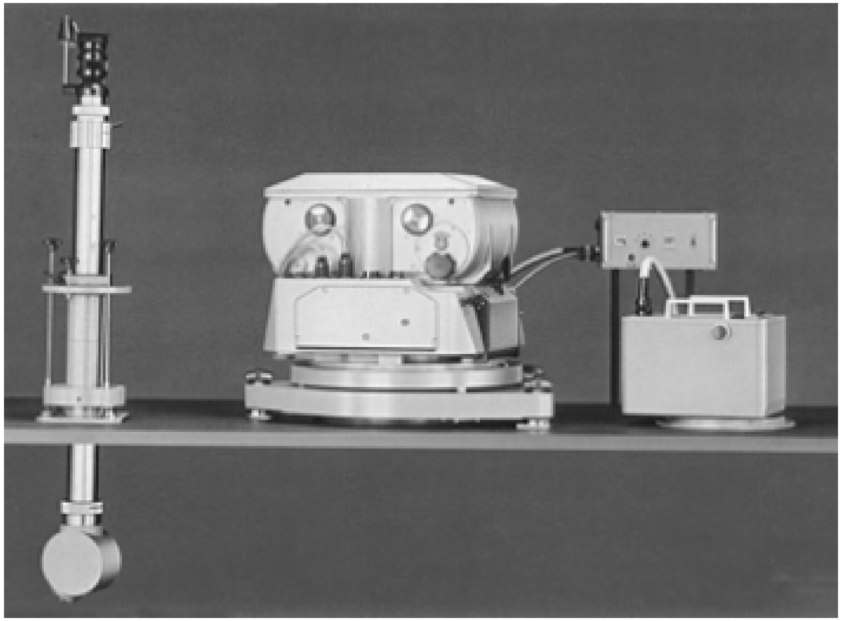
CAMERA CONTROLS

- Viewfinder
  - Can view the terrain beneath the aircraft and to see the ground coverage of each photo
- Exposure control
  - Exposure meter that measures terrain brightness



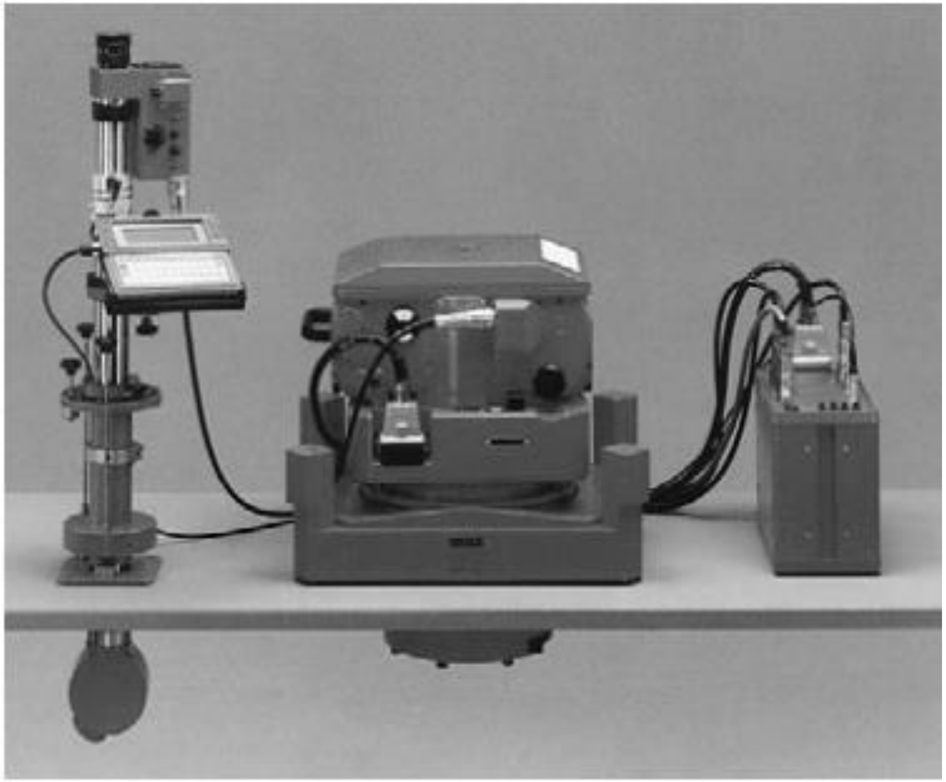
ZEISS RMK A 15/23 WIDE-ANGLE CAMERA

- With ICC/NS-1Central Interval Computer and NT-1 Navigation Telescope
- Pleogon A (153 mm) lens, 93º angular field of view, Max nominal distortion 2 μm
- Used for general work
  - Aerotriangulation, topographic and large-scale mapping



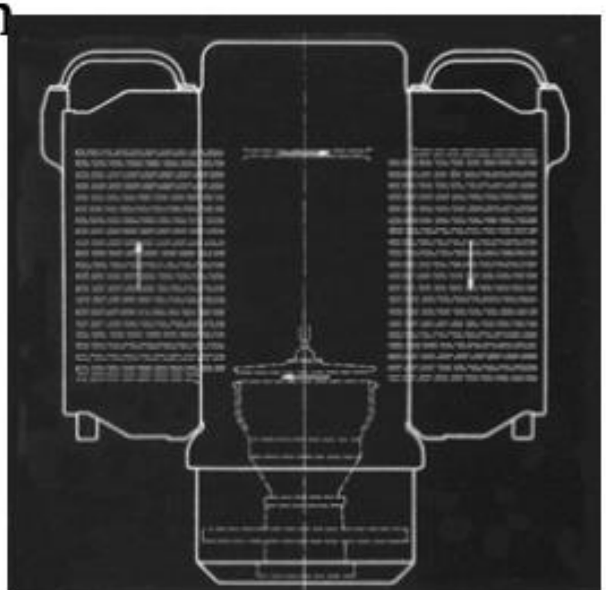
ZEISS RMK TOP 15 AERIAL CAMERA

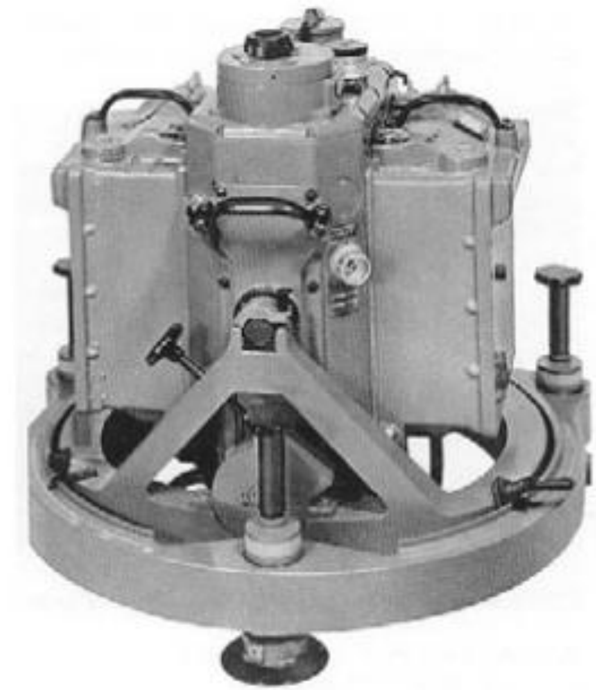
- Pleogon A 3 wide-angle lens, focal length = 153 mm
- Distortion ±3 µm max.
- Pulsed rotating-disk shutter
- 8 numbered, point-shaped fiducials
- FMC 0-64 mm/s
- TA-S gyro-stabilized suspension mount
  - Stabilized in φ & $\omega \pm 5^o$
  - Additional control in $\kappa \pm 30^o$



WILD RC 7 a AUTOMATIC PLATE CAMERA

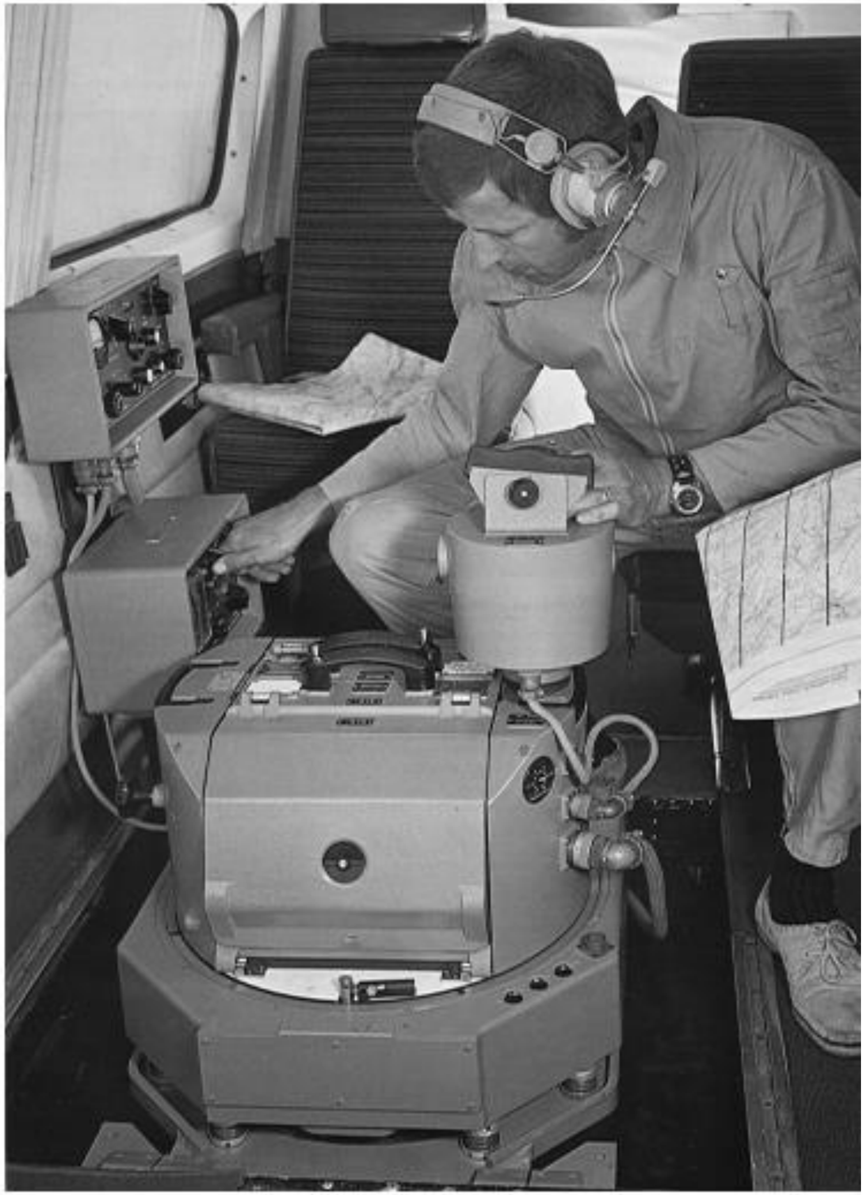
- Available with 2 lens cones: normal and wide angle
- Two symmetrically arranged magazines contain 40 plates each





WILD RC 10

- Rotary shutter between lens
- Electric vacuum pump with automatic regulator value for film flattening
- Film spools housed in its own individual cassette



LEICA RC 30

- Shown with gyro-stabilized mount and on-board ASCOT computer
- High quality lens
- Long-term stability
- FMC
- Gyro-stabilized mount
- Automatic exposure meter
- Communications with other systems & ASCOT
- Data annotation on each photo
- Modular design, microprocessor controlled

Camera Calibration

CAMERA CALIBRATION

- During this process, the *interior orientation of the camera is* determined.

- The interior orientation data describe the metric characteristics of the camera needed for photogrammetric processes.

The elements of interior orientation are:

1. The position of the perspective center with respect to the fiducial marks.

2. The coordinates of the fiducial marks or distances between them so that coordinates can be determined.

3. The calibrated focal length of the camera.

4. The radial and discentering distortion of the lens assembly, including the origin of radial distortion with respect to the fiducial system.

5. Image quality measures such as resolution

PURPOSE OF CAMERA CALIBRATION

- Cameras should be calibrated once in a while because *stress*, caused by temperature and pressure differences of an airborne camera, may change some of the interior orientation elements.

CALIBRATION

- Classes
  - Laboratory – outgrowth of manufacturers
    - Visual approach – optical goniometers
    - Photographic approach – bank of optical collimators
  - Field
    - Horizon method – only horizontal angles measured
    - Full field method – horizontal & vertical angles measured
    - Stellar method – use star field as control

OPTICAL GONIOMETER

- Center precise grid plate in camera focal plane
- Grid illuminated from rear and projected through cameral lens
- Angles to projected grid rays emerging from lens measured with a goniometer

CAMERA CALIBRATION

- Determine precise & accurate values for elements of interior orientation
    - Calibrated focal length (CFL)
        - Focal length producing mean distribution of lens distortion
        - Really a calibrated principal distance
    - Symmetric radial lens distortion
        - Occurs along radial lines from principal point
    - Decentering lens distortion
        - Further broken into asymmetric radial and tangential
        - Caused by manufacture imperfections and lens alignment

CAMERA CALIBRATION

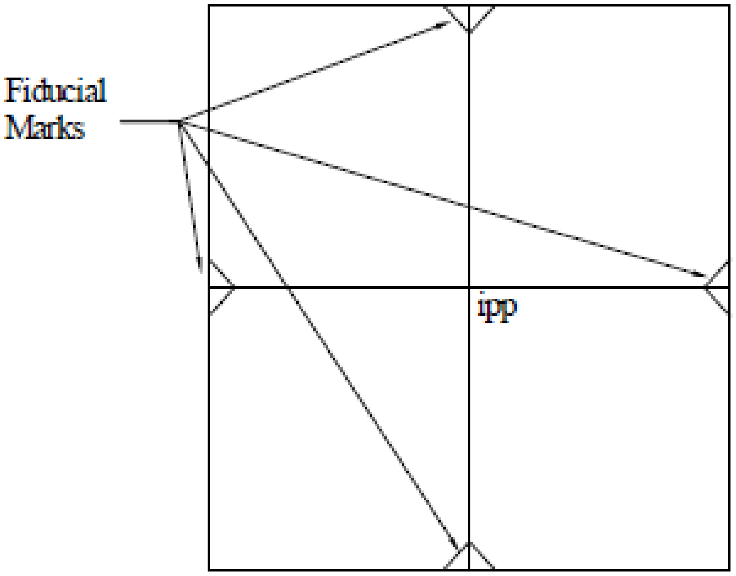
- Principal point location
  - x-, y-coordinates of principal point wrt the fiducial marks
- Fiducial mark coordinates
  - Provide 2-D positional reference for principal point as well as images on the photo
- Resolution
  - Sharpness or crispness
  - Highest near center
- Focal plane flatness
  - Deviation of platen from true plane
- Shutter efficiency
  - Ability to operate correctly

FOCAL LENGTH

- Nominal
  - focal length classification
- Equivalent (EFL)
  - Effective focal length near center of camera lens
- Calibrated (CFL)
  - Also called camera constant
  - Adjusted value of EFL – distribute lens distortion over entire field of camera

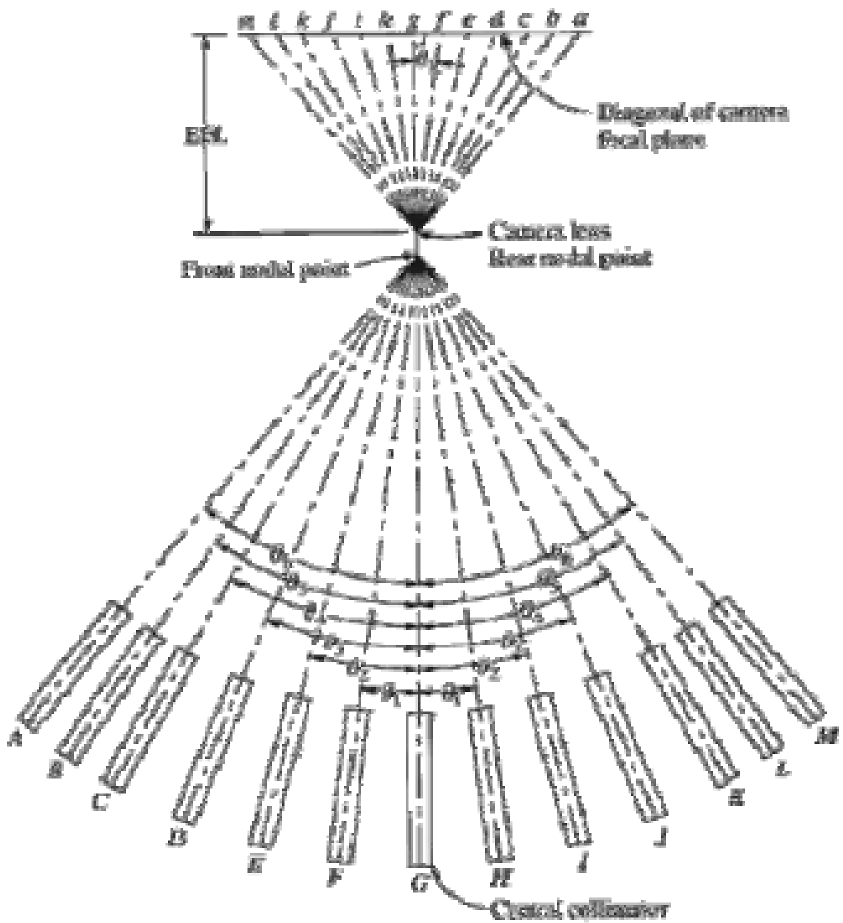
PRINCIPAL POINTS

- Indicated principal point (ipp)
  - "fiducial center" or "center of collimation"
  - Intersection of opposite fiducials
- Principal point of geometric optics (ppgo)
  - Point on optical axis at which the optical axis intersects the principal plane

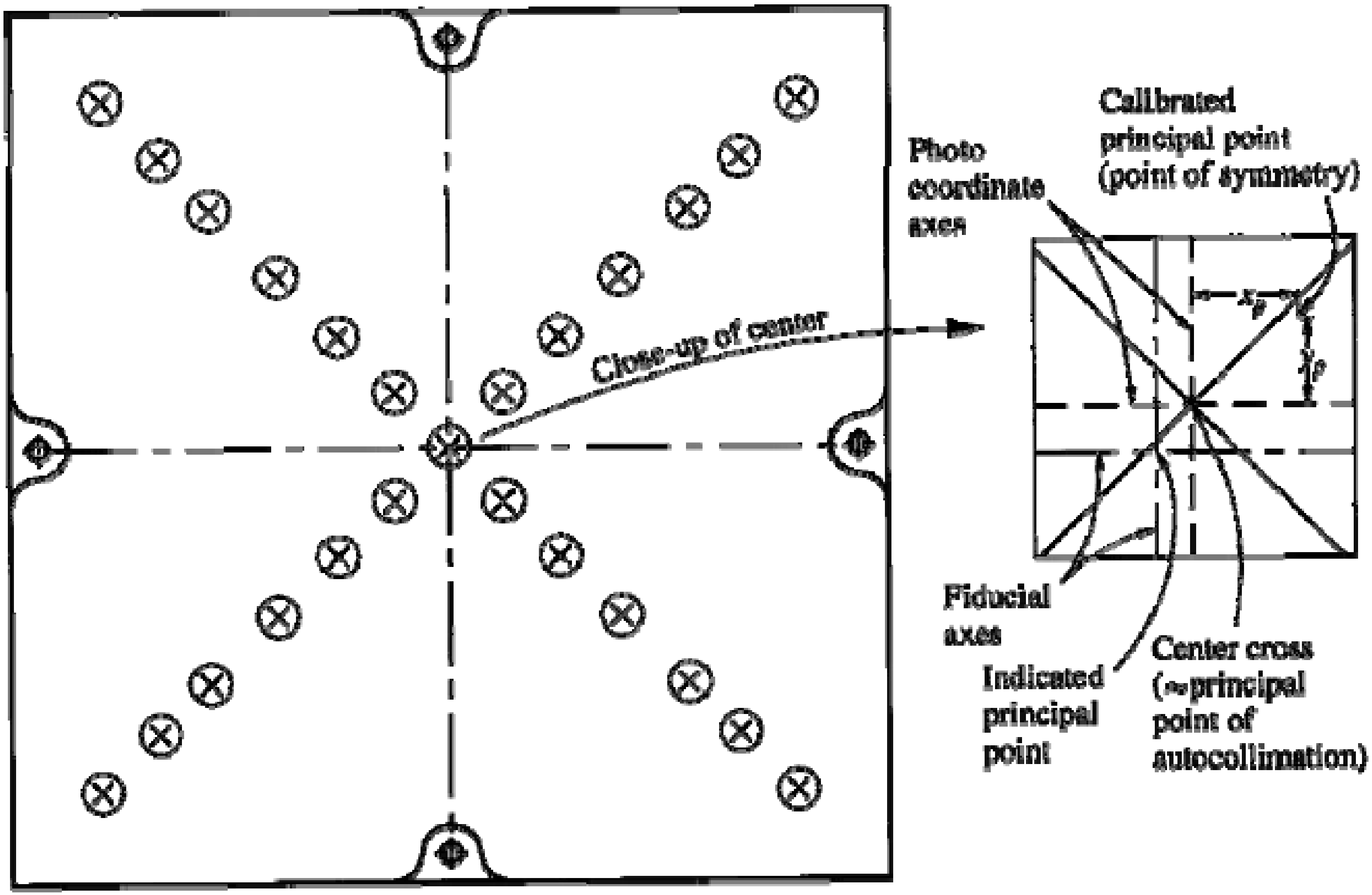


COLLIMATOR METHOD

- Photograph images projected through a number of individual collimators mounted in precisely measured angular array
- Collimator is a lens with a cross mounted on its plane of infinite focus



COLLIMATOR METHOD



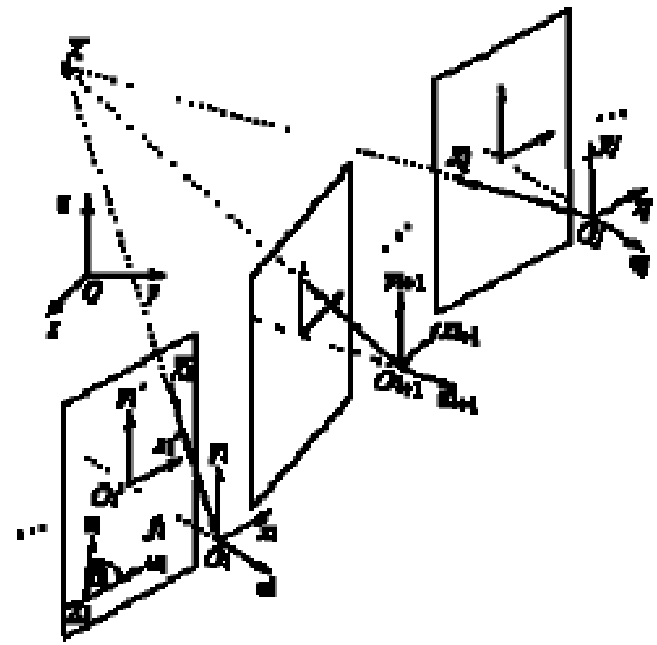
CAMERA CALIBRATION

Simple approach to calibration

- Compute equivalent focal length

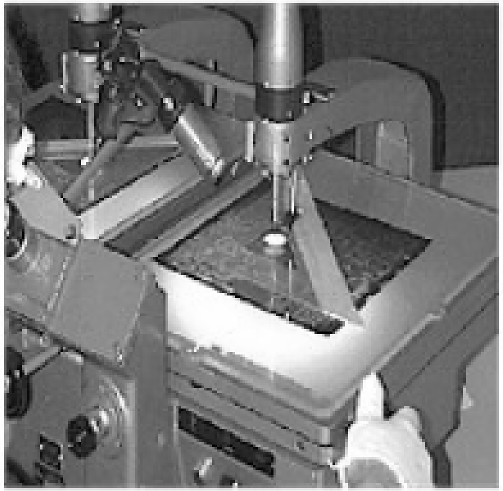
$$\mathrm{EFL} = \frac{s_{7.5^\circ}}{\tan 7.5^\circ}$$

  - s = measured distance from principal point to collimator target
  - α = angle from principal point to collimator target



CAMERA CALIBRATION

- Compute diagonals to the other crosses



$$s'_i = EFL \tan\theta_i$$

  - where i = 15°, 22.5°, 30°, 37.5°, 45°,

- Compute distortions at each point

$$d_i = s_i - s'_i = s_i - EFL \tan\theta_i$$

CAMERA CALIBRATION

- Calibrated focal length one which makes the maximum positive distortion equal to the maximum negative distortion

$$\{s_1 - CFL\tan\theta_1\} + \{s_2 - CFL\tan\theta_2\} = 0$$

$$s_1 + s_2 = CFL\left(\tan\theta_1 + \tan\theta_2\right)$$

$$CFL = \frac{s_1 + s_2}{\tan\theta_1 + \tan\theta_2}$$

CAMERA CALIBRATION

Example: Given the following data from collimator observations

Angular Value (degrees)	Measured Value (mm)
7.5	20.223
15.0	41.177
22.5	63.663
30.0	88.726
37.5	117.866
45.0	153.435

CAMERA CALIBRATION

Solution

$$\text{EFL} = \frac{s_{7.5°}}{\tan 7.5°} = \frac{20.223\,\text{mm}}{\tan 7.5°} = 153.609\,\text{mm}$$

$$d_{15°} = 41.177\,\text{mm} - (153.609\,\text{mm})\tan 15° = +0.018\,\text{mm}$$

$$d_{22.5°} = 63.663\,\text{mm} - (153.609\,\text{mm})\tan 22.5° = +0.036\,\text{mm}$$

$$d_{30°} = 88.726\,\text{mm} - (153.609\,\text{mm})\tan 30° = +0.040\,\text{mm}$$

$$d_{37.5°} = 117.866\,\text{mm} - (153.609\,\text{mm})\tan 37.5° = -0.002\,\text{mm}$$

$$d_{45°} = 153.435\,\text{mm} - (153.609\,\text{mm})\tan 45° = -0.174\,\text{mm}$$

CAMERA CALIBRATION

Solution

$$\text{CFL} = \frac{s_1 + s_2}{\tan\alpha_1 + \tan\alpha_2} = \frac{88.726\,\text{mm} + 153.435\,\text{mm}}{\tan 30^\circ + \tan 45^\circ} = 153.524\,\text{mm}$$

$$d_{7.5^\circ} = 20.223\,\text{mm} - (153.524\,\text{mm})\tan 7.5^\circ = +0.011\,\text{mm}$$

$$d_{15^\circ} = 41.177\,\text{mm} - (153.524\,\text{mm})\tan 15^\circ = +0.040\,\text{mm}$$

$$d_{22.5^\circ} = 63.663\,\text{mm} - (153.524\,\text{mm})\tan 22.5^\circ = +0.071\,\text{mm}$$

$$d_{30^\circ} = 88.726\,\text{mm} - (153.524\,\text{mm})\tan 30^\circ = +0.089\,\text{mm}$$

$$d_{37.5^\circ} = 117.866\,\text{mm} - (153.524\,\text{mm})\tan 37.5^\circ = +0.063\,\text{mm}$$

$$d_{45^\circ} = 153.435\,\text{mm} - (153.524\,\text{mm})\tan 45^\circ = -0.089\,\text{mm}$$

Summary of Interior Orientation

- The main purpose of interior orientation is to define the position of the perspective center and the radial distortion curve. A camera with known interior orientation is called *metric if the orientation elements do not change*.

- An amateur camera, for example, is non-metric because the interior orientation changes every time the camera is focused. Also, it lacks a reference system for determining the PPA *(Principle Point of Autocollimation*

- Modern aerial cameras are virtually distortion free. A good approximation for the interior orientation is to assume that the perspective center is at a distance *c from the* fiducial center.

- The elements of interior orientation are thus:

1. The calibrated focal length f,
2. The coordinates of the principle point,
3. The appropriate distortion curves