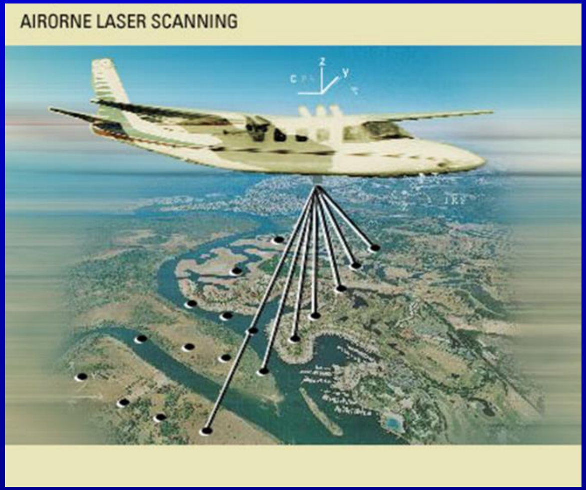
Photogrammetry



Photogrammetry SE 321

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- Surveying Engineering Program

- Introduction-Measurement on Single Photos-Stereo Viewing and Parallax

Photogrammetry SE 321

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- E-mail: ismat@ksu.edu.sa
- Textbook: Wolf, Dewitt & Wilkinson. 2014. “Elements of Photogrammetry with Applications in GIS”, 4th edition
- Evaluation:
- Two tests: 2x15 = 30
- Tutorials, HWs and Lab = 30
- Final Exam = 40

Course Objective and Learning Outcomes

- At the end of the course student will be able to:
- - Extract surveying information from single aerial photos;
- - Extract surveying information from stereo aerial photos;
- - Design aerial survey project

Course Contents

- Definition, Types and Importance of Photogrammetry
- Image Acquisition (Cameras)
- Survey Data from Measurements on Single (Vertical and Tilted) Aerial Photograph
- Stereo Viewing and Extraction of survey data from stereo photographs
- Stereo Plotters: Components, Types, Orientation and operation to provide survey data
- Flight planning

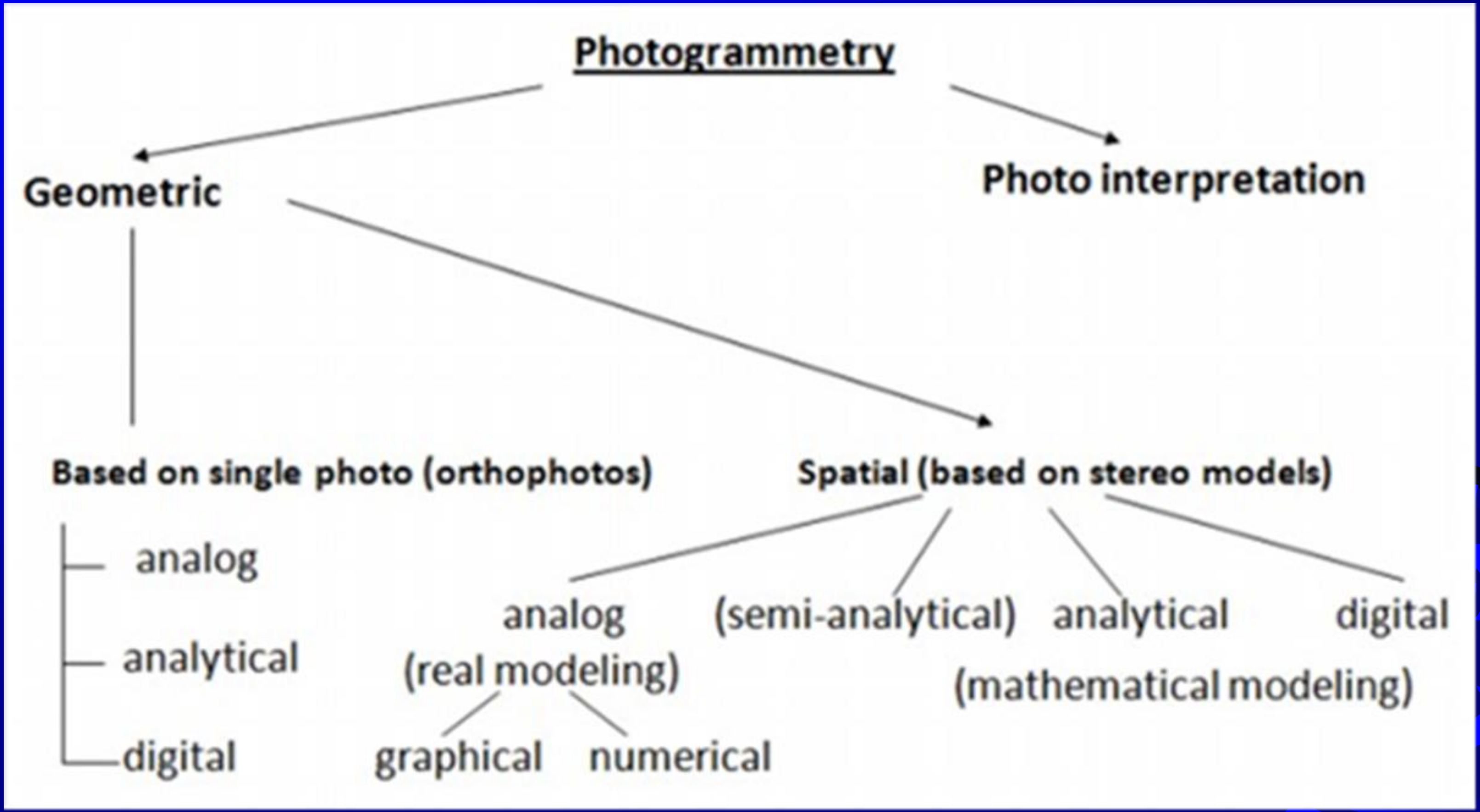
Introduction

- Photogrammetry is the science, art, and technology of obtaining reliable information from photographs.
- Two major areas: metric, and interpretative.
- Terrestrial, aerial and Space Photogrammetry.
- Uses of Photogrammetry: survey data (distances, angles, elevations), topographic mapping, determine precise point coordinates, cross sections, deflection monitoring, and many other engineering applications.

- Types of Photogrammetry:

Types of Photogrammetry

- The following chart summarize types of photogrammetry:



Advantages of Photogrammetry

- Some advantages of photogrammetry over conventional surveying and mapping methods are:
- It provides a permanent photographic record of conditions that existed at the time the aerial photographs were taken.
- Since this record has metric characteristics, it is not only a pictorial record but also an accurate measurable record.
- If information has to be re-surveyed or re-evaluated, it is not necessary to perform expensive field work. The same photographs can be measured again and new information can be compiled easily. Continue:

Advantages of Photogrammetry

- It can provide a large mapped area more efficiently and economically than other conventional methods.
- It provides a broad detailed view of the project area, identifying both topographic and cultural features.
- It can be used in locations that are difficult, unsafe, or impossible to access,
- Road surveys can be done without closing lanes, disturbing traffic. Once a road is photographed, measurement of road features, including elevation data, is done in the office, not in the field. This applies for all construction projects.

Disadvantages of Photogrammetry

- **Disadvantages:**
- 1. Seasonal conditions, including weather, vegetation, and shadows can affect both the taking of photographs and the resulting measurement quality.
- 2. Overall accuracy depends on camera quality and flying height (photo scale).
- 3. Identification of planimetric features can be difficult or impossible (*e.g.* type of curb, size of culverts, type of fences, and information on signs).
- 4. Underground utilities cannot be located, measured, or identified.
- 5. Features under clouds and bridges are affected.

Image Acquisition

- Image can be acquired using cameras.
- Classification of cameras:
- According to platform: Terrestrial, Aerial and Space.
- According to function: Metric for measurements and Reconnaissance (non-metric) for interpretation.
- According to design: Optical, film (single or multi-lens) and Digital.
- Aerial Metric cameras are mostly used for survey data production.

Aerial Cameras

- For precise results, cameras must be geometrically stable, fast, have efficient shutters, sharp lenses
- Single-lens frame cameras: figure 27-2
  - most used format size is 23cm, focal length 150mm
  - components: lens, shutter, diaphragm, filter, focal plane, fiducial marks.
  - shutters can be operated manually or automatically.
  - The camera could be leveled regardless of the plane orientation (vertical optical axis).
  - Exposure station and principal point.
  - Camera calibration.

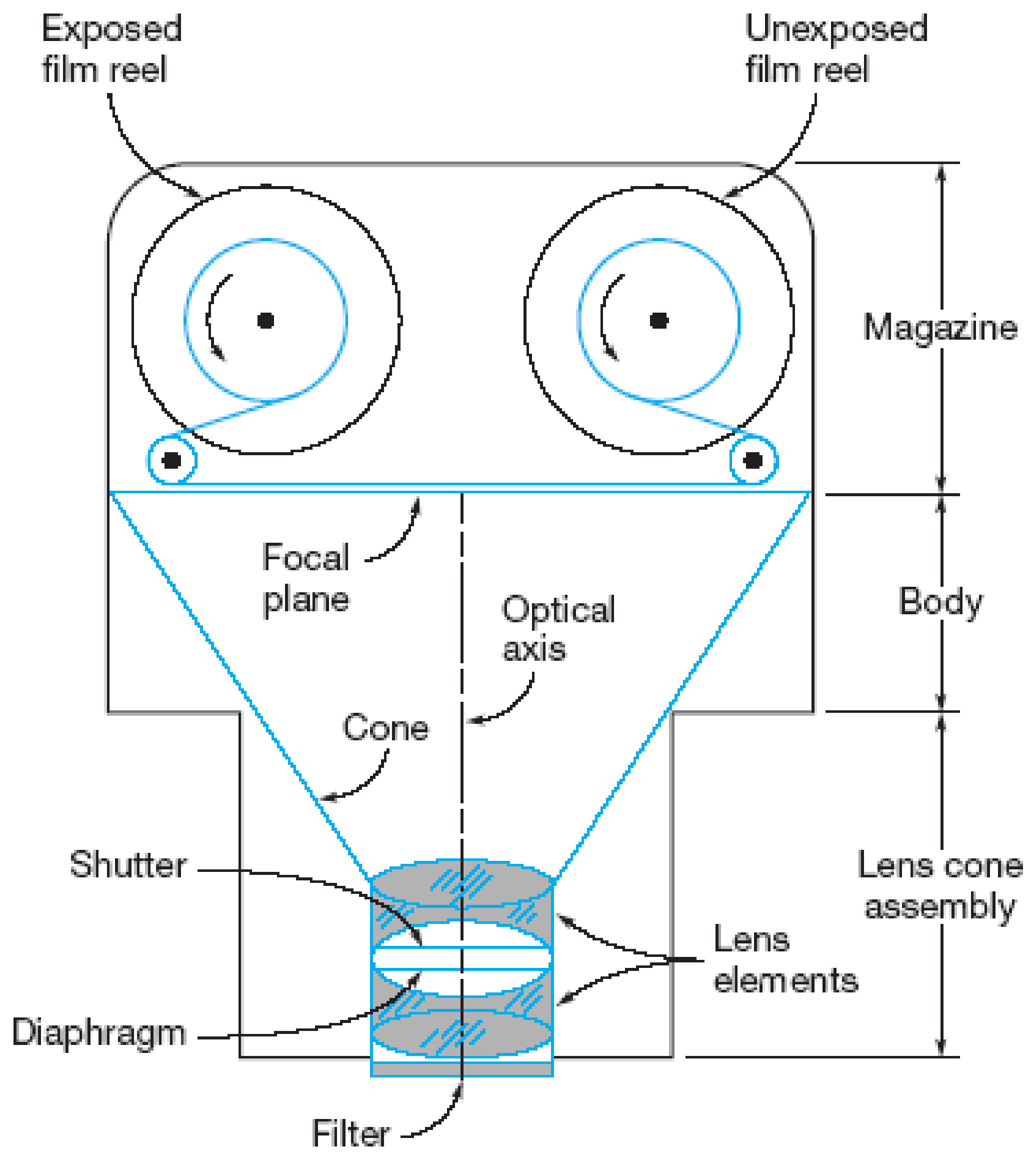


Figure 27–2 Principal components of a single lens frame aerial camera.

Aerial Photographs

- Aerial Photographs can be classified according to optical axis attitude:
- - True Vertical: if the camera axis is exactly vertical, (normal to horizontal) or near vertical.
- - Tilted Photographs, if optical axis is tilted to vertical within 3degrees.
- - Oblique photographs: high where horizon appears on photo and low oblique (horizon does not appear)
- Vertical or near Vertical Photos are the most used type for surveying applications

Figure 27–4 Vertical aerial photograph. (Courtesy Pennsylvania Department of Transportation.)

Figure 27–5 Low oblique aerial photograph showing state capital and downtown Madison, Wisconsin. (Courtesy State of Wisconsin, Department of Transportation.)

High Oblique Photo

- Horizon appears on photo

Color Vertical Aerial Photo
See Fiducial Marks (side and corner)

Geometry of Vertical Photographs

- Definitions:
- **Principal point:** geometric center of photo, which can be located by joining opposite Fiducial Marks.
- **Exposure station**: position of lens center at time of exposure
- **Principal distance** (focal length: f or c): distance from lens center to principal point
- Image (photo) coordinate system (right handed), principal point, exposure station as origin, x-axis along flight line, y-axis perpendicular to x-axis
- Measurements could be done on negative or positive, same geometry.

Negative and Positive Film

- Film received from flight is **negative**. After processing and contact prints it is provided as **positive** where measurement will be done (They are geometrically identical):

Negative Film

Positive Film

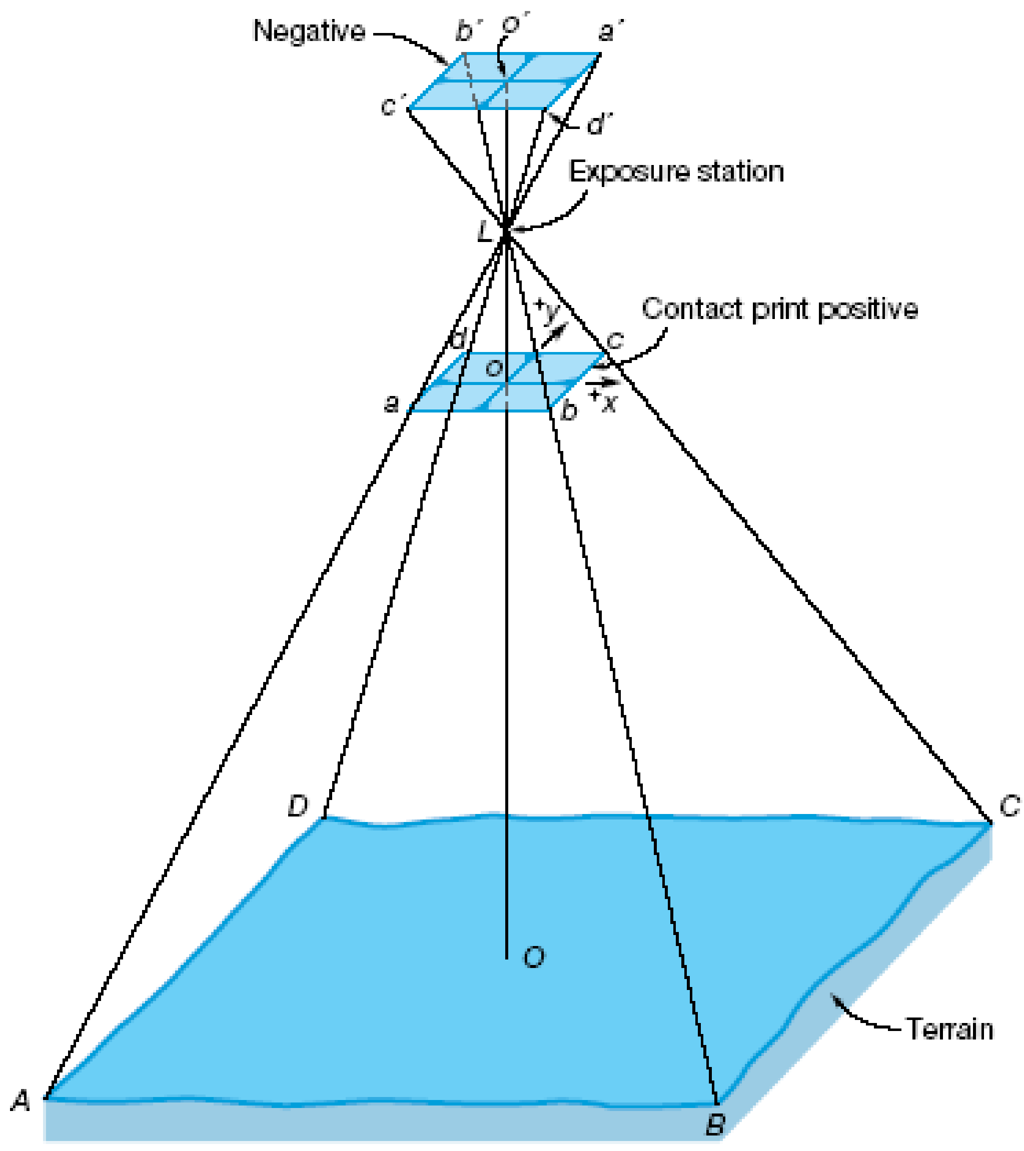


Figure 27–6 Geometry of a vertical aerial photograph.

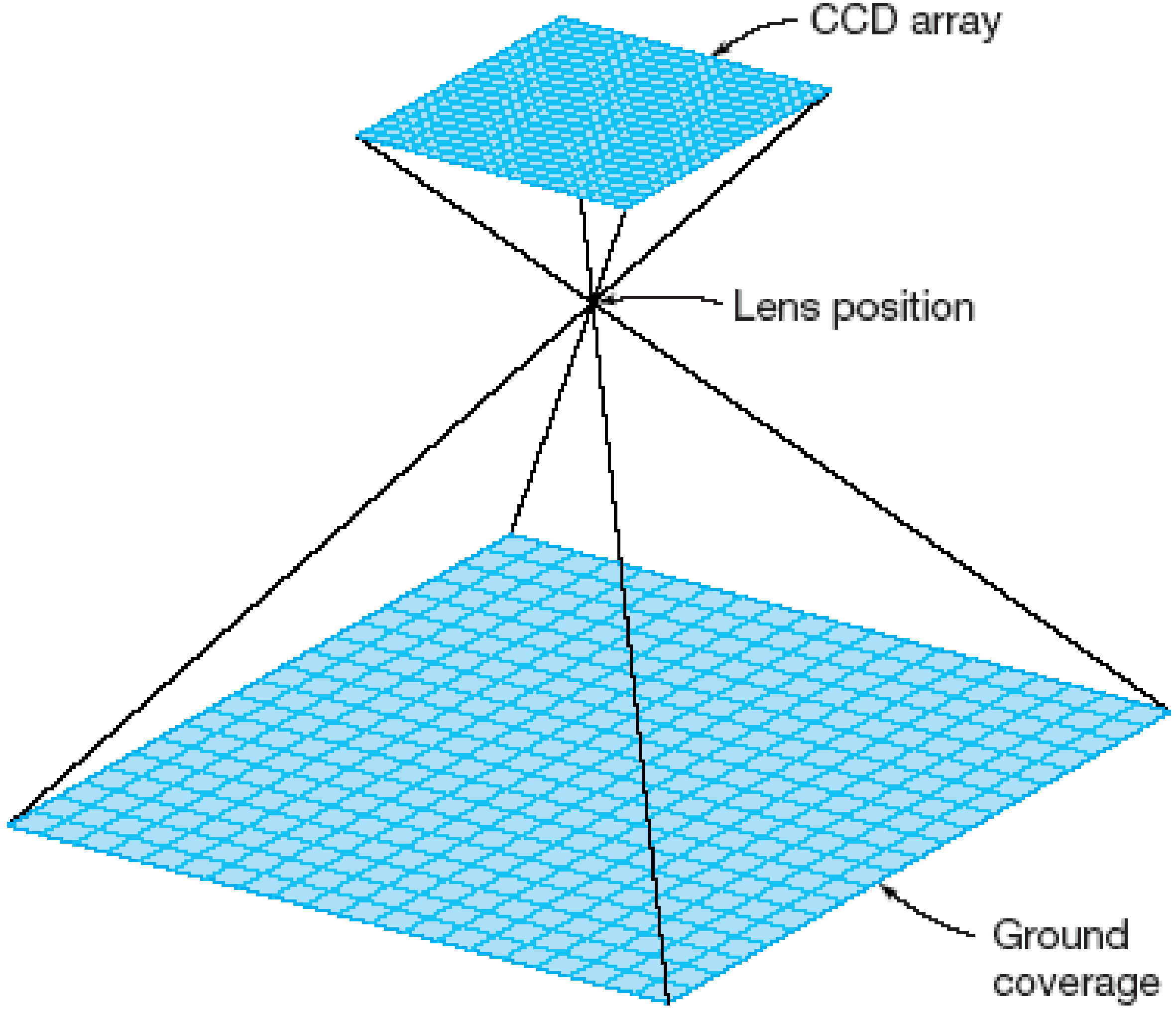


Figure 27–3 Geometry of a digital frame camera. (From *Elements of Photogrammetry, With Applications in GIS*, 3rd Ed., Wolf & Dewitt, 2000; Courtesy McGraw-Hill Book Co., Inc.)

Scale of a Vertical Photograph

- Figure 27-7
- Scale of a photograph is the ratio of a distance on a photo to the same distance on the ground.
- Geometrically it is the focal length/flying height = f/H
- For a point of level h above sea level:
- Scale (s) at the point: f / (H – h)

•Average scale of a photograph: $S_{avg} = \dfrac{f}{H - h_{avg}}$

If the f, H, and h are not available, but a map is available then:

$$\text{Photo Scale} = \frac{\text{photo distance}}{\text{map distance}} \times \text{map scale}$$

Example

- If a 1 km stretch of highway covers 4 cm on an air photo, the scale is calculated as follows:

$$\frac{\text{PHOTO DISTANCE}}{\text{GROUND DISTANCE}} = \frac{4\text{ cm}}{1\text{ km}} = \frac{4\text{ cm}}{100\,000\text{ cm}} = \frac{1}{25\,000} \qquad \text{SCALE: } 1/25\,000$$

- If vertical photo scale is 1:20000 and image distance ab = 3 cm, Ground distance AB = 3/(1/20000) = 3cm x 20000 = 600m
- If ground distance AB = 400m and photo scale is 1:5000, image distance ab=400mx(1/5000)=8cm

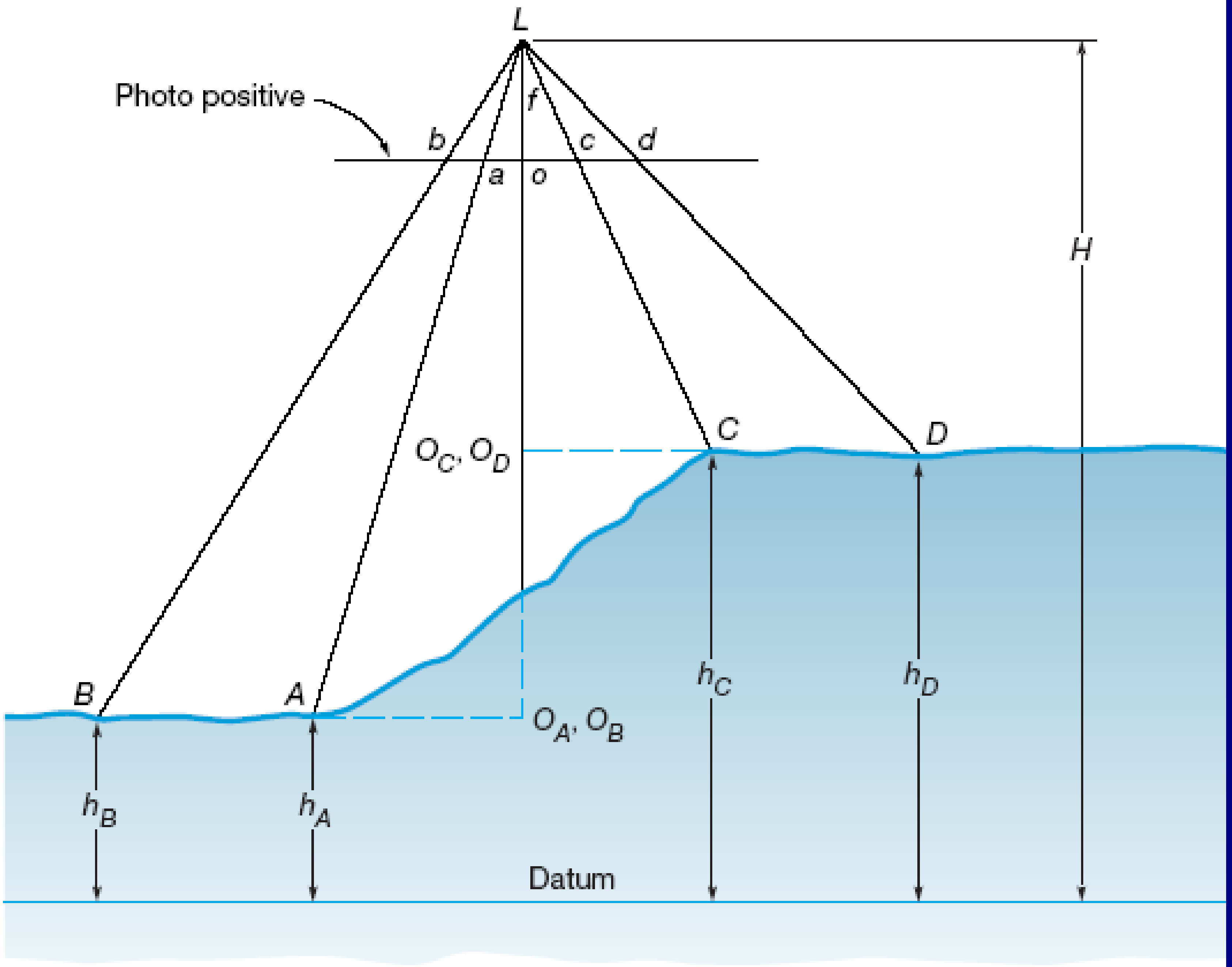


Figure 27–7 Scale of a vertical photograph.

Undulating Ground

- For undulating ground with points of different elevations above datum (Fig. 27-7)
  - Scale at each point will be different:
  - Scales at a and b will be:
- Scale at a = S_A = $f/(H- h_A)$
- Scale at b = S_B = $f/(H- h_B)$
  - If given elevations of A, B, C and D, average ground elevation above datum will be
- $\mathbf{h_{av} = (h_A + h_B + h_C + h_D) / 4}$
- Average photo scale = $f/(H- h_{av})$
- Approximate distance AB = $\mathbf{ab \times (H- h_{av}) / f}$

Photo Coordinates System

- x-axis along flight line, y-axis perpendicular to it at principal point (ppt.) origin of the system and located by joining opposite **fiducial marks**.

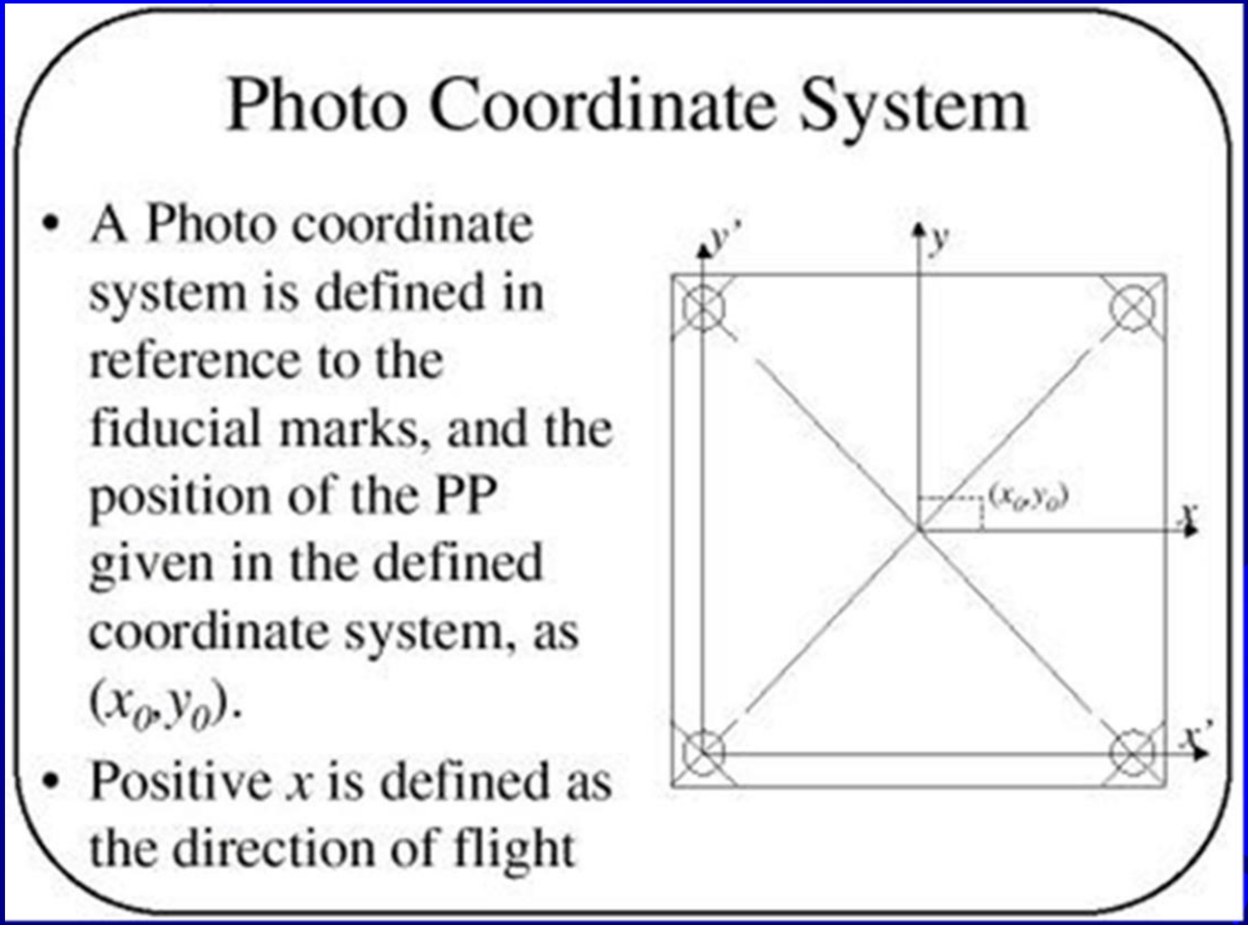
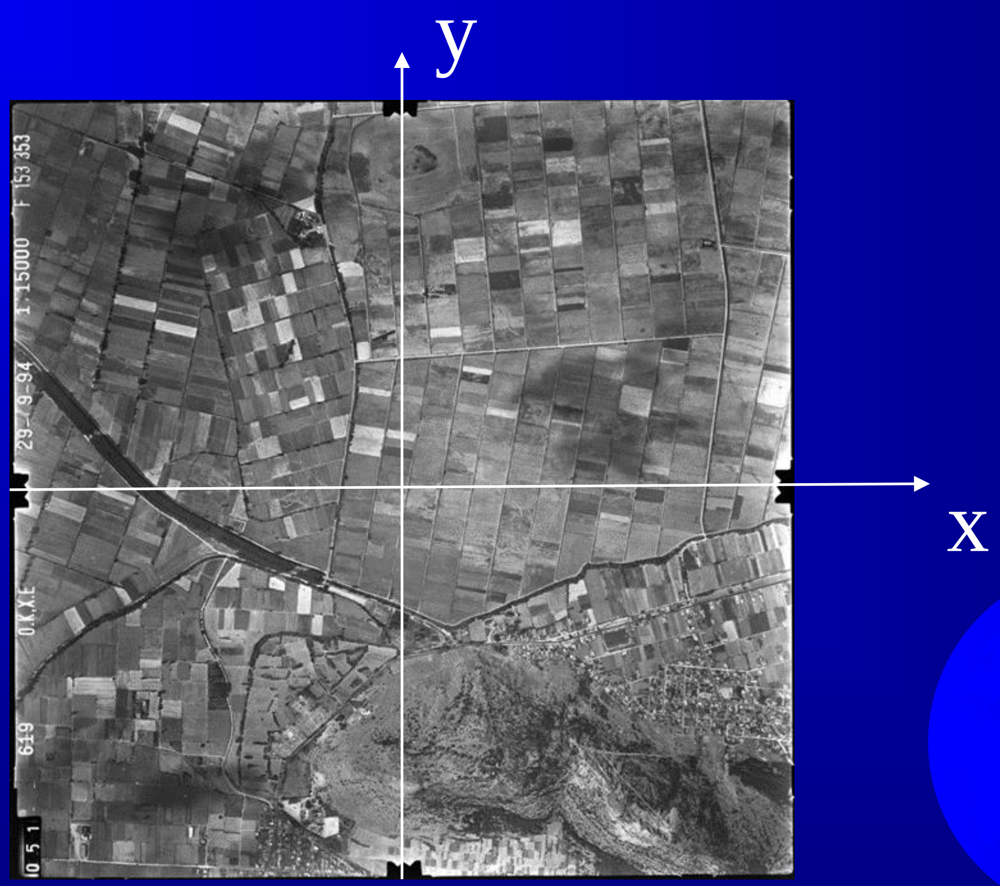


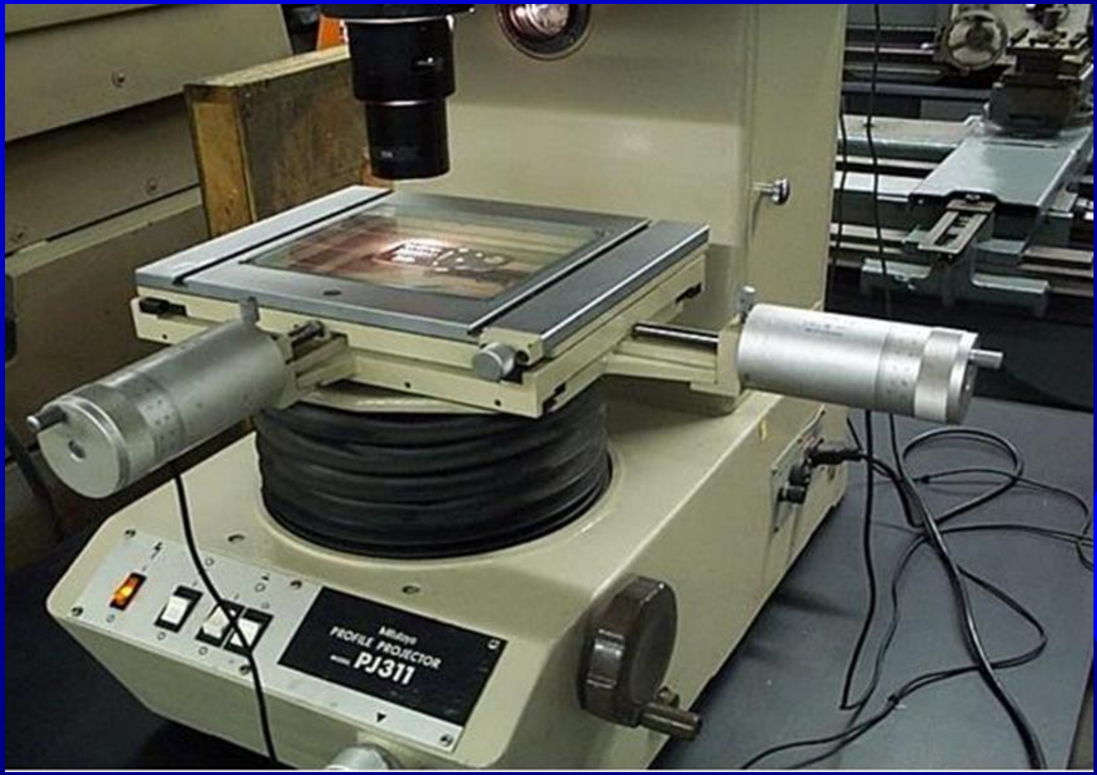
Photo coordinates measurement

- This can be done manually or indirectly by measurement of coordinates on a mono comparator.



Mono comparator

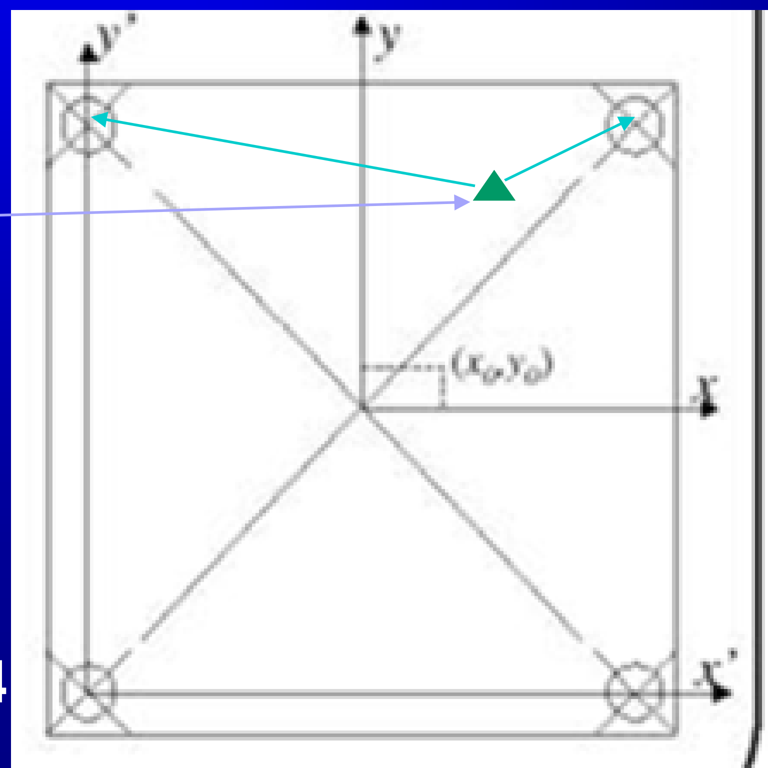
- Coordinates of ppt. and of other image points are measured on mono comparator coordinates and then reduced to ppt. as origin, a flat plate with flat glass, optical projector, hand wheels and coordinate system.



Indirect Measurement of Photo coordinates

- Another method is to measure distances from image point to two of the **fiducial marks whose coordinates are given** in calibration and use intersection method to calculate position of image point.

- F1
- a
- Measure a-F1
- and a-F2
- Compute
- F1-F2 from
- Compute **a** **F4**
- Coordinates!



F2

F3

Example

- Coordinates of fiducial points F1 and F2 as measured on the photo coordinate system are: F1(-110.015; 110.002)mm and F2(110.005; 110.006)mm. Measured distances F1-a = 130.000mm and F2-a = 60.000mm. Compute coordinates of image point a:
- Solution steps:
- From given coordinates of F1 and F2 compute distance F1-F2; In Δ F1-F2-a compute angles of the triangle using cosine rule first. Using coordinates of F1 and F2 and angles a-F1-F2 and F1-F2-a use intersection method to calculate coordinates of point a.

Ground Coordinates from a Single Aerial Vertical Photograph

- Figure 27-8
- With phot coordinate system defined, we define an arbitrary ground coordinate system.
- That ground system could be used to compute distances and azimuths. Coordinates can also be transformed to any system
- In that ground system: Scale at a = $S_A = f/(H - h_A)$

$X_A = x_a$ * (photograph scale at a)

$Y_A = y_a$ * (photograph scale at a)

Horizontal Ground Distance **AB** =

$$[(X_A - X_B)^2 + (Y_A - Y_B)^2]^{1/2}$$

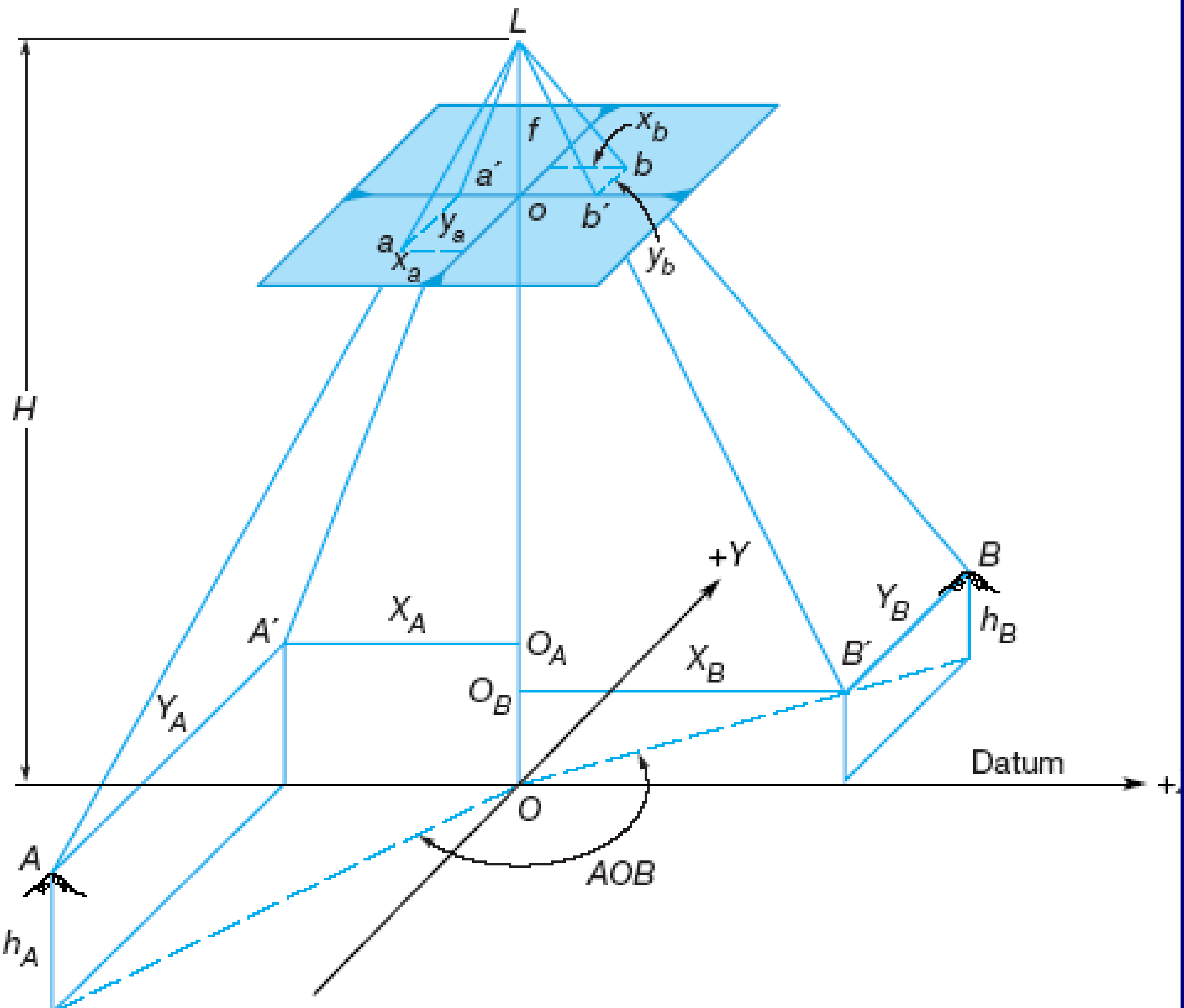


Figure 27–8 Ground coordinates from a vertical photograph.

Flying Height of Vertical Photo

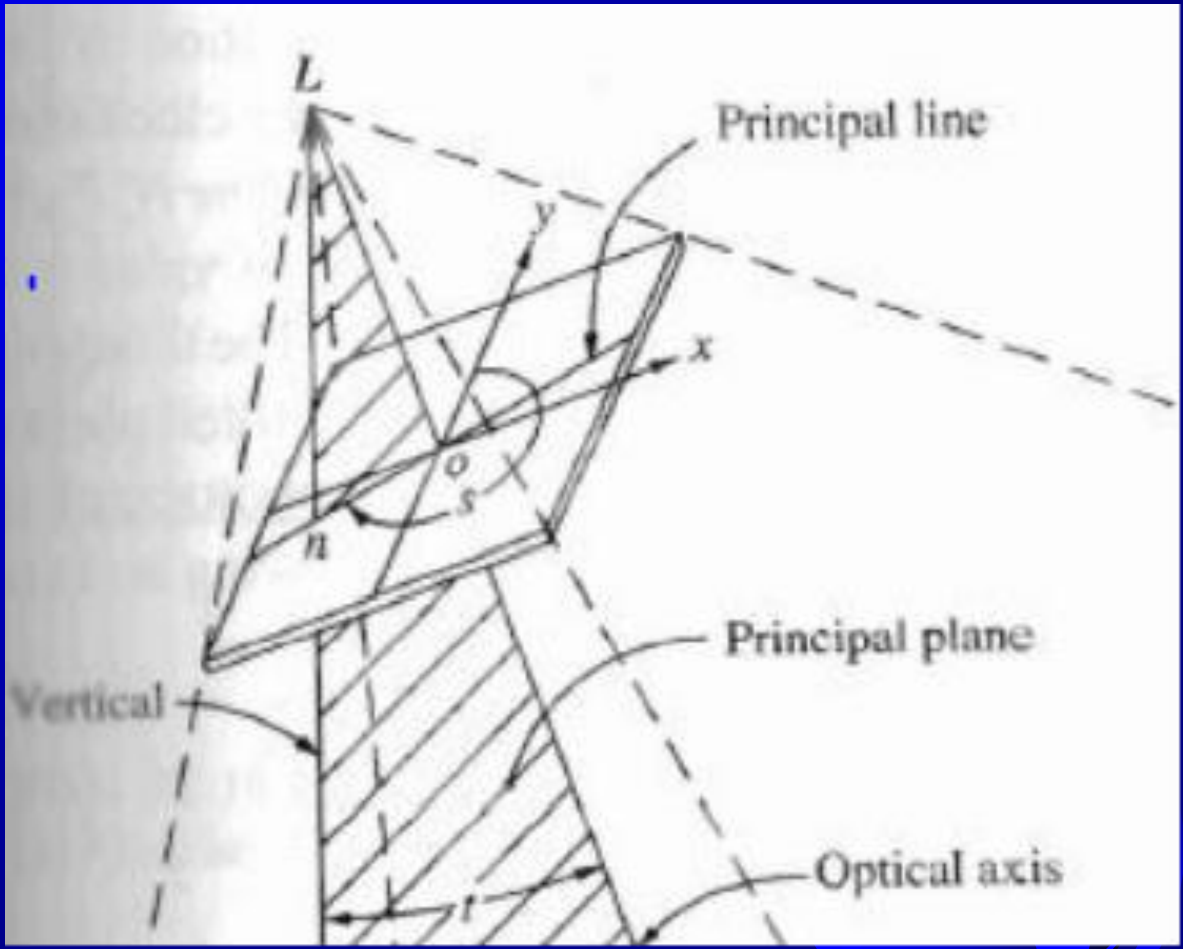
- Flying height (H) can be determined by:
  - Direct readings on the photo
  - Applying scale equation, if scale could be computed
    - Example: what is the flying height above datum if f=150mm, average elevation of ground is 600m, scale is 1:4000?
    - Or, if two control points of ground distance, L appear in the photograph, solve the equation: $L^2 = (X_B - X_A)^2 + (Y_B - Y_A)^2$

replacing the ground coordinates with the photo coordinates: $X_A = x_a$ * **(photograph scale at a)**

where photo scale at a $= f/(H - h_A)$

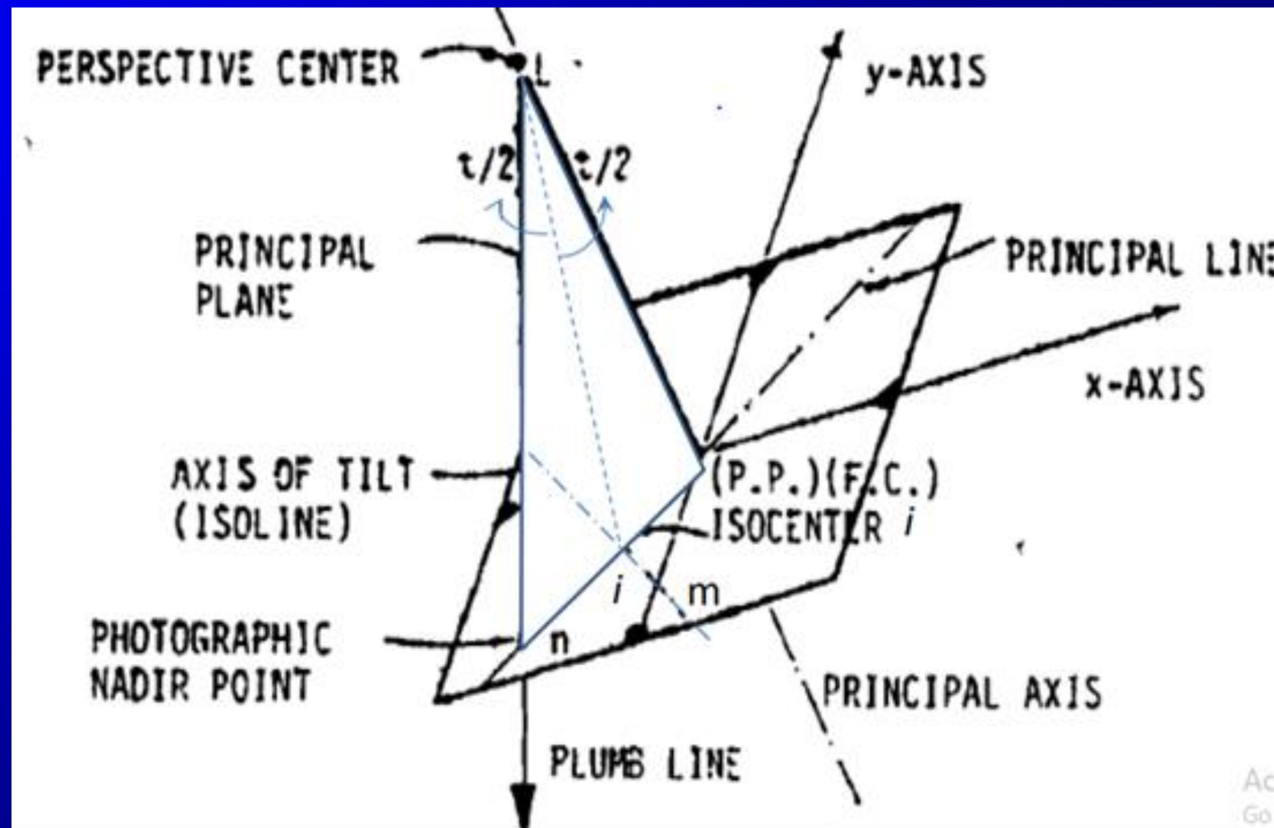
Tilted Aerial Photos

- Camera axis cannot always be vertical. An angle from the vertical is called tilt angle.
- Nadir point, **n**
- is intersection
- of vertical and
- Photo plane;
- Principal Line is
- line joining **n**
- with principal
- point O or P;
- Tilt angle, **t** is
- Angle between
- Vertical and optical axis



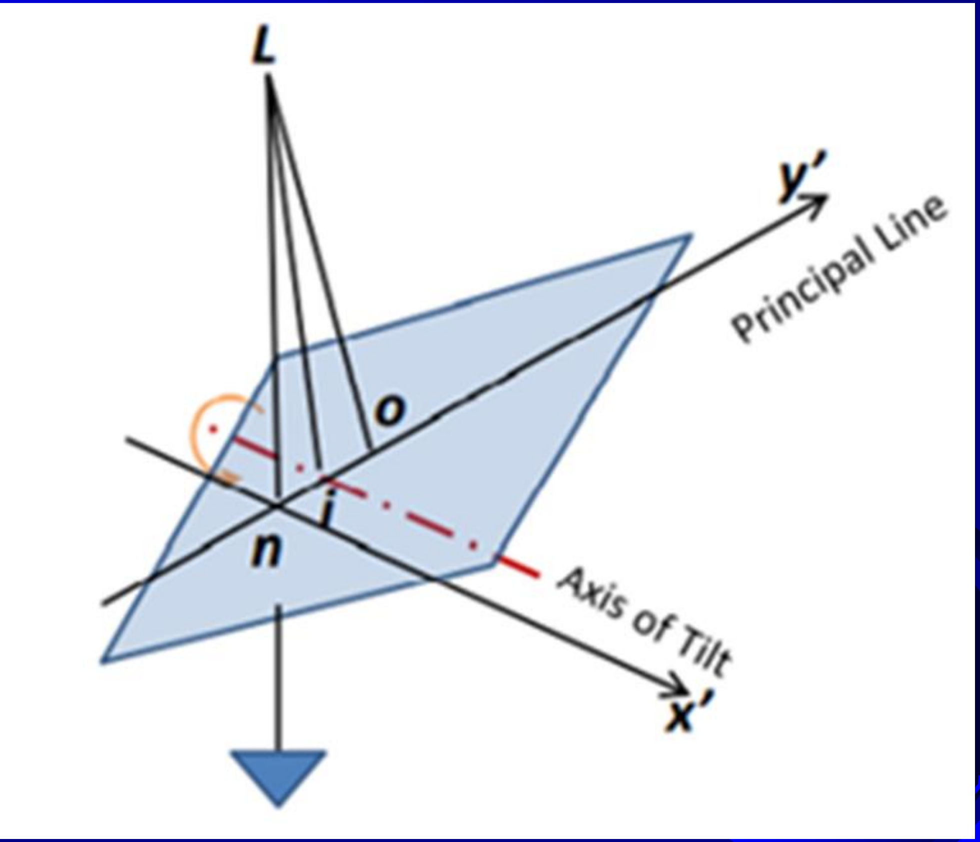
Tilted Aerial Photo

- Definition:
- Isocenter, **i**
- on bisector
- of tilt angle
- and principal
- Line; n, i and
- P are on
- Principal
- line



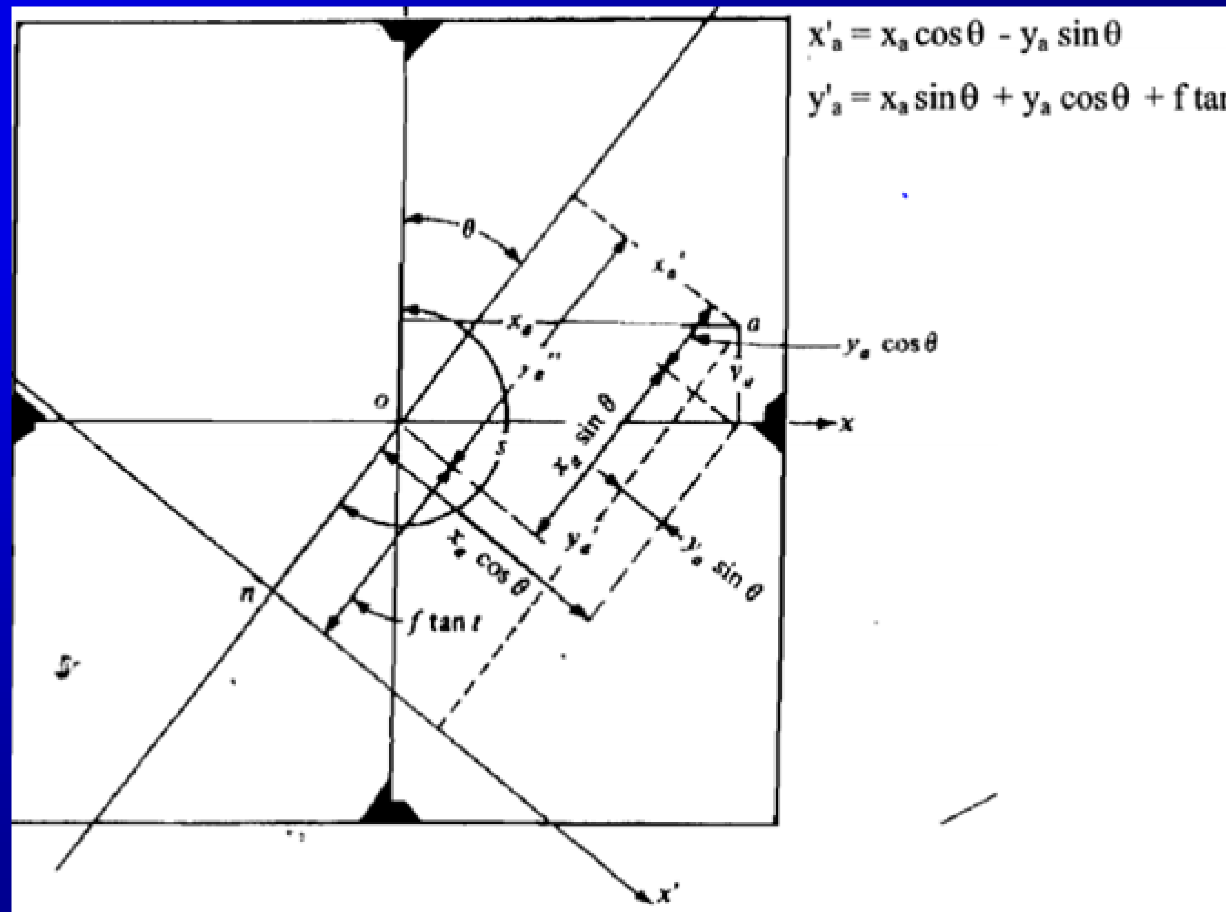
Coordinates system of tilted photo

- Nadir point, n is the origin of the system;
- Y’ axis along the principal line;
- X’ perpendicular
- to y’ at n.
- The tilt of photo
- is around the axis
- of tilt along the
- Principal line



Tilted Aerial Photo

- Coordinates on tilted photo in relation with vertical photo:
- y'-axis along
- Principal line
- n is the origin
- t = tilt angle
- Θ = Azimuth
- or swing
- Angle measured
- Clockwise from
- y-axis to principal line, on (Pn)

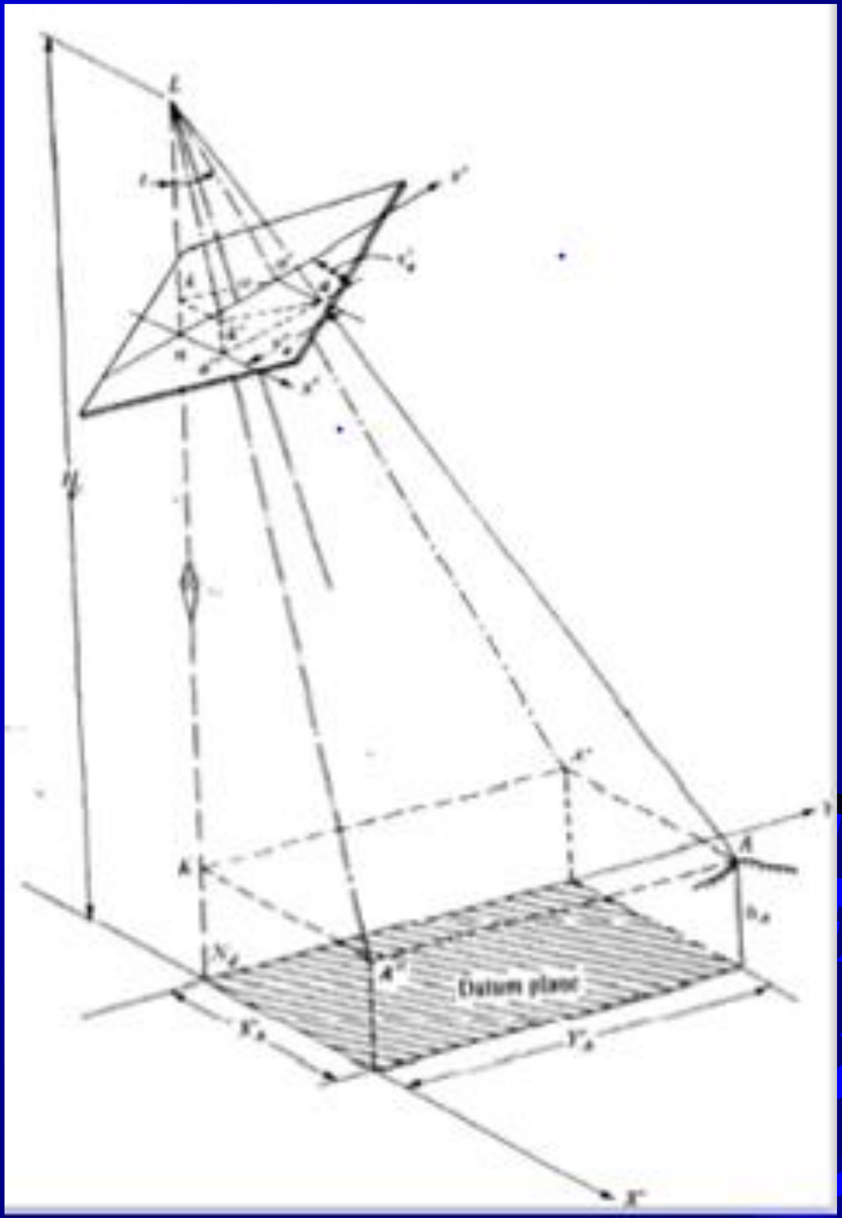


Tilted Photo Coordinates

- Relation between vertical photo system and tilted photo system.
- Rotate vertical system an angle Θ c.w. and shift origin from ppt. to nadir point, n.
- Tilted photo coordinates for any point are:
- $x' = x \cos \Theta - y \sin \Theta$
- $y' = x \sin \Theta + y \cos \Theta + f \tan t$

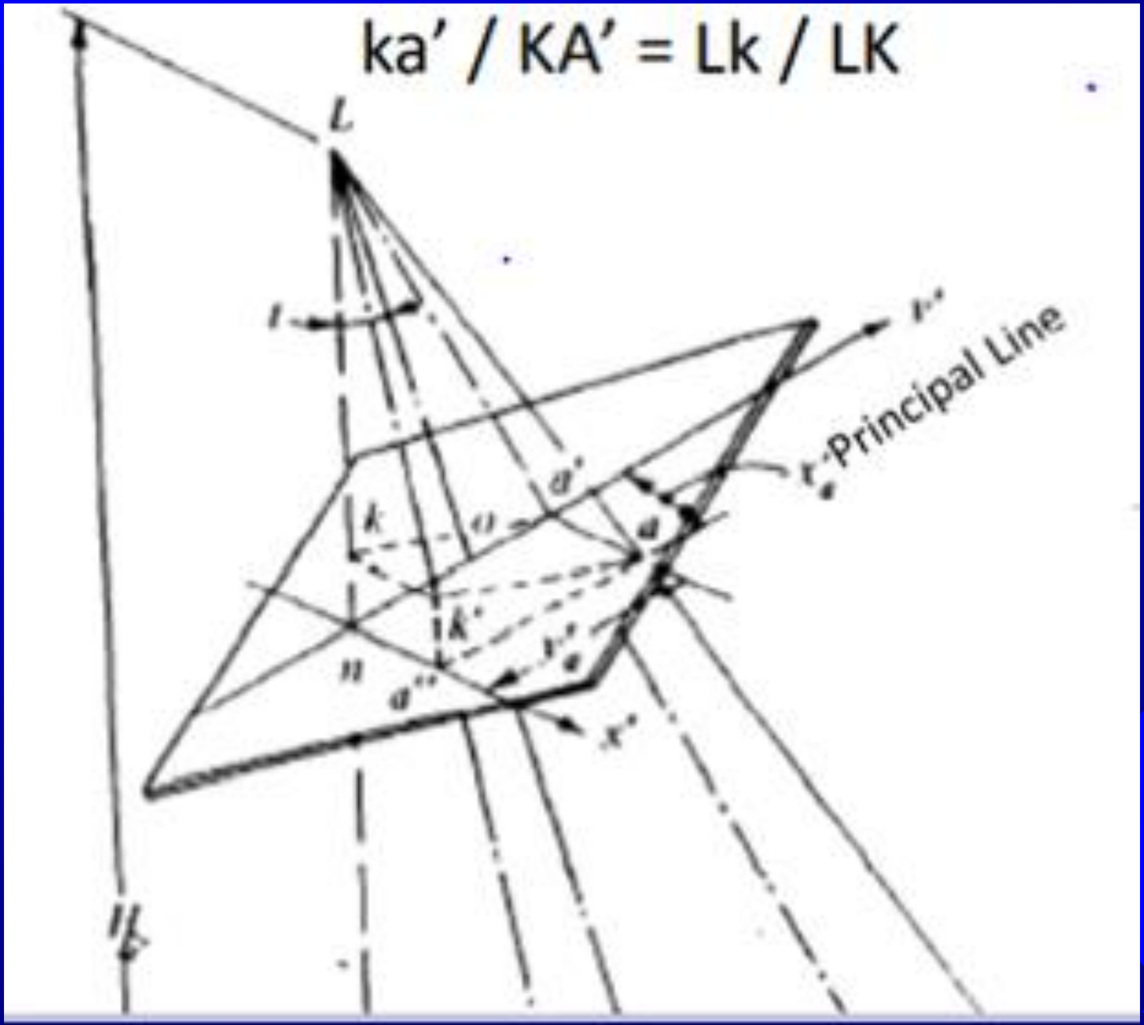
Tilted Aerial Photo Scale

- Tilted photo scale =
- Horizontal distance
- On photo / horizontal
- Distance on ground =
- Ka’ / KA’ = Lk / LK



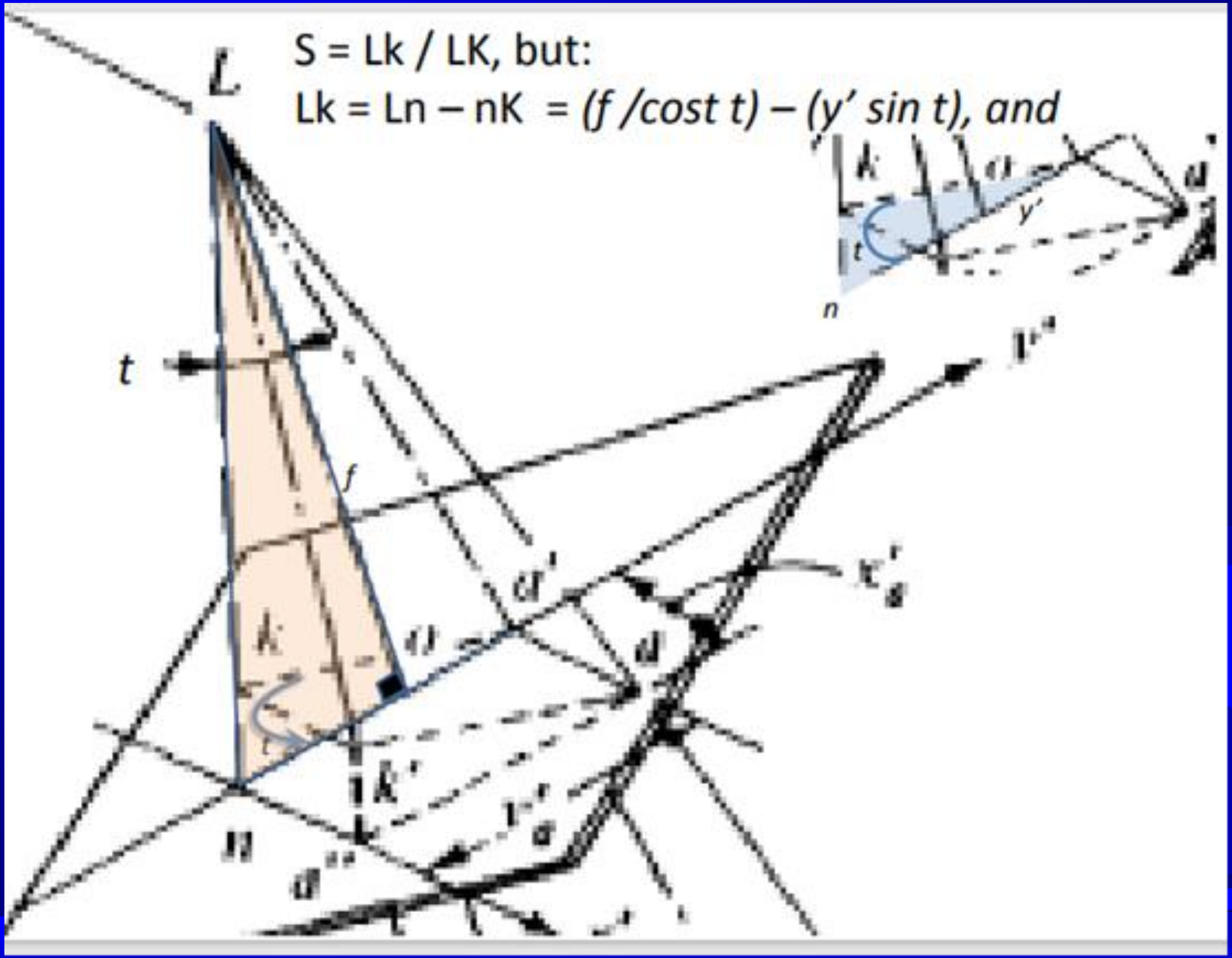
Tilted Aerial Photo Scale

- Scale of tilted aerial photo = Lk/LK;



Tilted Aerial Photo Scale

- Lk=Ln – nk; Ln = f / cos t; nk = y' sint;
- Hence, Lk=f/cos t – y' sin t; LK=H – h
    - **Scale = [f/cos t – y' sin t] / (H – h)**



Tilted Photo Scale

- Example:

- A 3^{o} tilted aerial photo is exposed with a camera of 150mm focal length from a flying altitude 3000m above MSL. Swing angle of photo is 218^{o}.
- Point A with elevation 600m above MSL has image coordinates: -60.00mm and 80.00mm, compute the scale of the photo at point a.

Ground Coordinates from Tilted photo

- X Ground Coordinate

Ground Coordinates from a tilted photograph

- Coordinates of point A in a ground coordinate system X’, Y’ where:
- X’, Y’ are parallel to *x’* and *y’* (auxiliary system)
- Ground Nadir N is the origin of the ground system
- Note that in the auxiliary coordinate system, lines parallel to *x’* are horizontal, thus *x’* on the photo is horizontal and directly related to ground X by the scale, or

$$X'_A = x' / S_A$$

Ground Coordinates from Tilted Photo

Y Ground Coordinate

- But in the auxiliary system, y’ is in the direction of maximum tilt and not horizontal, the scale is ratio between horizontal projections.
- Ka: Horizontal projection of y’ = $y' \cos t$
- Then,
- $Y' = y' \cos t / S$

Tilted Photo and Ground Coordinates

Example

- An aerial tilted photo of 150mm focal length and 3000m flying height above MSL has tilt angle 3^{o} and swing angle 218^{o}. Point A has elevation of 600m above MSL and image coordinates -60mm and 80.00mm in x and y respectively.
- Another ground point Q has photo coordinates 75mm and 40mm in x and y respectively and ground elevation 620m above MSL.
- Compute ground distance AQ.

Relief Displacement on a Vertical Photograph

- Figure 27-9
- The shift of an image from its theoretical datum location caused by the object's relief. Two points on a vertical line will appear as one line on a map, but two points, usually, on a photograph.
- In a vertical photo, the displacement is from the principal point.
- Relief displacement (d) of a point wrt a point on the datum :

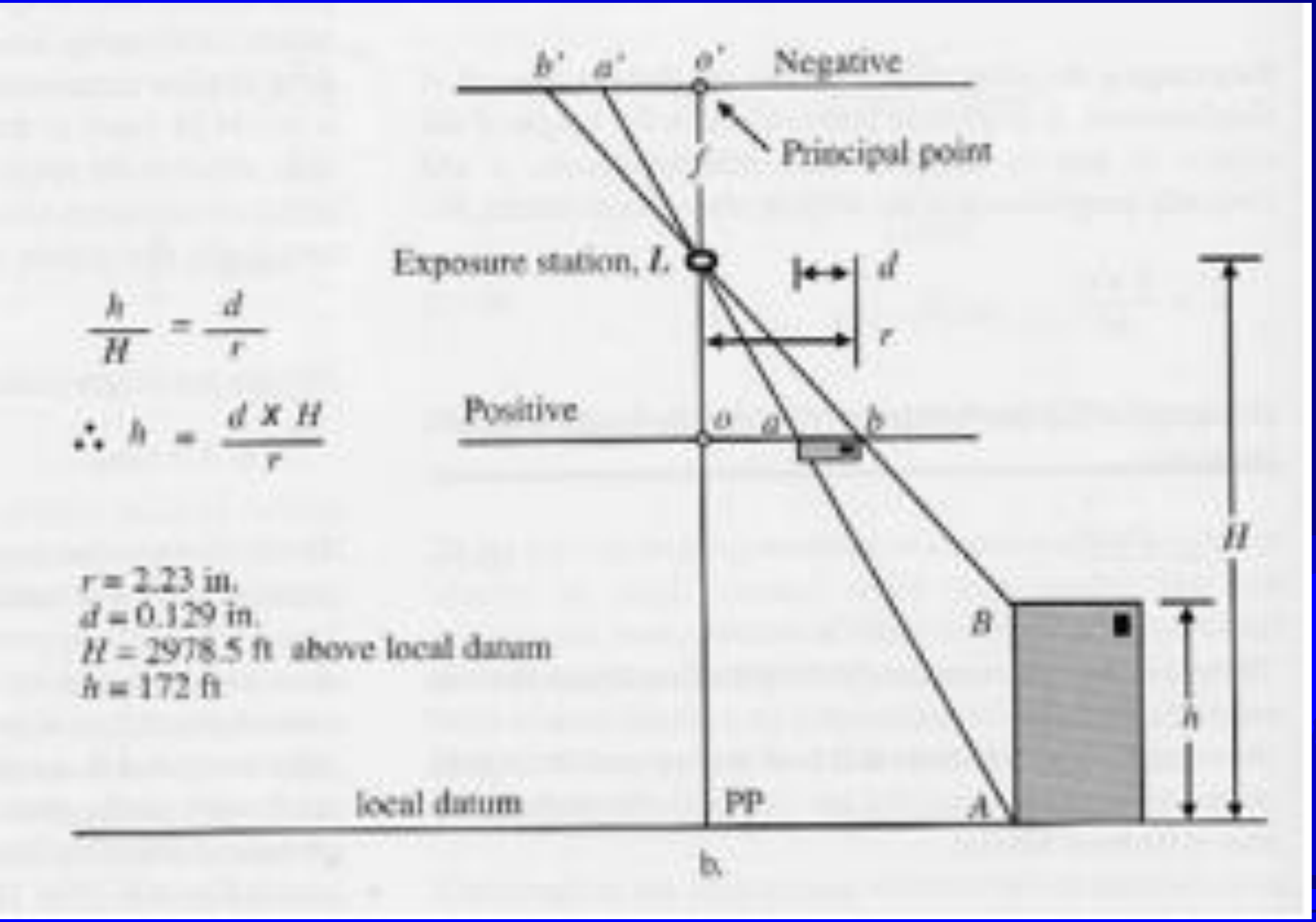
$$d = \frac{r\,h}{H}$$

where: r is the radial distance on the photo to the high point
h : elevation of the high point, and H is flying height above datum

•Assuming that the datum is at the bottom of vertical object, H is the flying height above ground, the value h will compute the object height.

Relief Displacement

- RD caused by change in ground height
- Object height, h = dr x H / r (r is image distance from p.p. to image of top of object (image of B)



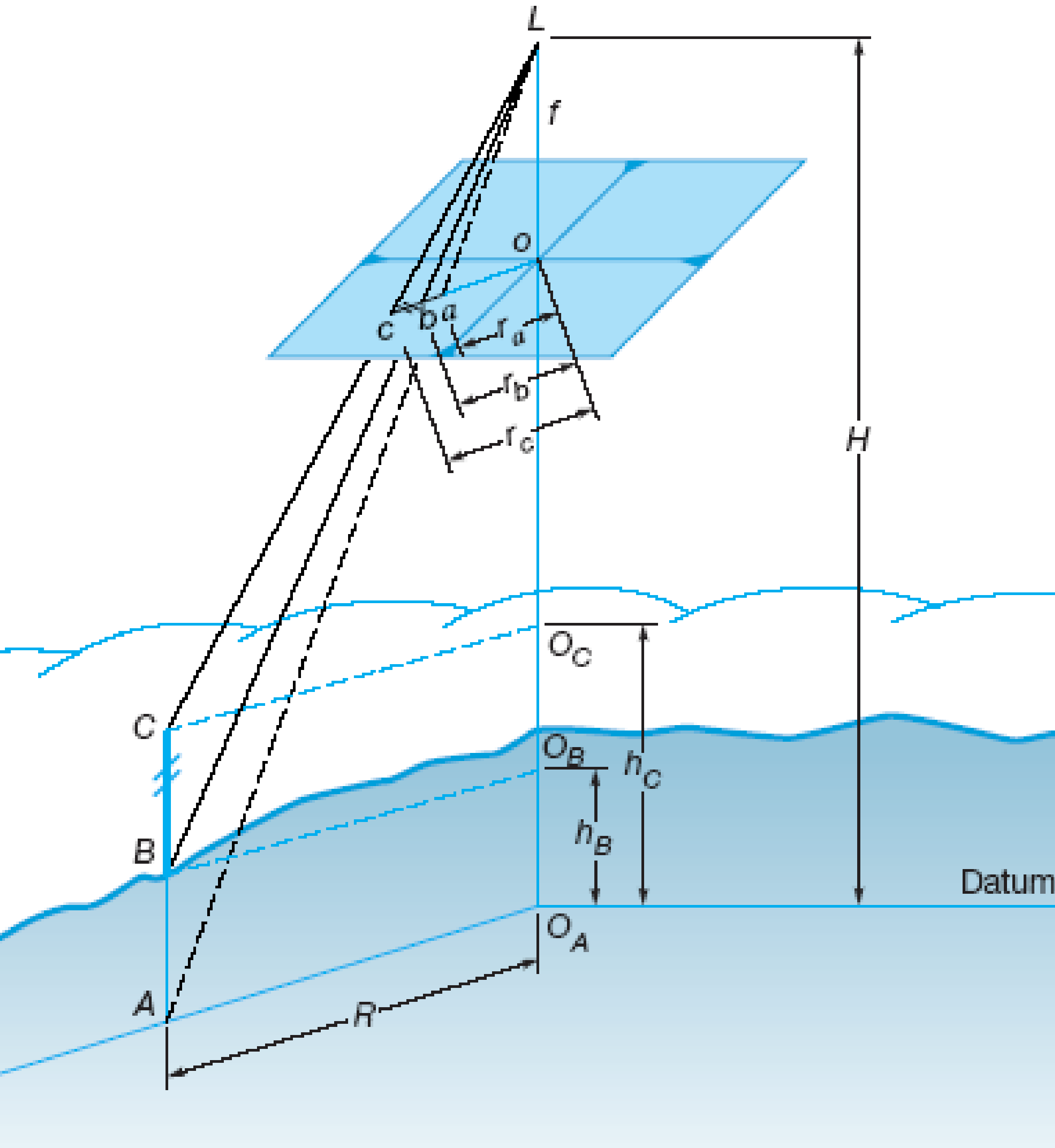


Figure 27–9 Relief displacement on a vertical photograph.

$r_a/R = f/H$

Or: $r_a * H = R * f$ ----(1)

$r_b/R = f/(H-h)$

Or: $r_b * (H-h) = R * f$ ---(2)

Then from (1) and (2);

$r_a * H = r_b * (H-h)$ then;

$RD = r_b - r_a = r_b * h_b / H$

$RD = r_t - r_b = r_t * h_T / H$

Example

- Given:
- Flying height above ground surface = 2000m
  - Readings on the photo:
  - Radial distance to image top=85mm
  - Radial distance to image base= 83mm
  - Solution:
  - Relief displacement dr = 85 – 83 = 2mm
  - Object height = h = [dr / r_t] * H
  - = [2/85] * 2000 = 47.06m