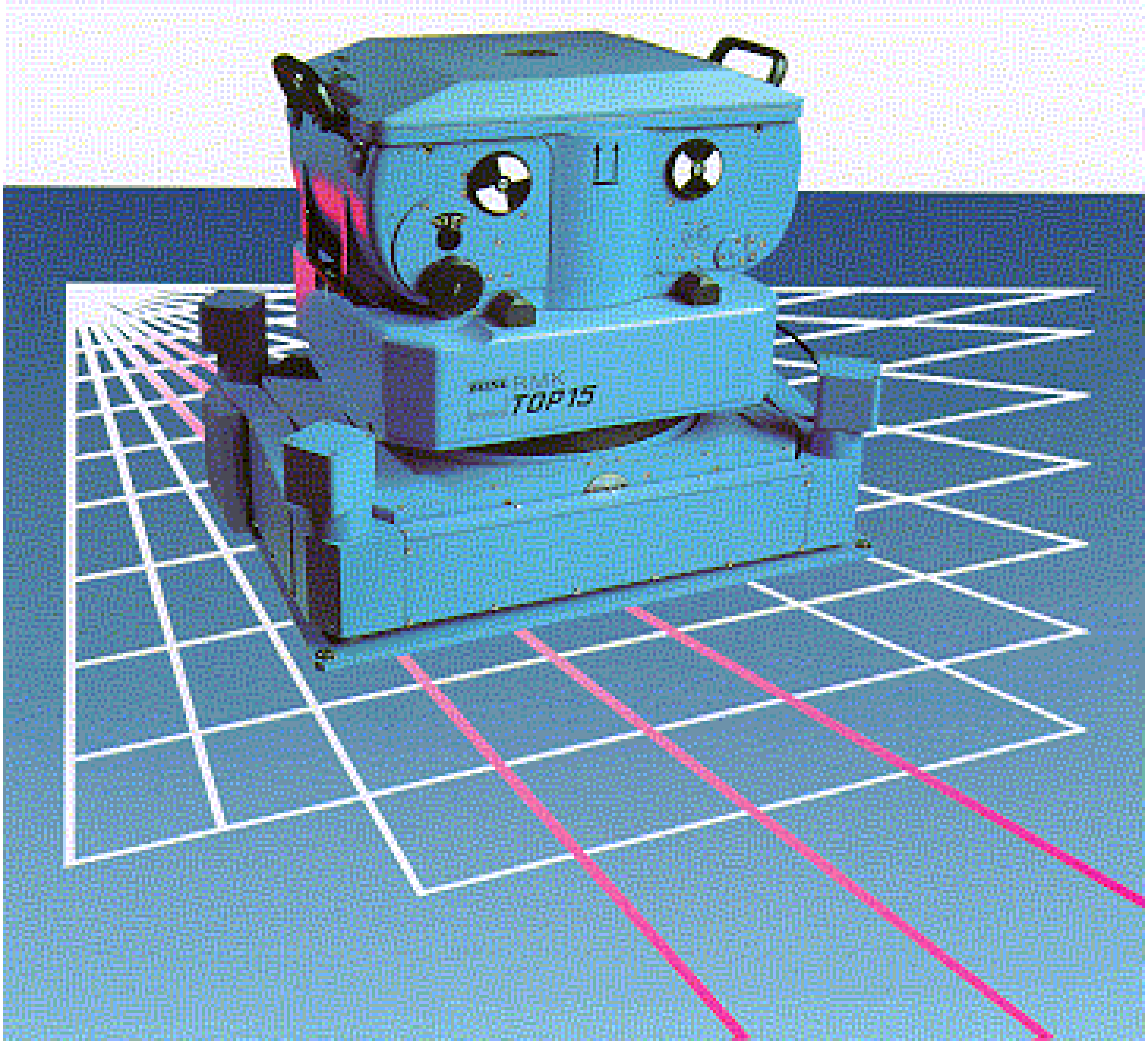
Geometry of Aerial Photographs

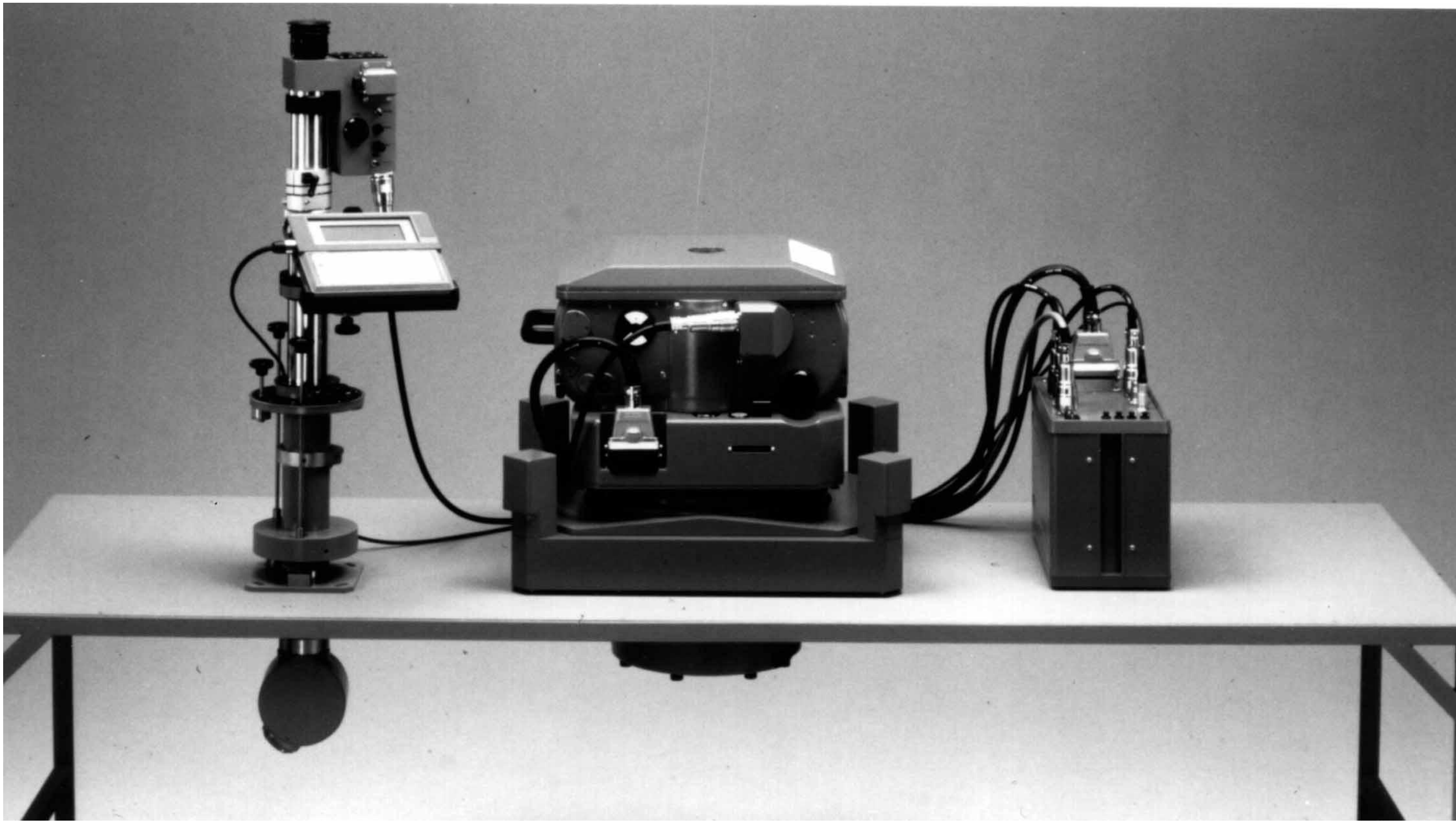
Aerial Cameras

- **Aerial cameras must be *(details in lectures)*:**
  - Geometrically stable
  - Have fast and efficient shutters
  - Have high geometric and optical quality lenses
- **They can be classified according to type of frame**:
  - Single lens Frame
  - Multiple frame
  - Strip Frame
  - Panoramic
- **They can also be either film or digital cameras**.

THIS COURSE WILL DISCUSS ONLY SINGLE FRAME CAMERAS


TOP 15

Aerial camera with viewfinder and electronic control



Aerial Camera in action

Single lens Frame Cameras

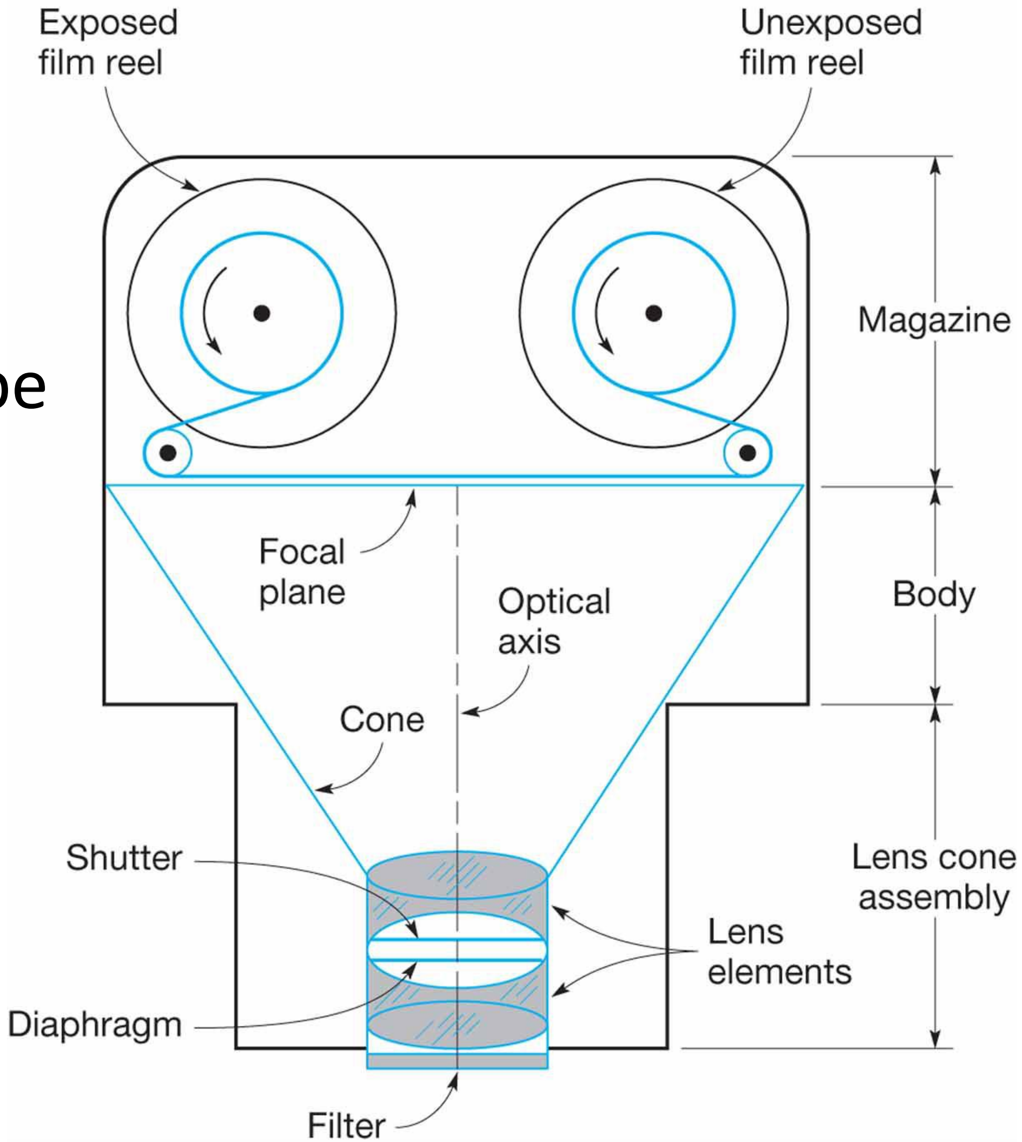
- Standard is 9” (23 cm) frame size and 6” (15.24 cm) focal length(f).
- They can be classified, as mentioned before, according to the field of view to:
  - Normal angle (up to 75°)
  - Wide angle (up to 75°)
  - Super-wide angle (greater than to 75°)

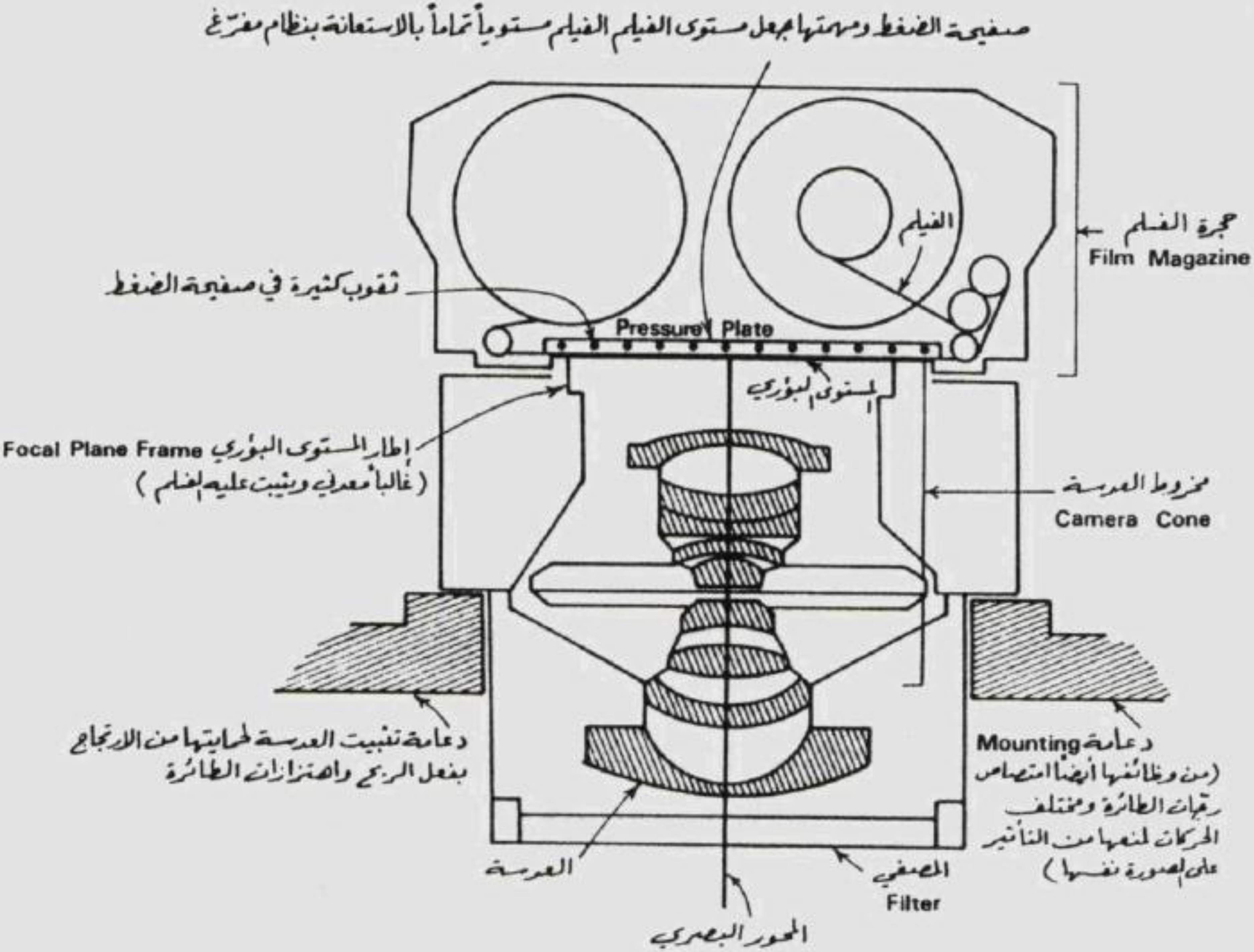
Components of a single frame film camera.

Three main parts:

1. Magazine
2. Body
3. Lens cone assembly

Components and notes to be discussed din lecture





صفيحة الضغط ومهمتها جعل مستوى الفيلم مستوياً تماماً بالاستعانة بنظام مفرّغ
حجرة الفلم
Film Magazine
الفيلم
ثقوب كثيرة في صفيحة الضغط
Pressure Plate
المستوى البؤري
Focal Plane Frame إطار المستوى البؤري
(غالباً معدني ويثبت عليه الفلم)
مخروط العدسة
Camera Cone
دعامة تثبيت العدسة لحمايتها من الارتجاج بفعل الريح واهتزازات الطائرة
دعامة Mounting
(من وظائفها أيضاً امتصاص رجفات الطائرة ومختلف الحركات لمنعها من التأثير على الصورة نفسها)
العدسة
المصفي
Filter
المحور البصري

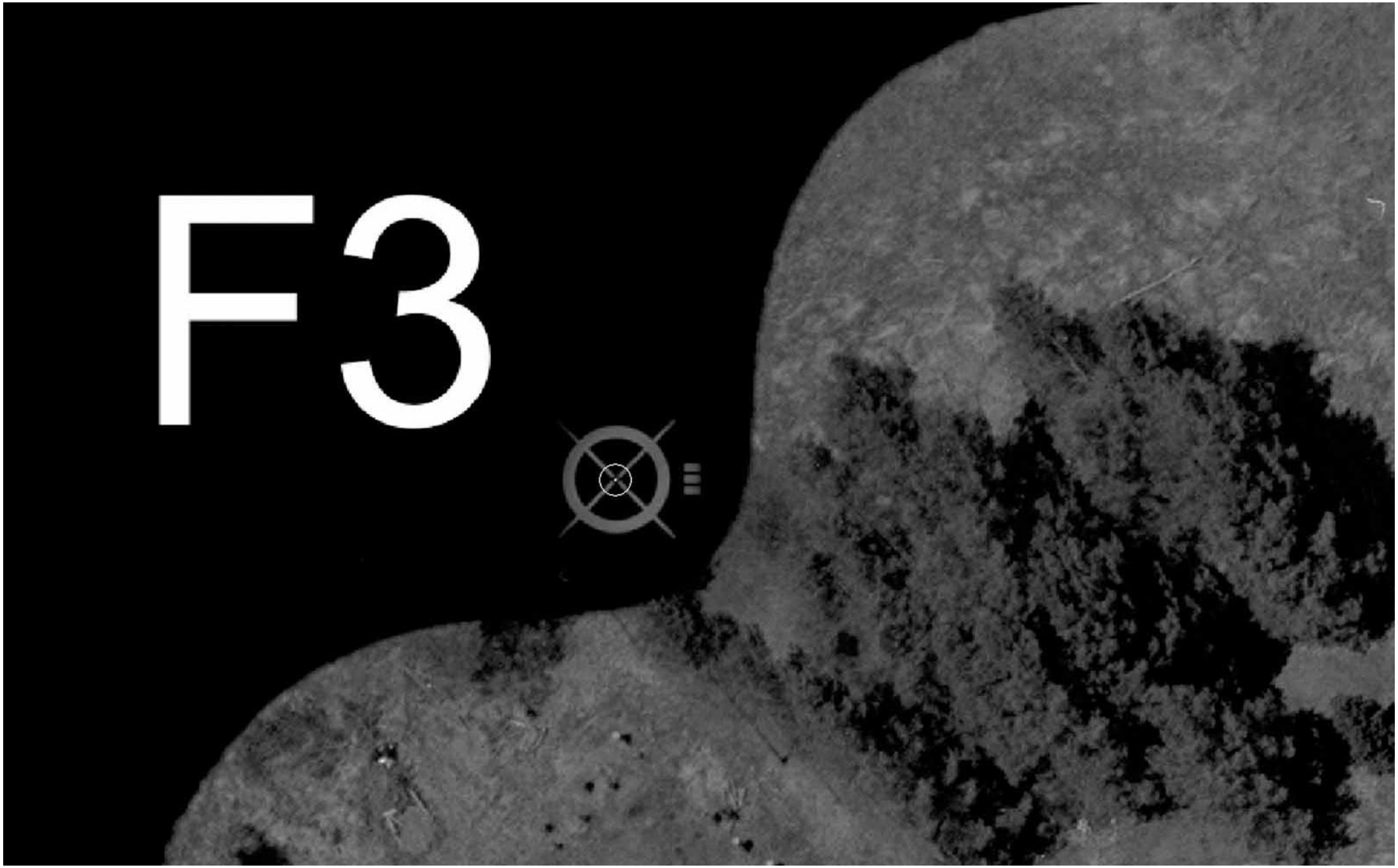

EXPERIMENTAL

Components of a single frame film camera.

Fiducial Marks

A vertical Photograph

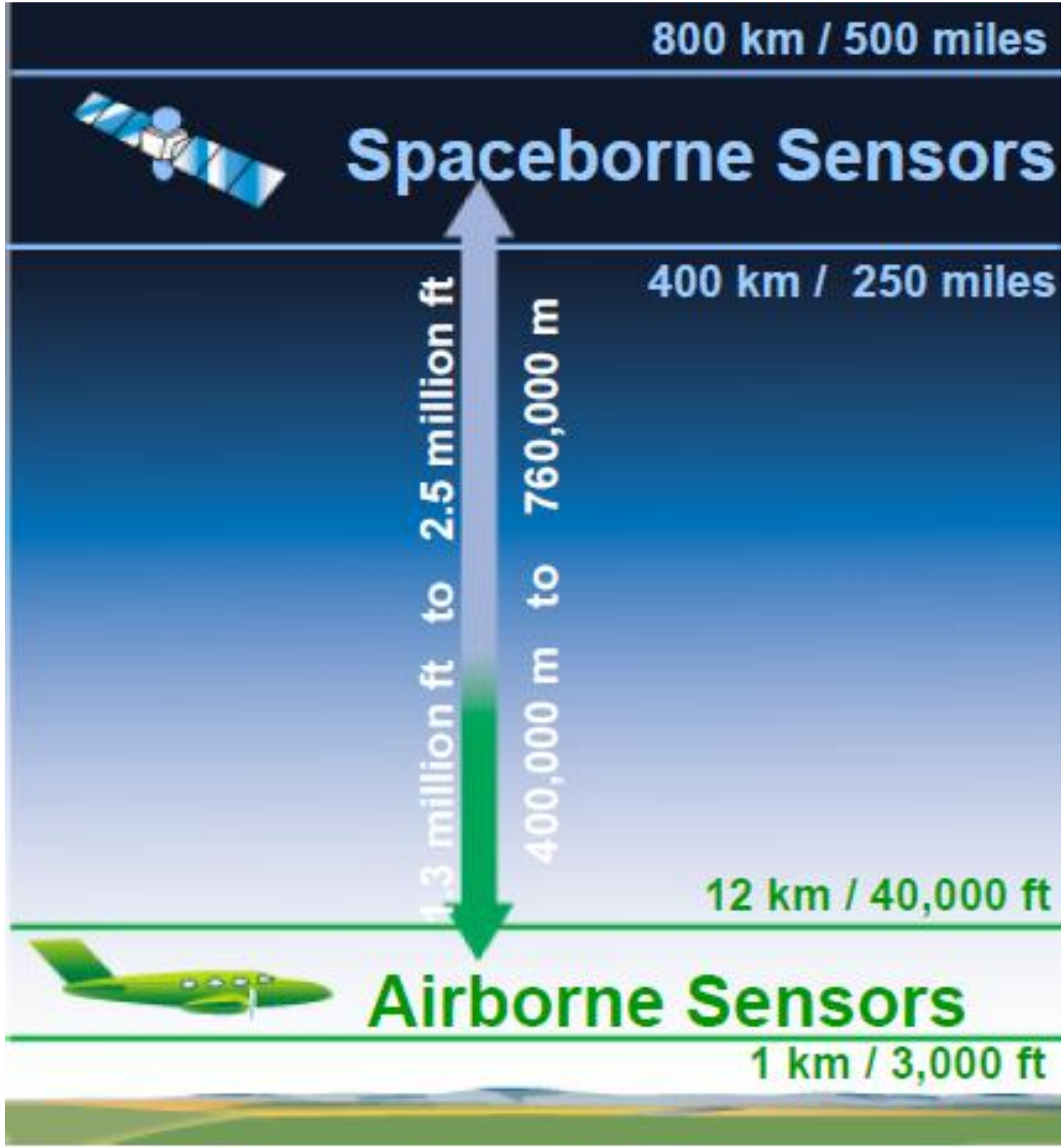
Components of a single frame film camera.



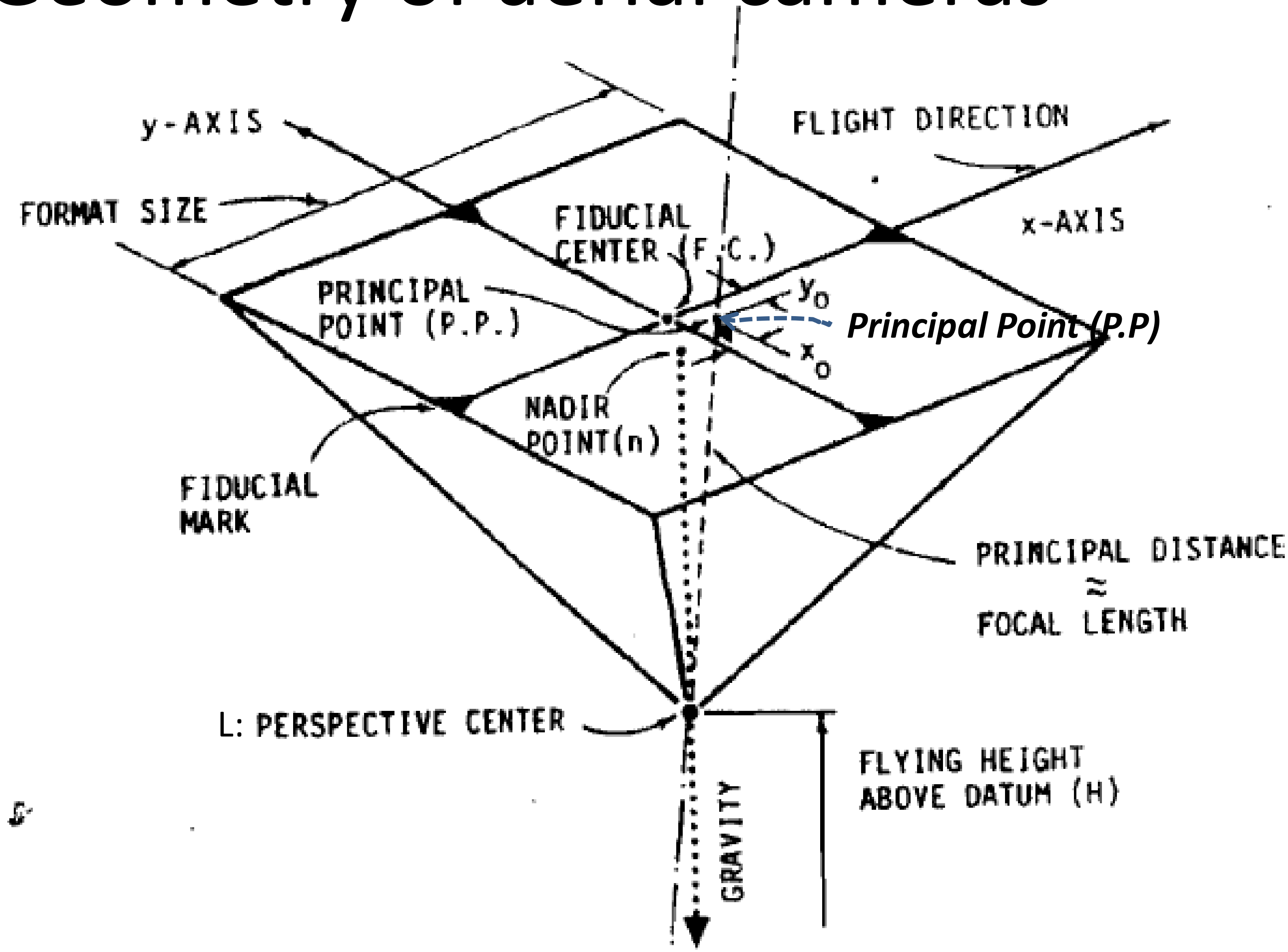
Example of a corner Fiducial Mark under Magnification

Figure 2.31 The LH Systems ADS 40 digital camera.

Airborne and Spaceborne Imagery



Geometry of aerial cameras



Geometry of aerial cameras

- Identify the following:

- L: perspective center.
- Fiducial Center F.C.
- Principal Point (P.P) or O: the point where the perpendicular from the perspective center intersects the photograph. Usually deviates from the F.C by a very small distance.
- Principal axis: the line perpendicular from the principal center on the plane of the photograph (negative).
- f the focal length, equals the Principal Distance.

Types of Photographs (by tilt)

Aerial Photos are:

1- Vertical or tilted

- Vertical photos are taken with the optical axis (Principal Line) vertical or tilted by no more than 2°
- Tilted: if the optical axis is tilted by no more than 3°

Types of Photographs (by tilt)

2- Oblique Photos

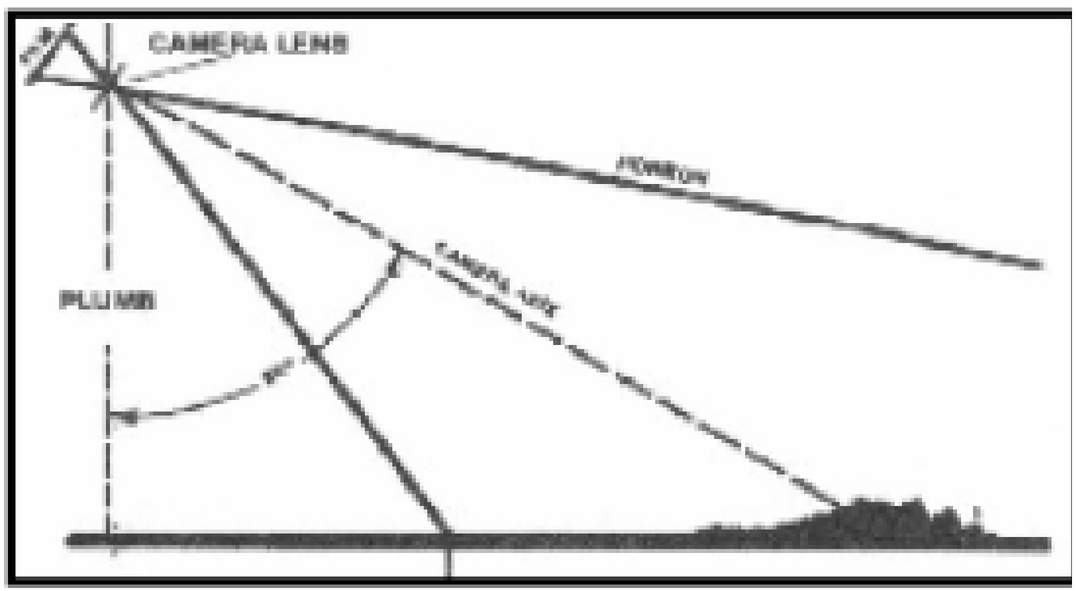
If the optical axis is intentionally strongly tilted to increase coverage, they are:

- Low oblique: if the tilt is not enough to show the horizon, usually 3 to 30 °

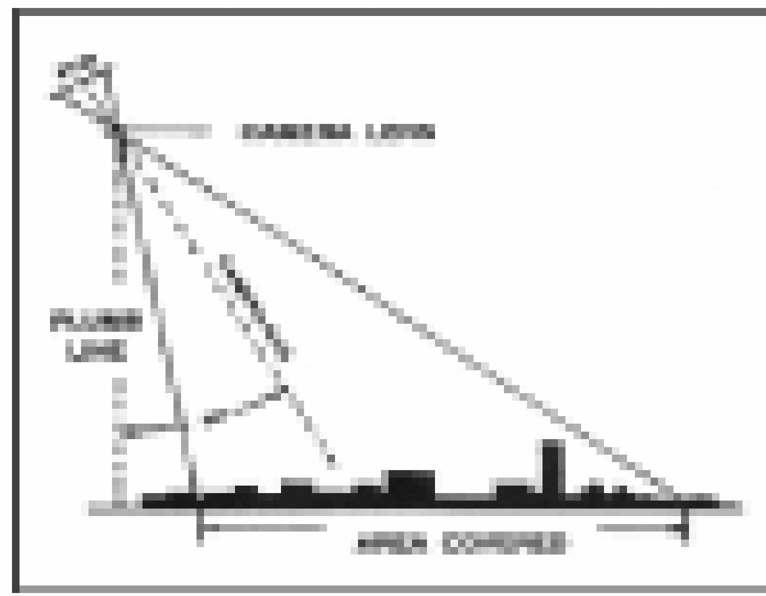
Types of Photographs (by tilt)

2- Oblique Photos

- Low oblique
- High oblique: if the horizon is shown on the photograph

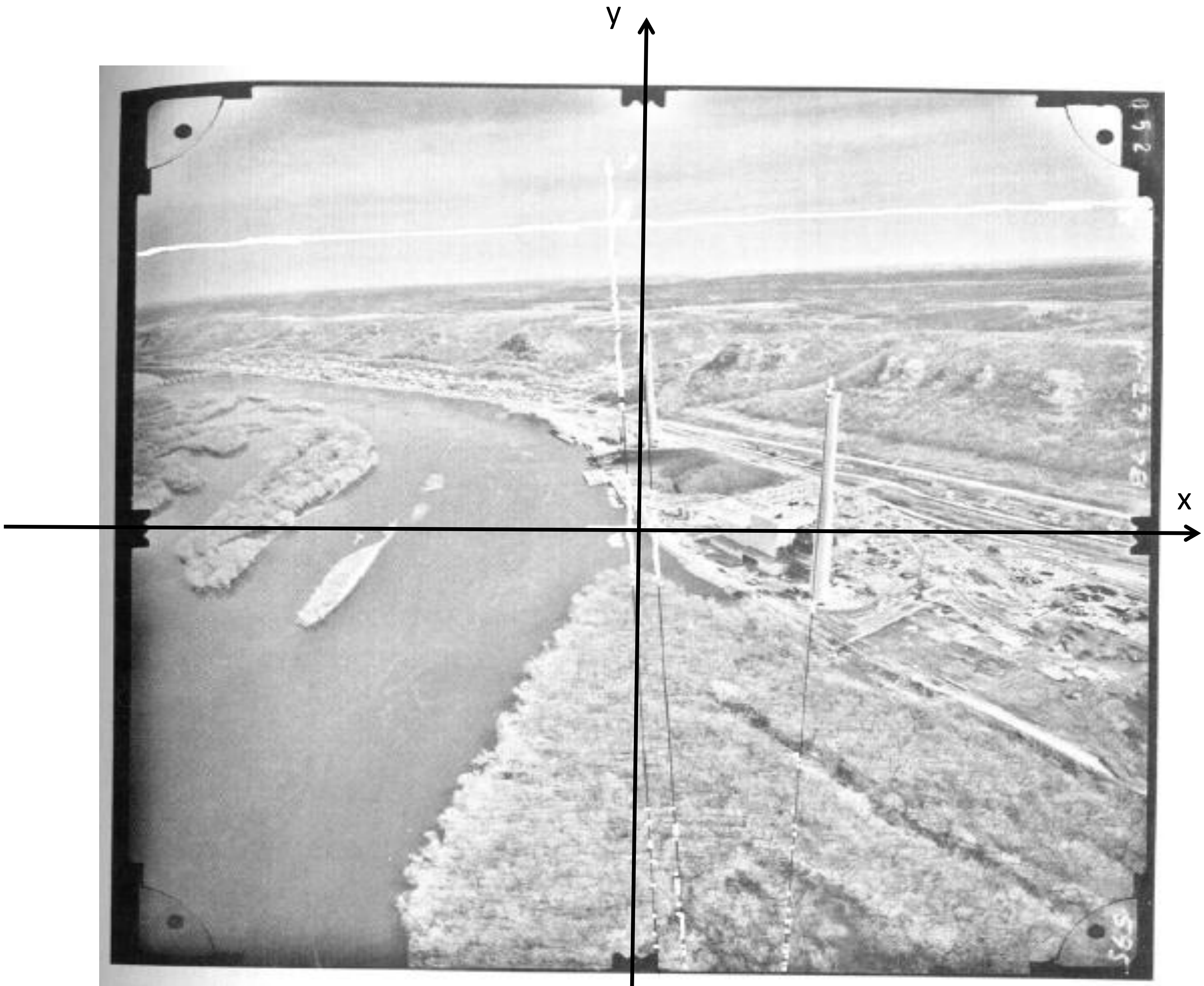


High oblique



Low oblique

High Oblique Vertical Photograph

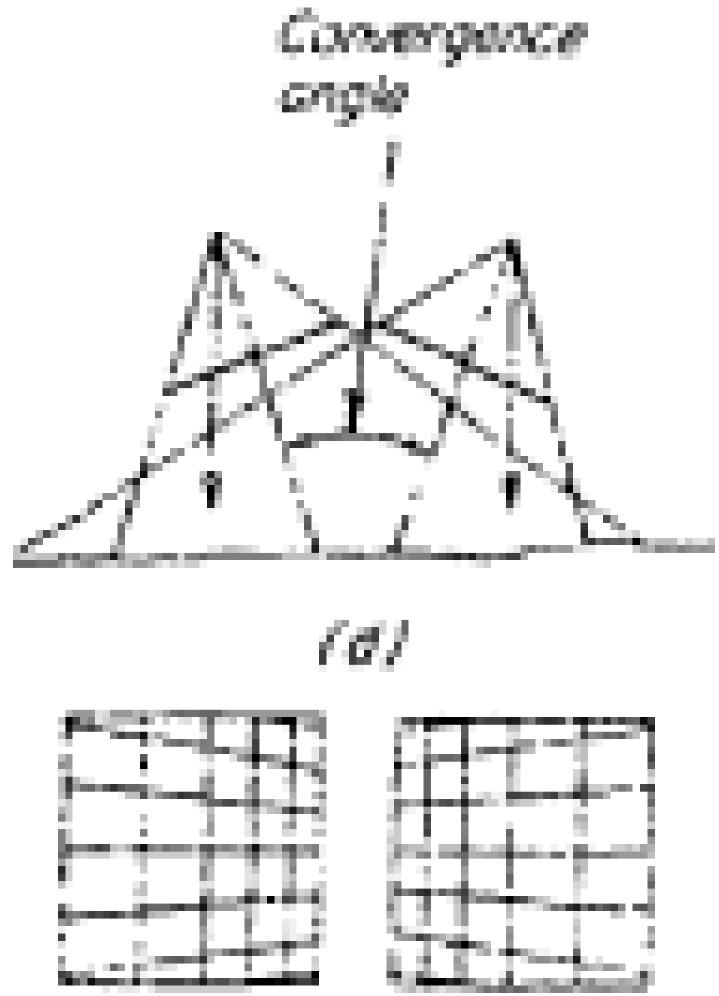


Example of vertical, high, and low oblique photos

Types of Photographs (by tilt)

3- Convergent Photographs

Low oblique photos in which camera axis converge toward one another



Comparison between vertical and oblique photos

- Coverage
- Geometry
- Low cloud?
- View: issues with tall features and views of sides of features.
- Others

Photo Coordinates (film)

- We use positives for ease of geometry and familiarity of feature shapes, negatives may be used in certain applications
- Lines connecting middle **fiducials ON THE POSITIVE** define a photo coordinate system, in which x is in the direction of flight, A RIGHT-HAND coordinate system
- Measurements can be as accurate as 1 micron = 1/1000 mm

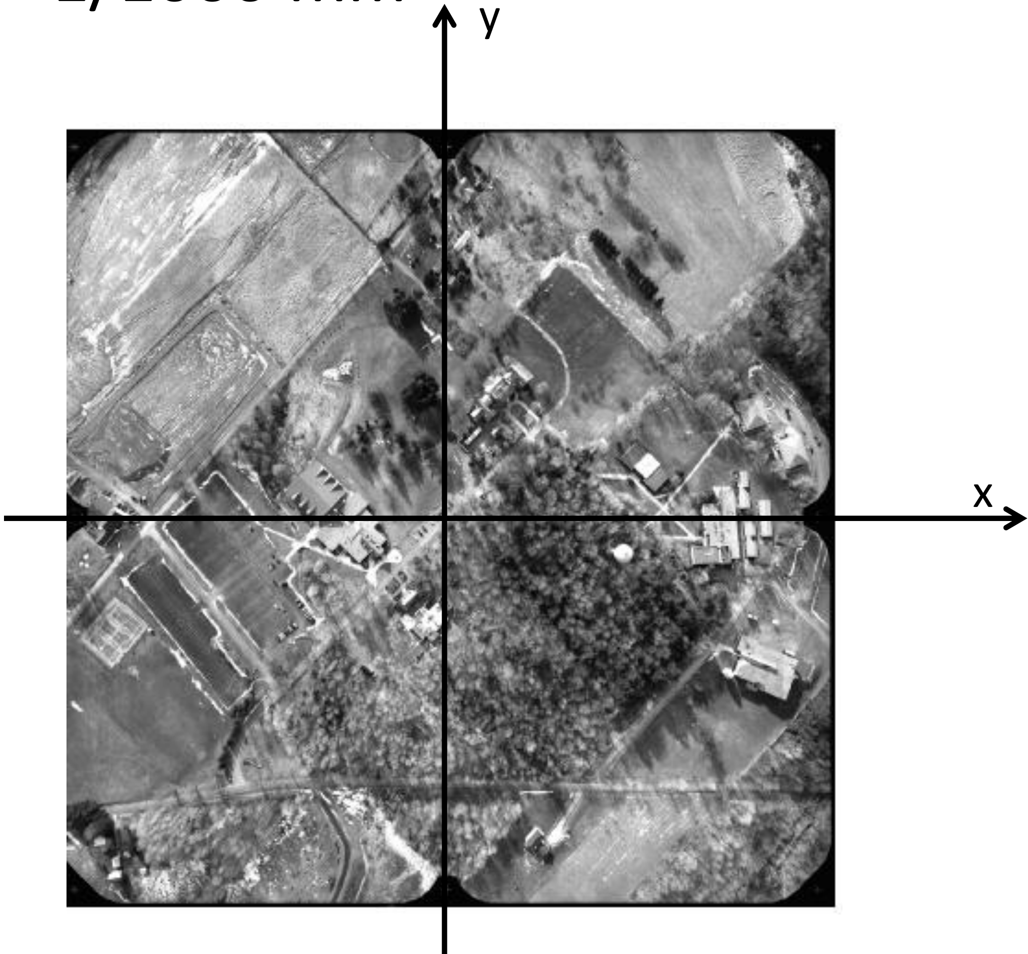
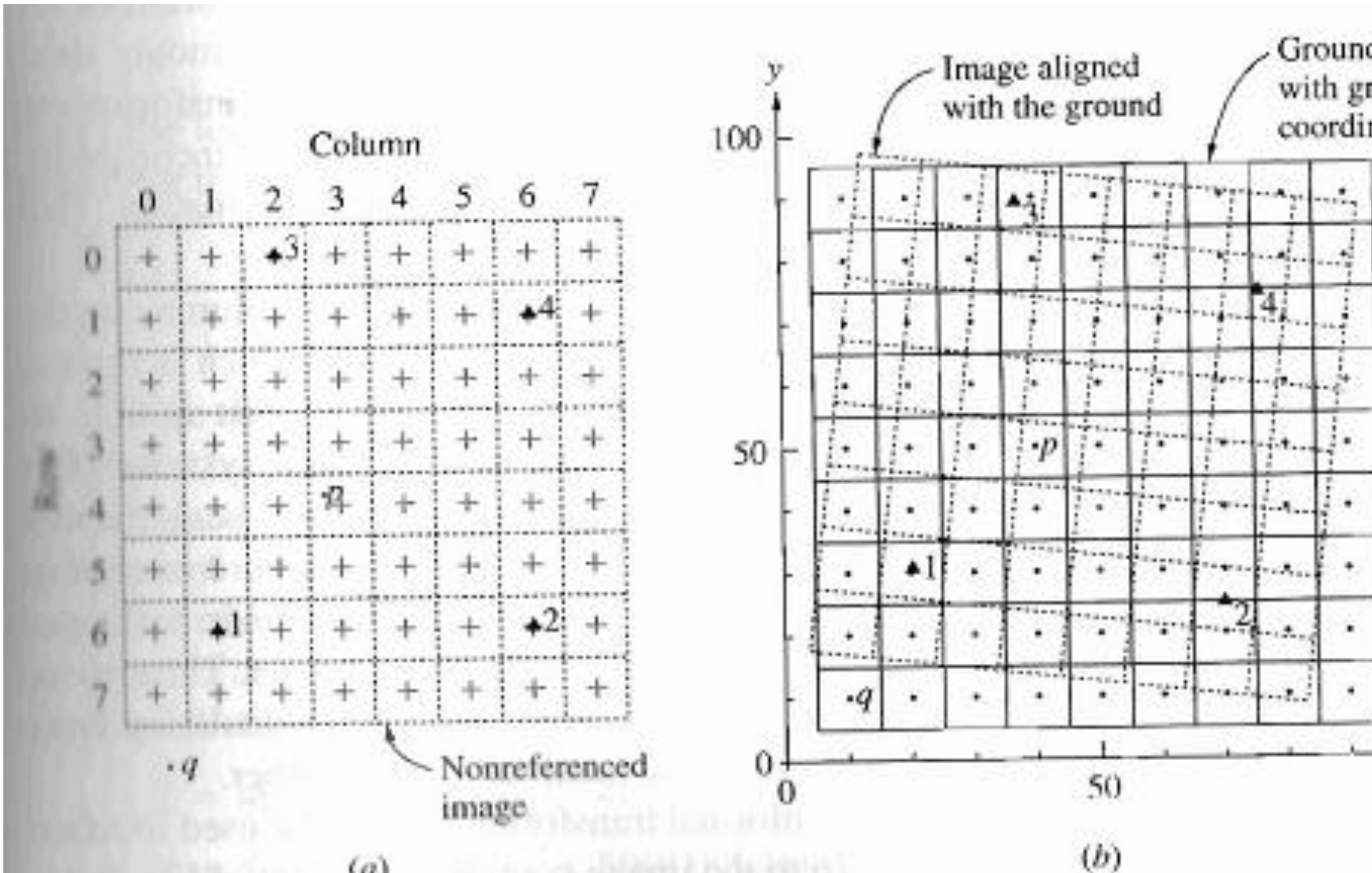
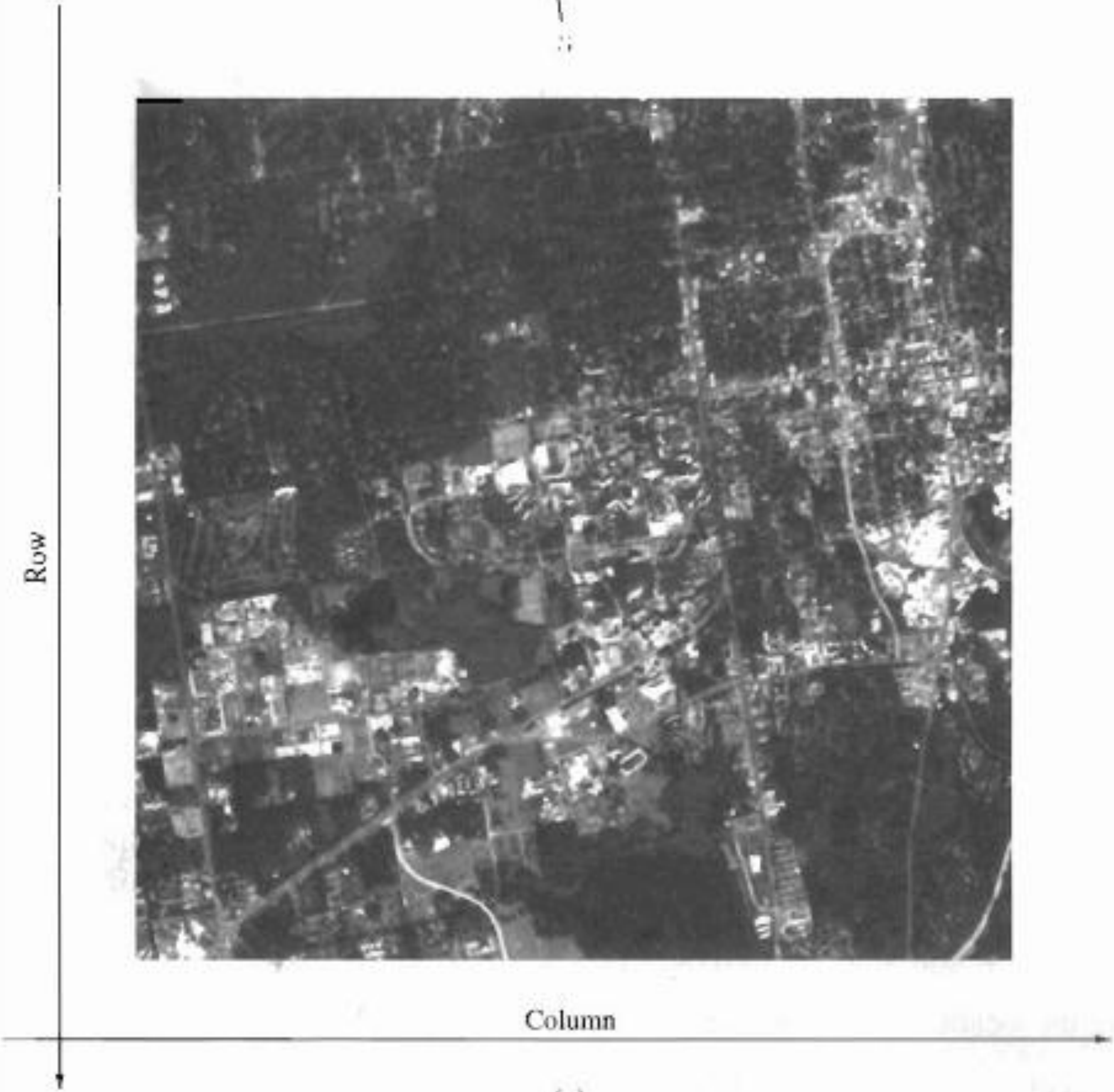


Photo Coordinates (digital)

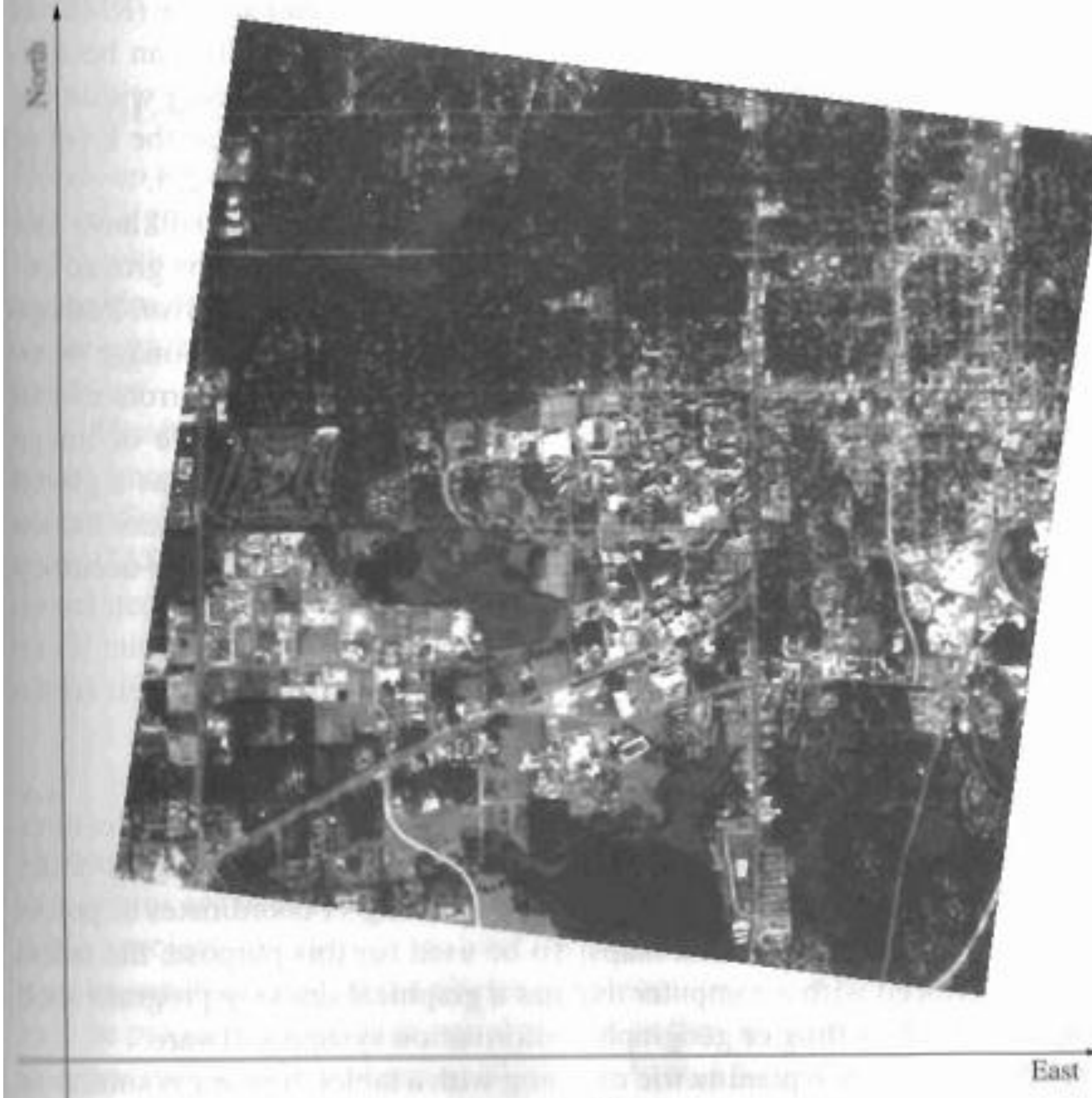
- Pixels in a digital image represent coordinates of rows and columns.



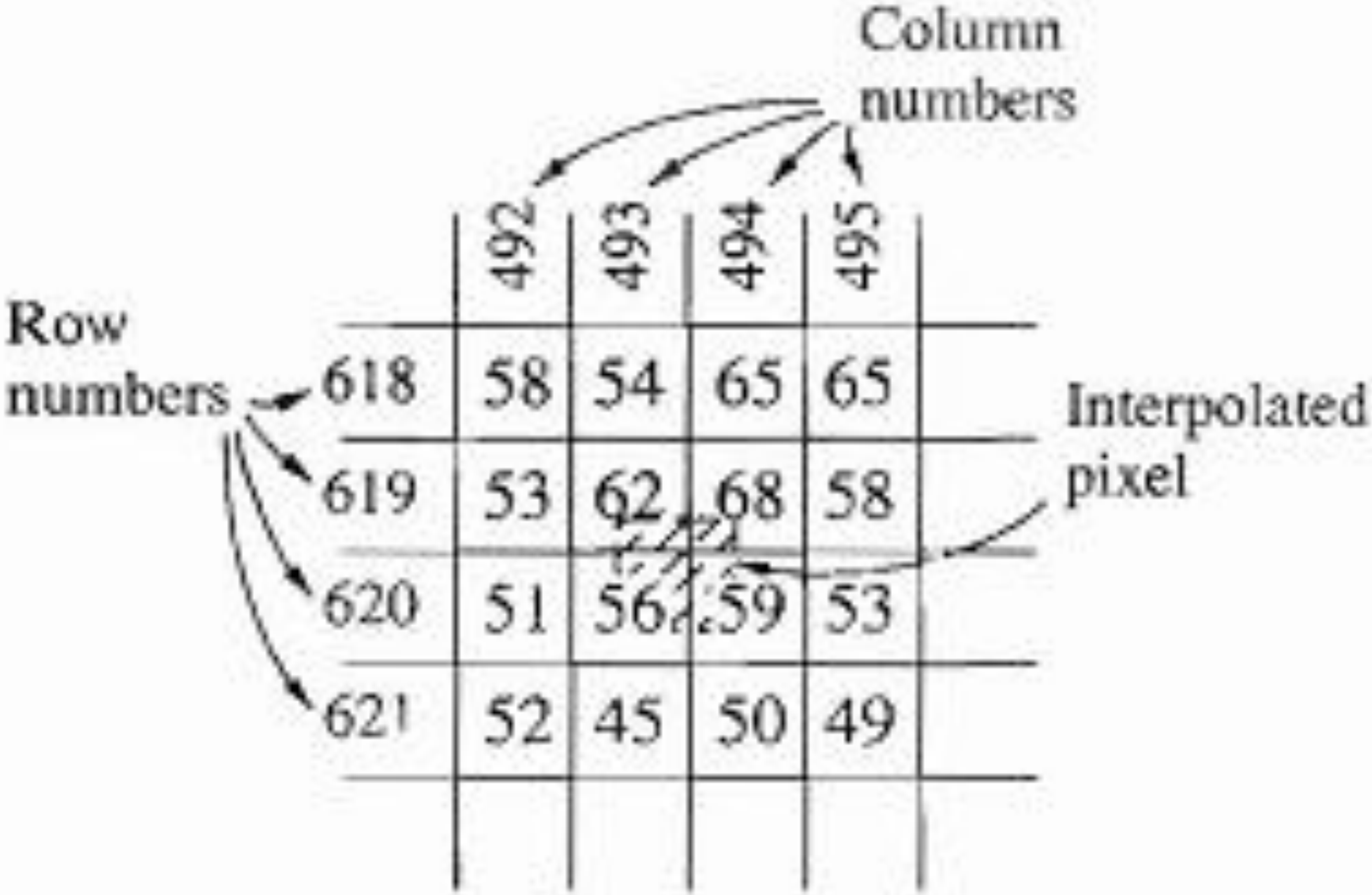


(*a*)

FIGURE 9-3
(*a*) Nonreferenced satellite image. (*b*) Georeferenced image. (*Courtesy University of Florida.*)

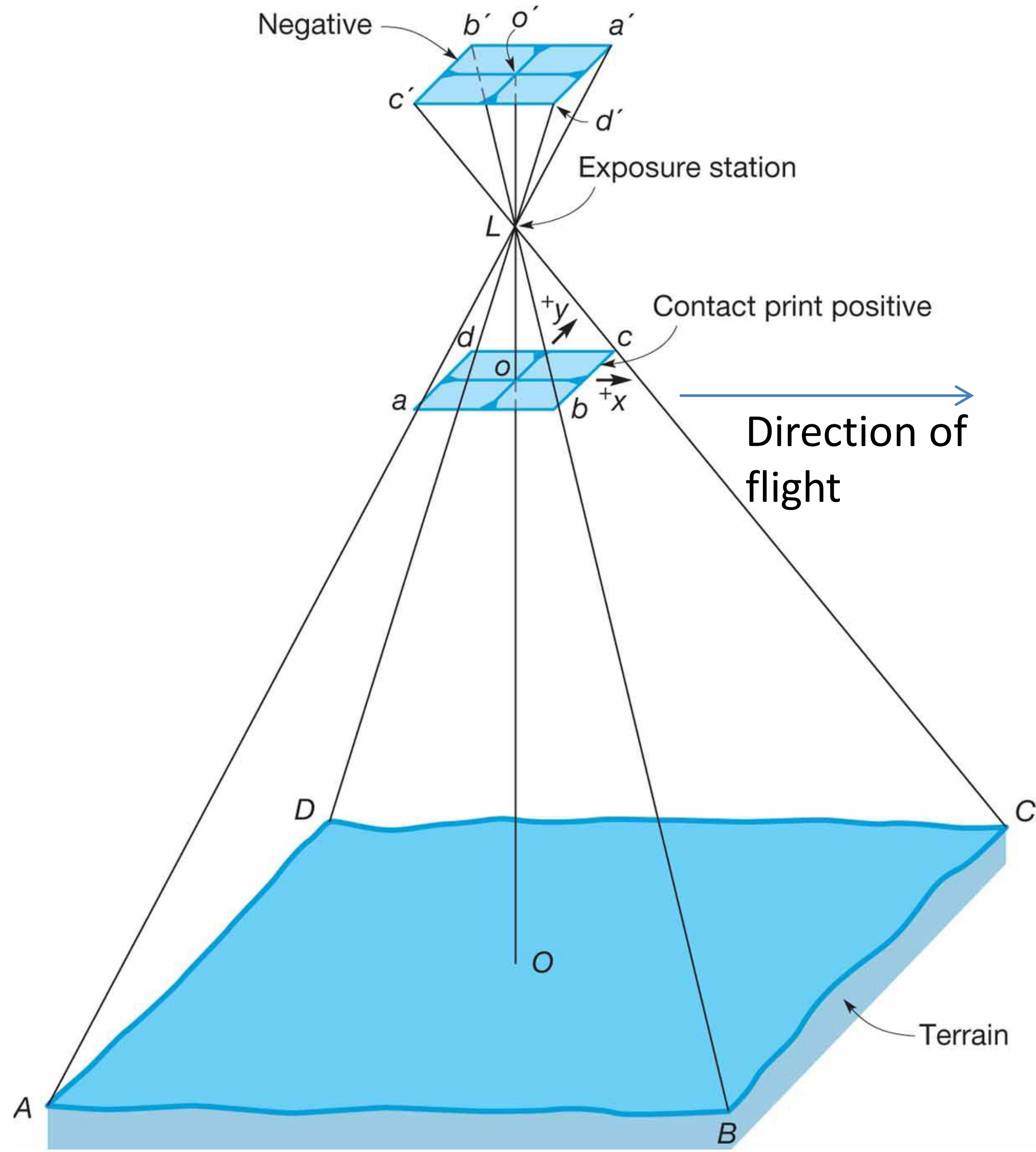


(*b*)


Column numbers
492
493
494
495
Row numbers
618
619
620
621
58
54
65
65
53
62
68
58
51
56
59
53
52
45
50
49
Interpolated pixel

Geometry of a vertical photographs

- The line LoO, the optical axis is assumed truly vertical



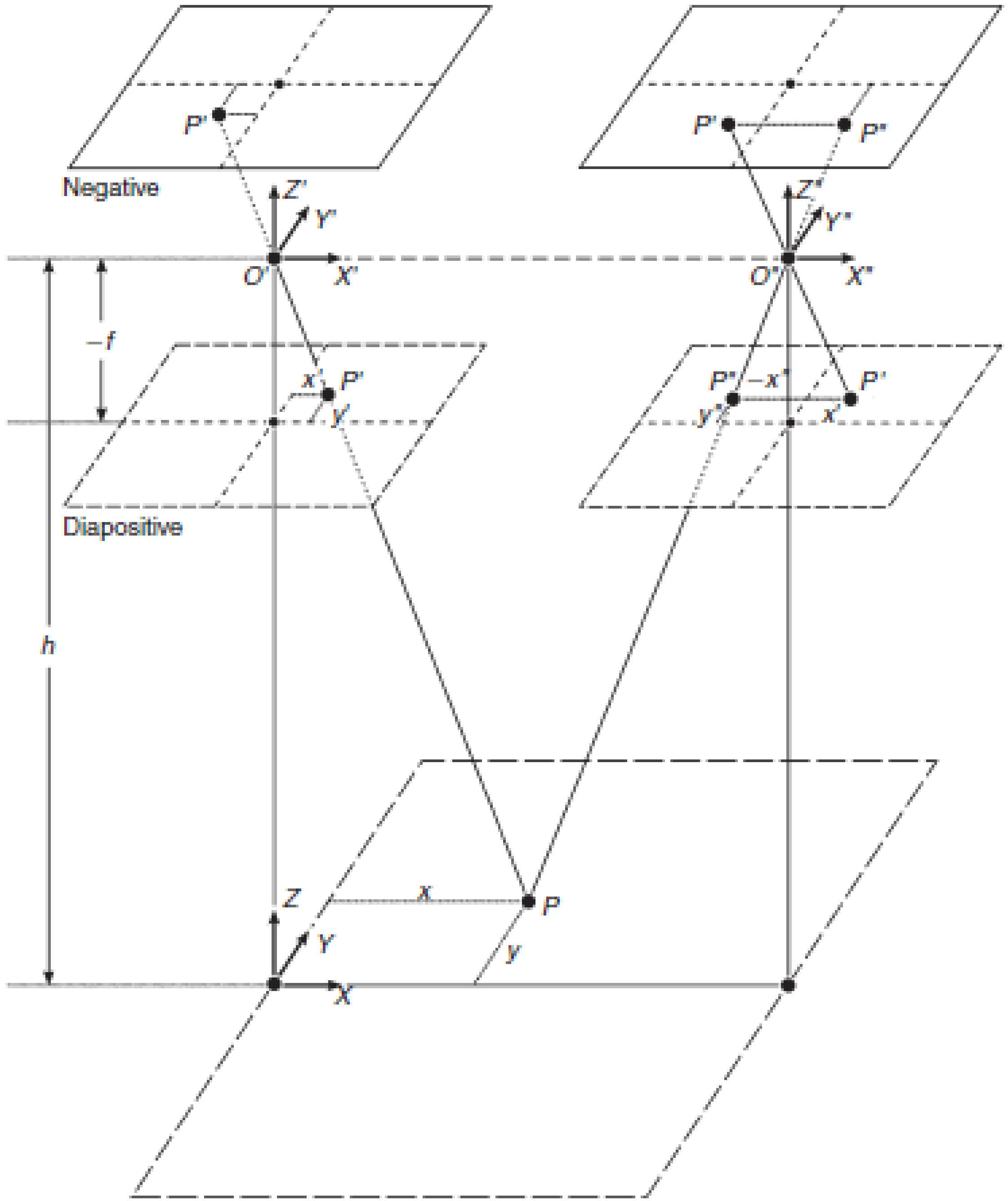
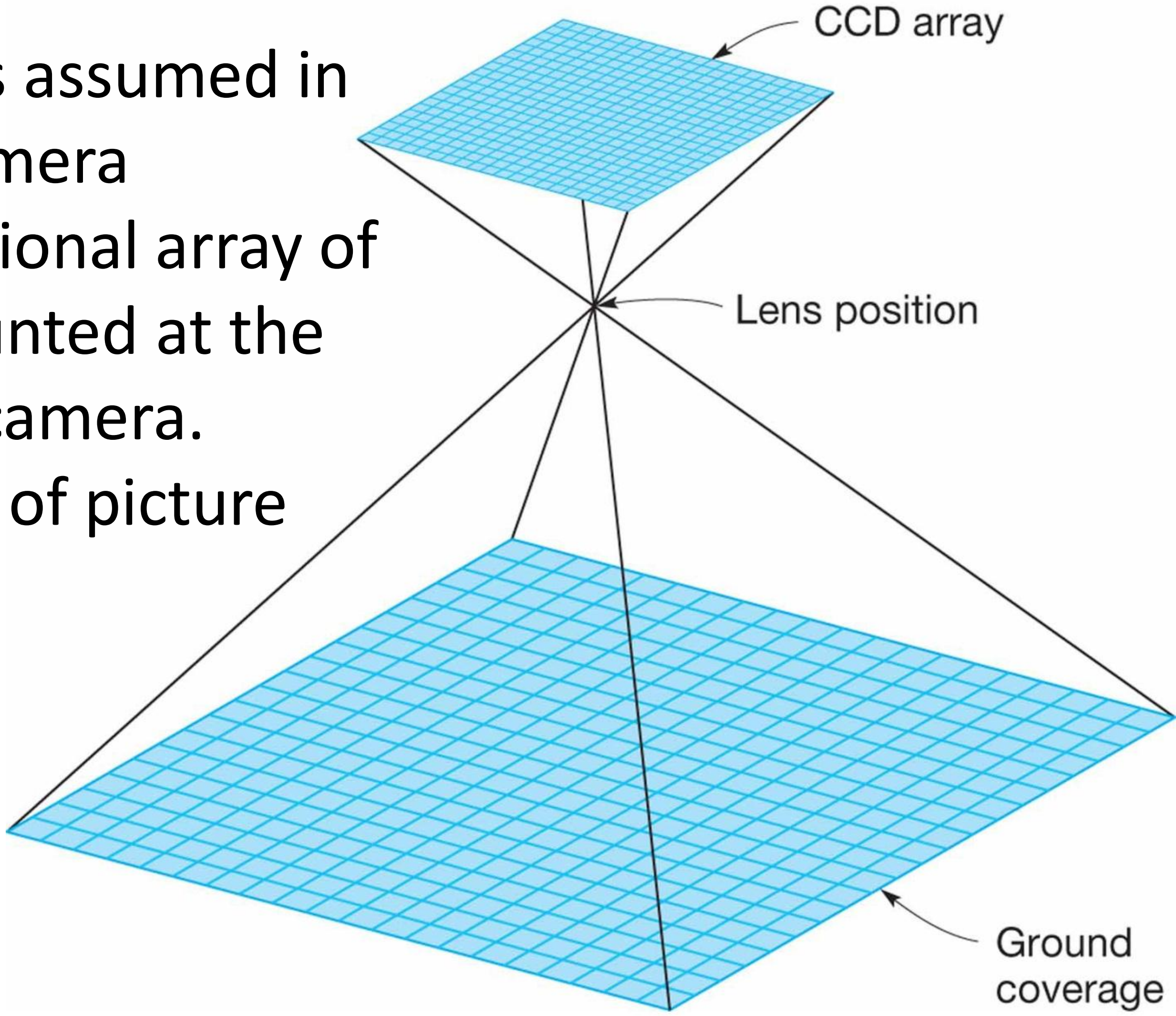


Figure 3.8 Geometry of vertical photographs.

Geometry of a digital frame camera

- Similar geometry is assumed in case of a digital camera
- Uses a two dimensional array of CCD elements mounted at the focal plane of the camera.
- The image is a grid of picture elements (pixels)

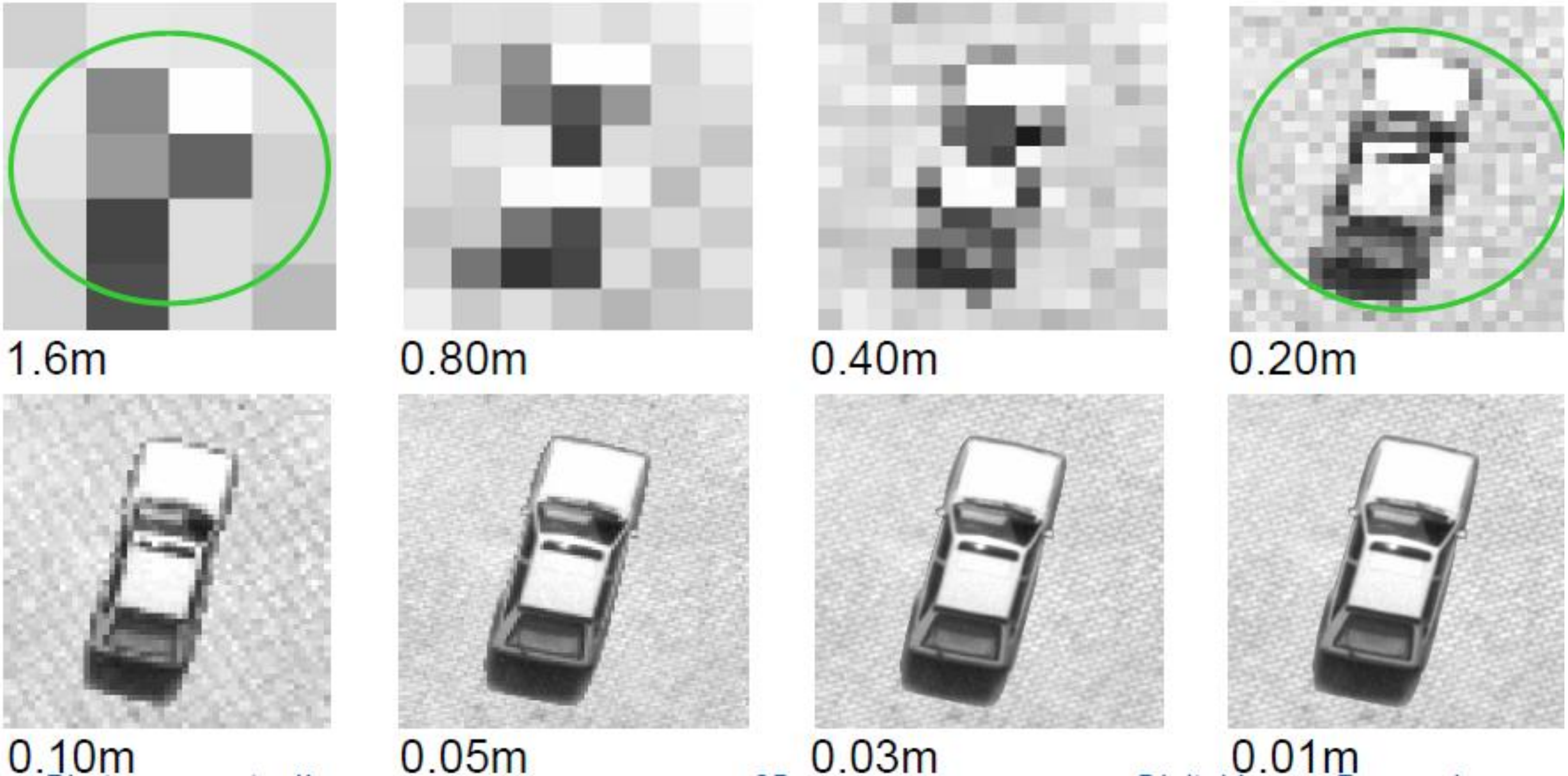


- Similar geometry is assumed in case of a digital camera
- Uses a two dimensional array of CCD elements mounted at the focal plane of the camera.
- The image is a grid of picture elements (pixels)
- The size of pixels in one image represent the resolution of the image, the smaller the pixel, the higher (better) the resolution.
- A mega (million) pixel image includes one million pixel
- Number of pixels can be as low as 500X500 = 250,000 pixels, or megas of pixels for commercial cameras, or gegapixels in classified cameras.
- What is the size of image of a camera that includes a CCD frame sensor, that is 1024 X1024 elements, if the size of a pixels is 5μ? How many megapixels are there?

Answer: image size = = mm,

No of pixels = = mega pixel

Digital image resolution



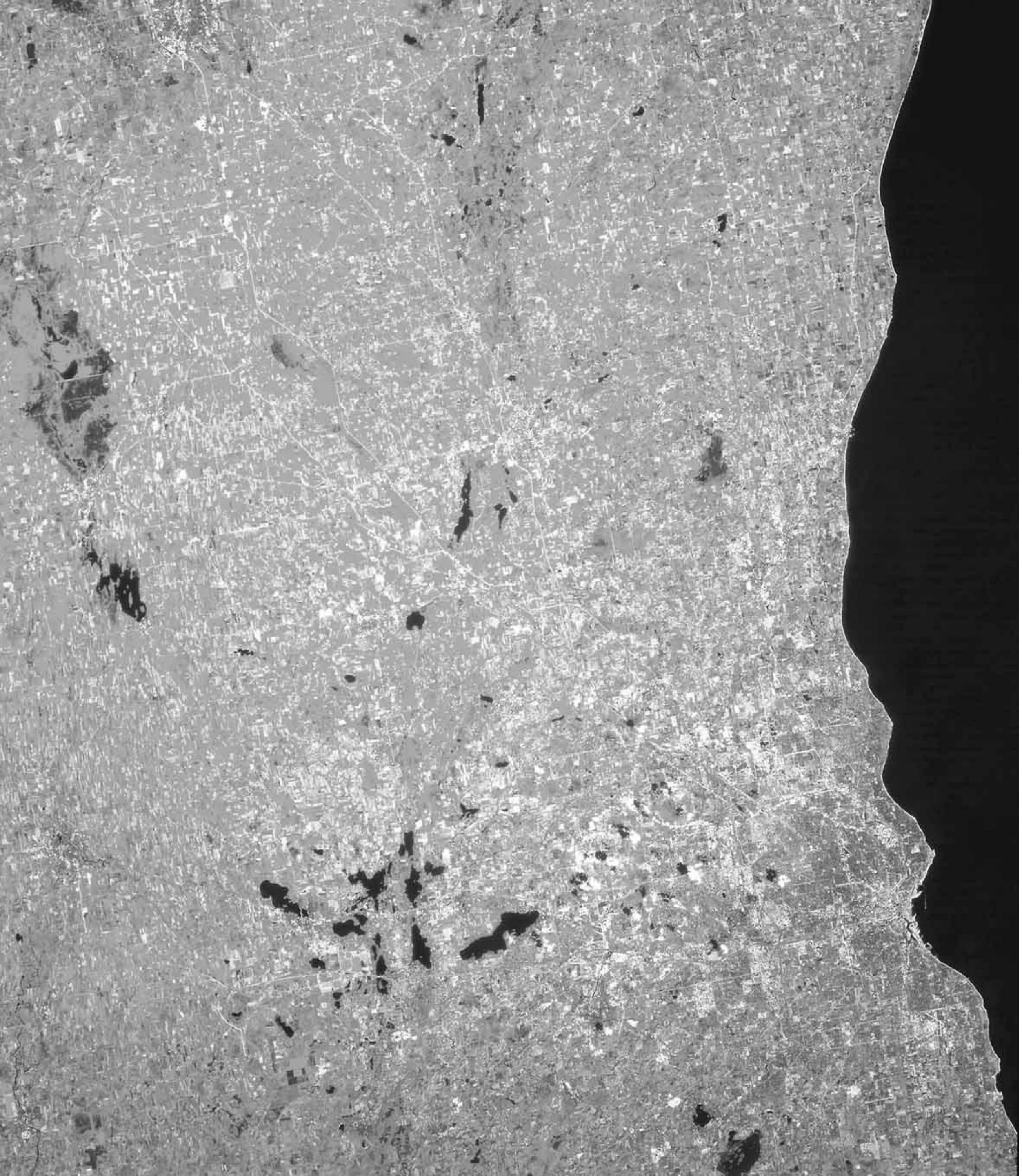


image taken from a first-generation Landsat satellite over Milwaukee, Wisconsin.

1-m resolution image obtained from the IKONOS satellite showing San Francisco.

Concept of image pyramids

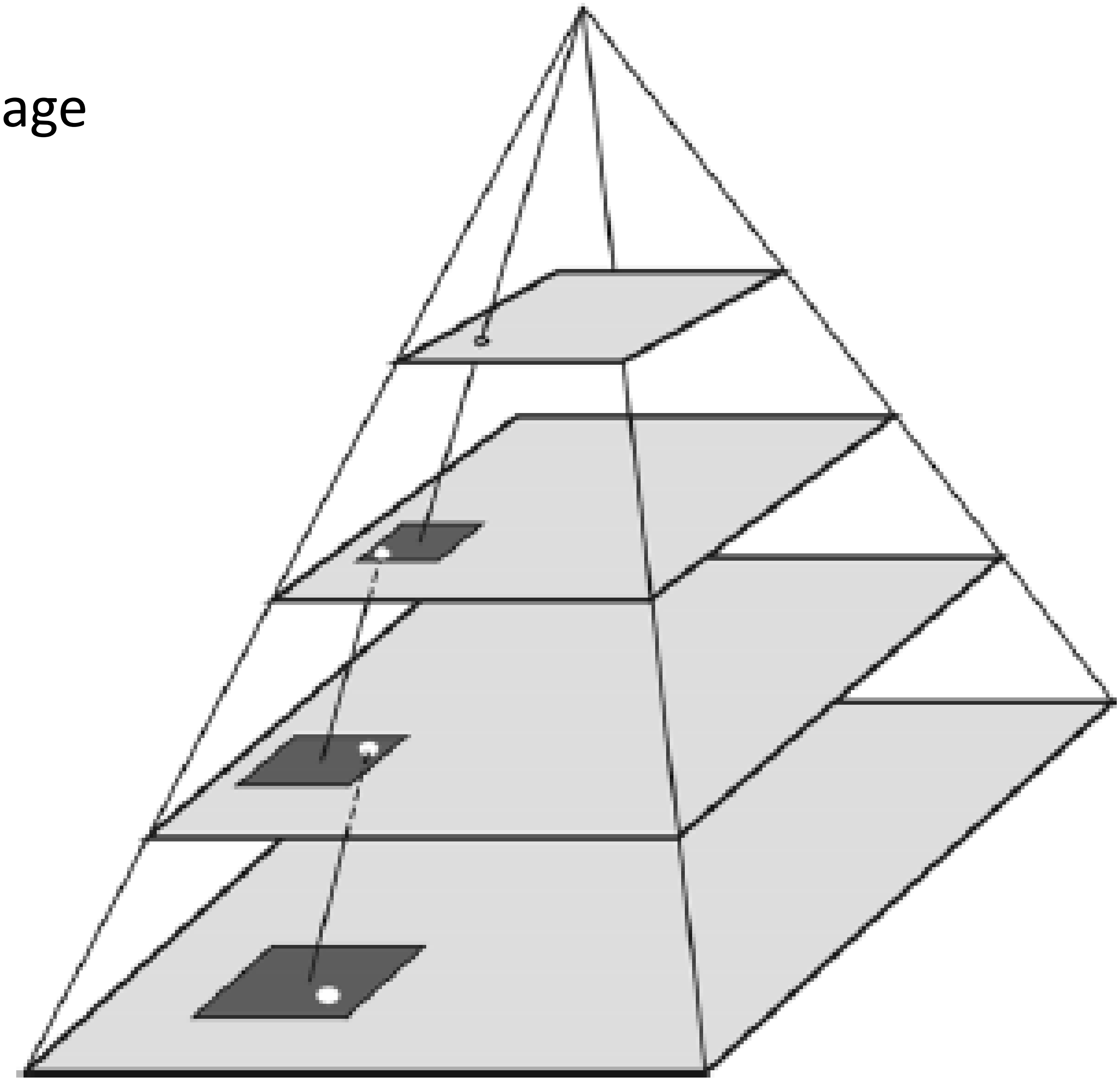


Figure 2.32 Raw ADS 40 image.

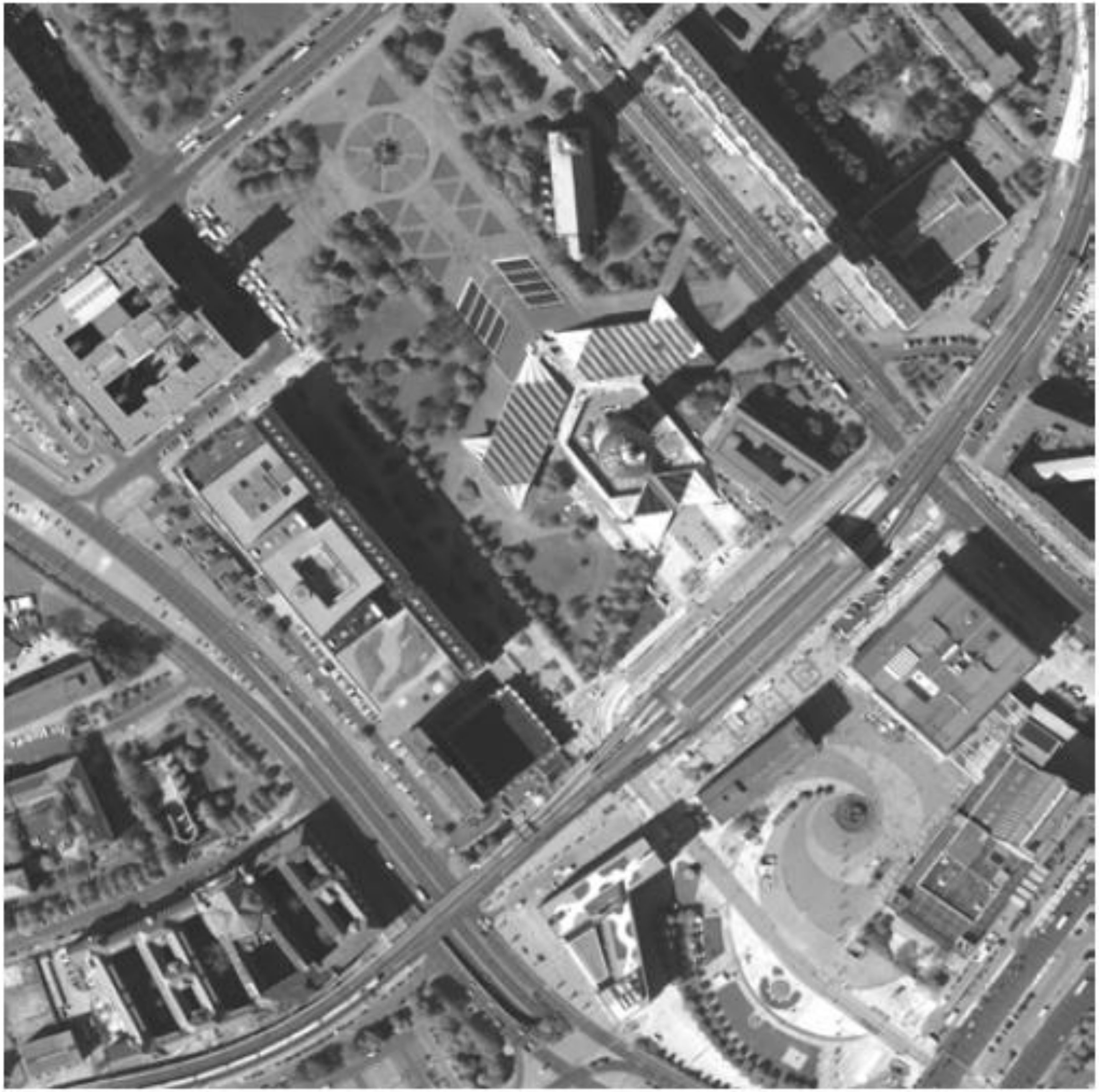
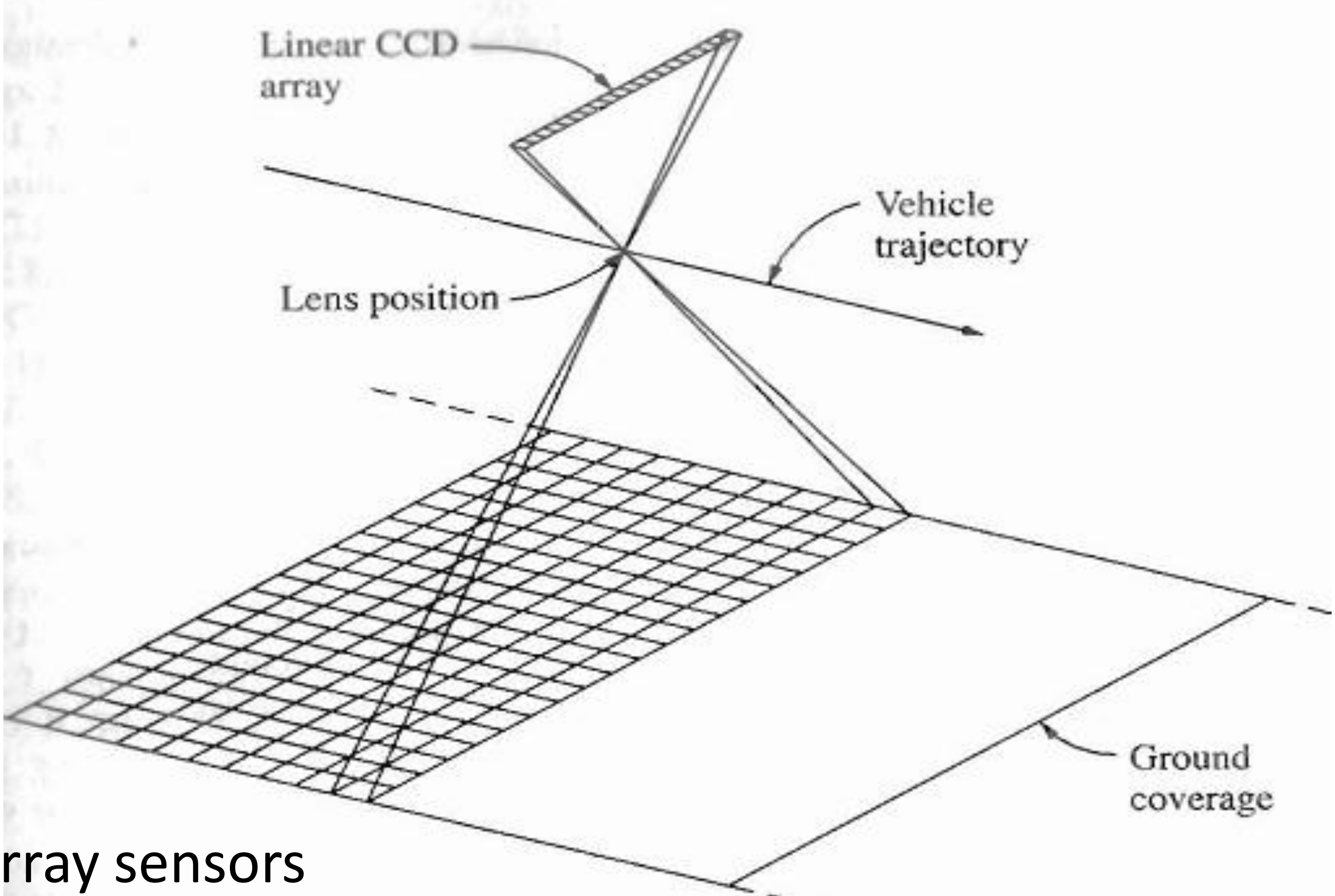
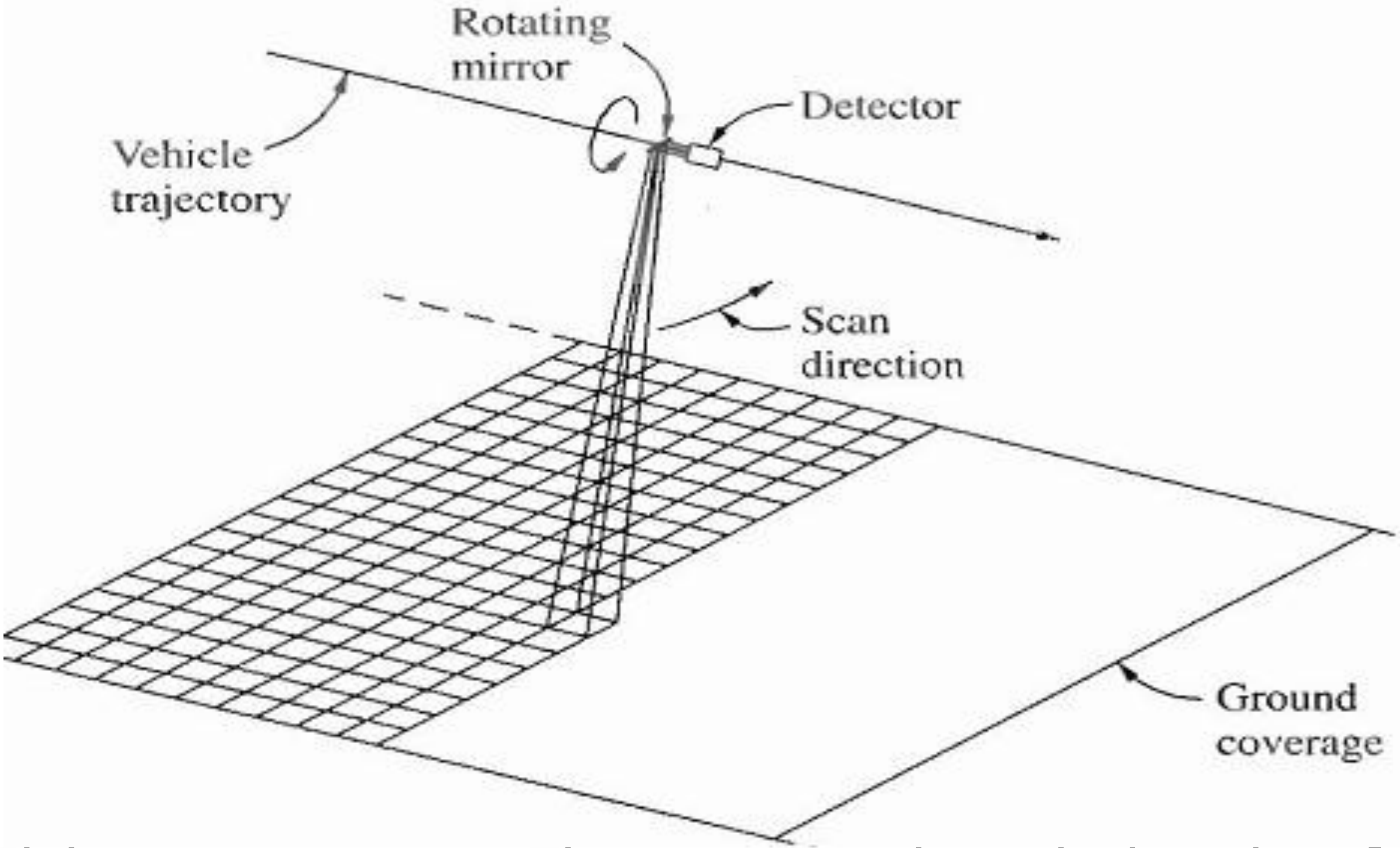


Figure 2.33 Rectified ADS 40 image.



linear array sensors

A linear CCD scans the ground at a given time. The vehicle advances a distance equals to one array and capture the next line. Will the entire image be scanned at the same time?



Flying spot scanner: The geometry is such that the after a row is finished being scanned, the vehicle advanced to the beginning of the next row.

- <u>Which digital system is suitable for what purpose??</u>
- <u>Why??</u>

Image coordinate corrections

Our goal is to measure photo coordinates and relate them to ground coordinates by equations to obtain ground coordinates. Once you have ground coordinates, you can draw a map, establish cross section, etc.

Measured photo coordinates need to be corrected prior to substation in equations, for the following:

- Film shrinkage
- Principal point location
- Lens distortions
- Atmospheric refraction
- Earth curvature
- Which of the corrections inapplicable for digital images??

Effect of Earth Curvature

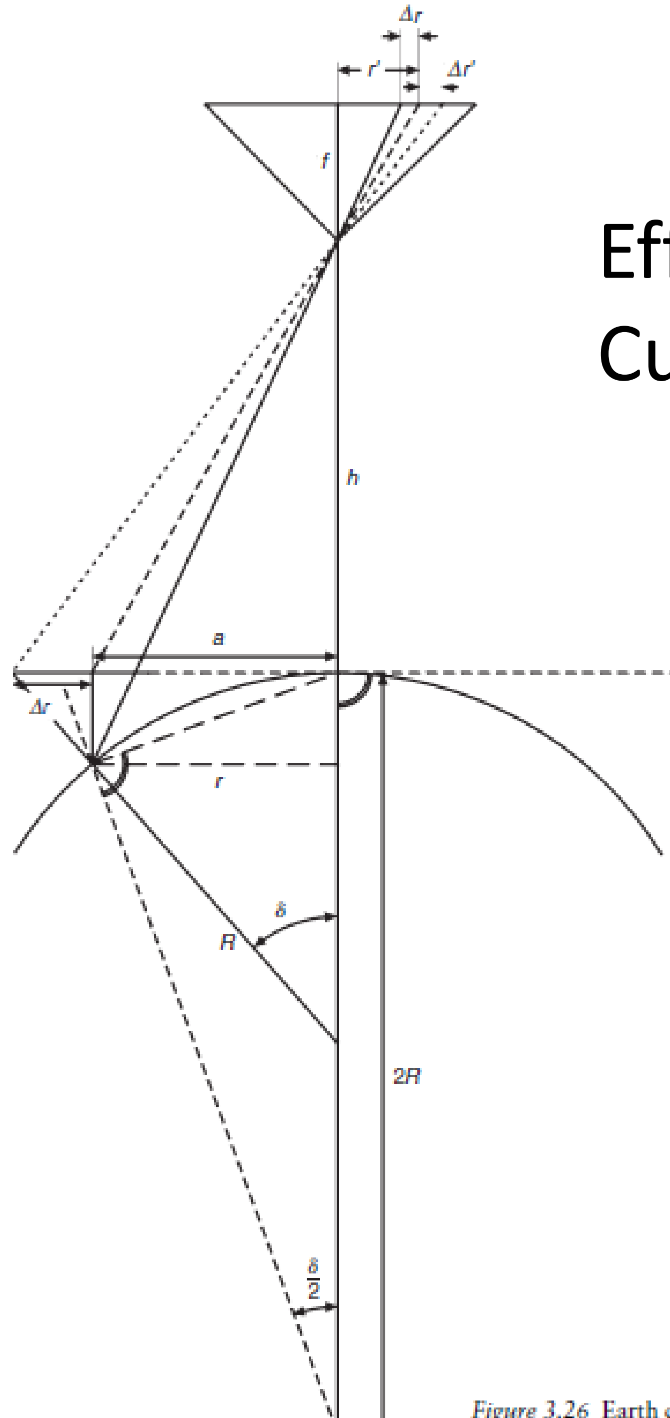


Figure 3.26 Earth curvature.

Atmospheric Refraction

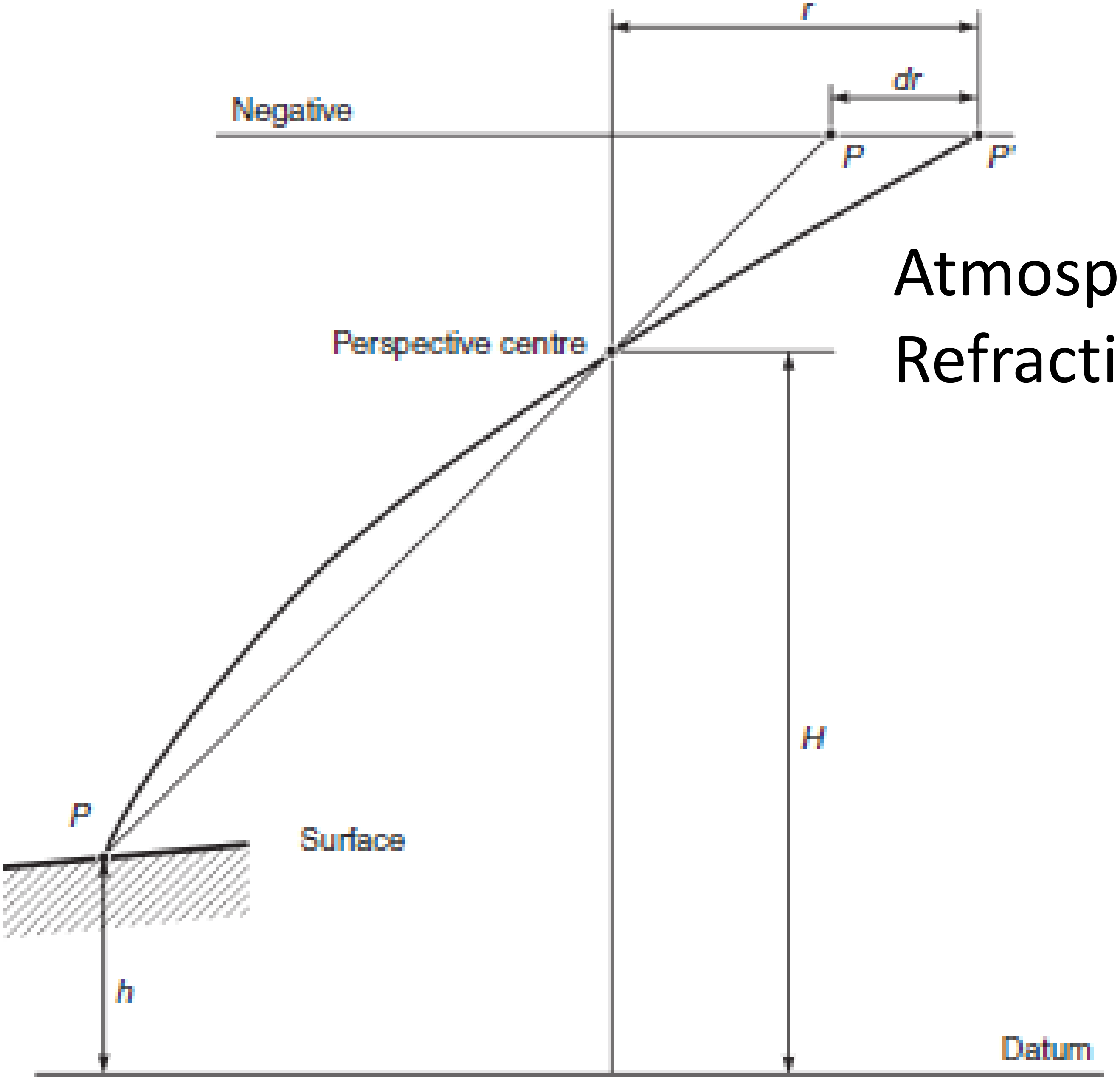


Figure 3.27 Atmospheric refraction.

Vertical Photographs

Scale of a Vertical Photograph

- Scale of a photograph is the ratio of a distance on a photo to the same distance on the ground.
- Photographs are not maps, why?
- Scale of a map and scale of a photograph.
- Orthphotos (orthophoto maps), what are they?
- Scale (s) at any point:

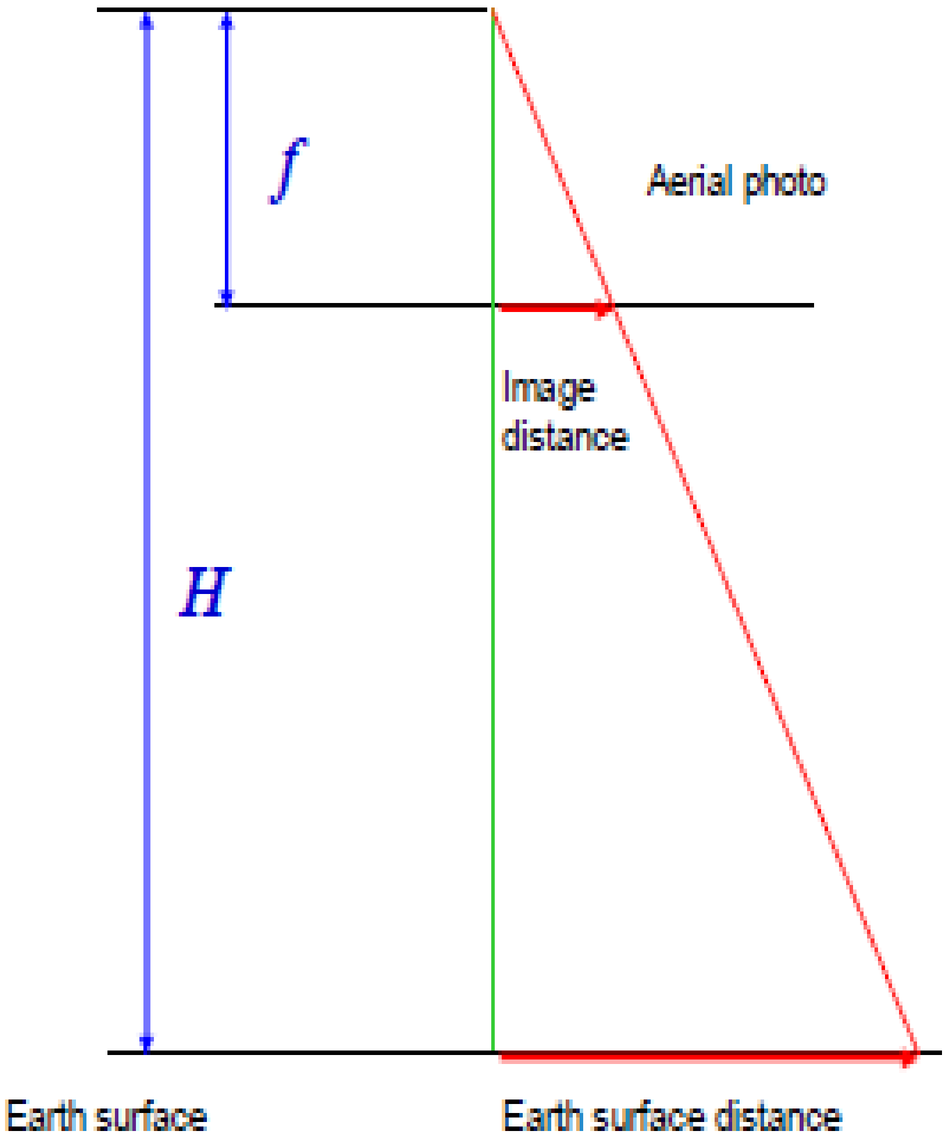
$$\boxed{S = \frac{f}{H - h}}$$

- Average scale of a photograph:

$$\boxed{S_{avg} = \frac{f}{H - h_{avg}}}$$

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

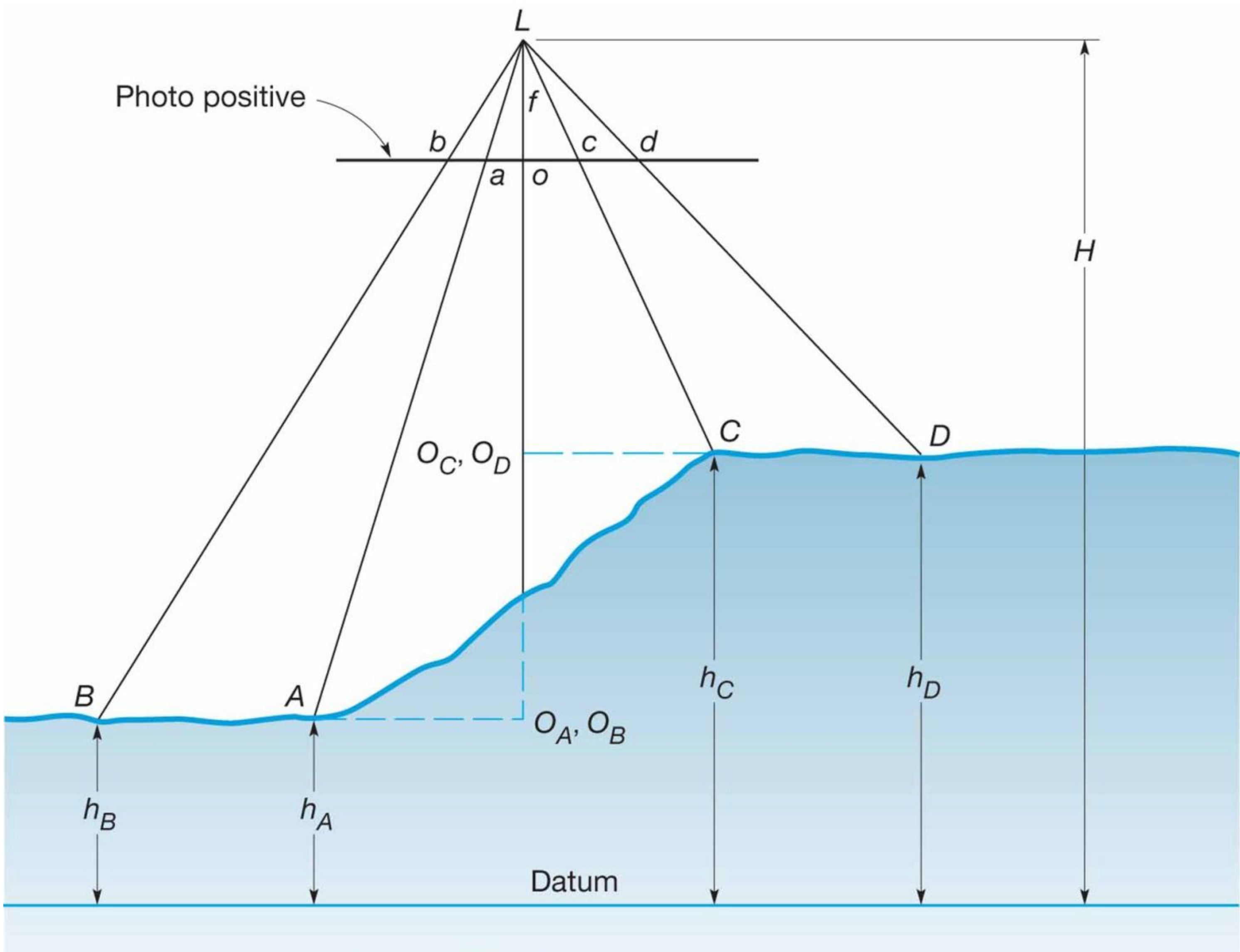
$$\boxed{\text{Photo Scale} = \frac{\text{photo distance}}{\text{map distance}} \times \text{map scale}}$$



The scale of a vertical photograph approximately equals to the ratio of the flying height above the ground (*H*) and the focal length of the camera lens (*f*)

$$Scale = \frac{imageDist}{surfaceDist} = \frac{f}{H}$$

Scale of a vertical photograph.



Ground Coordinates from a Single Vertical Photograph

- With image coordinate system defined, we may define an arbitrary ground coordinate system parallel to (x,y) origin at nadir.
- That ground system could be used to compute distances and azimuths. Coordinates can also be transformed to any system
- In that ground system:

$$\boxed{\begin{array}{l} X_a = x_a * \text{(photograph scale at a)} \\ Y_a = y_a * \text{(photograph scale at a)} \end{array}}$$

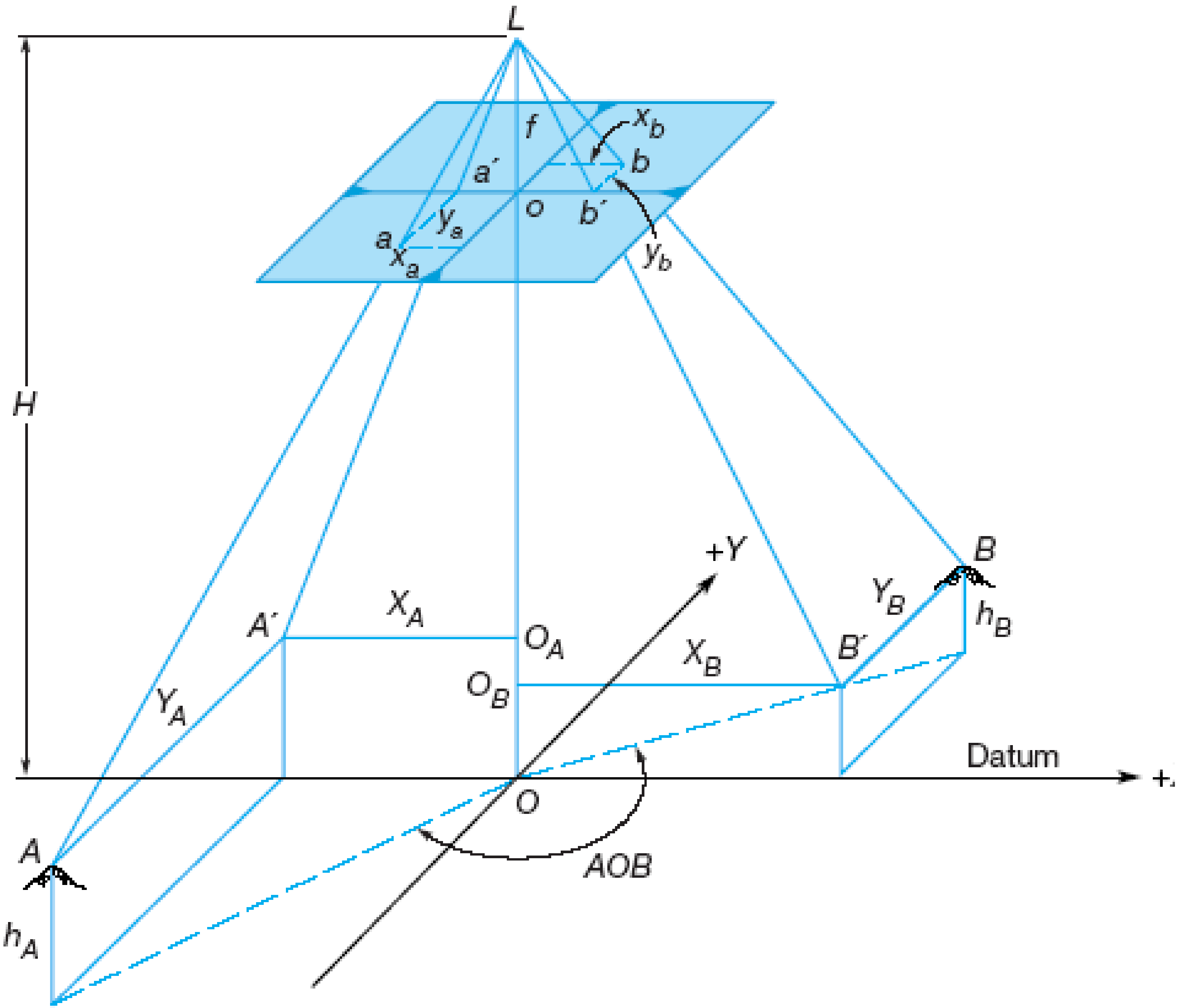


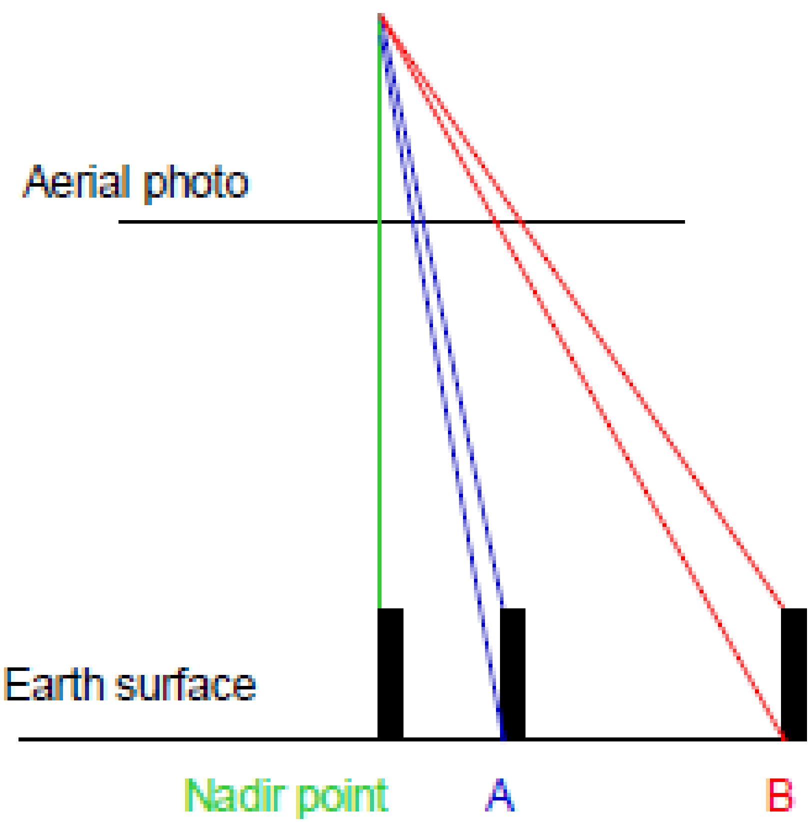
Figure 27–8 Ground coordinates from a vertical photograph.

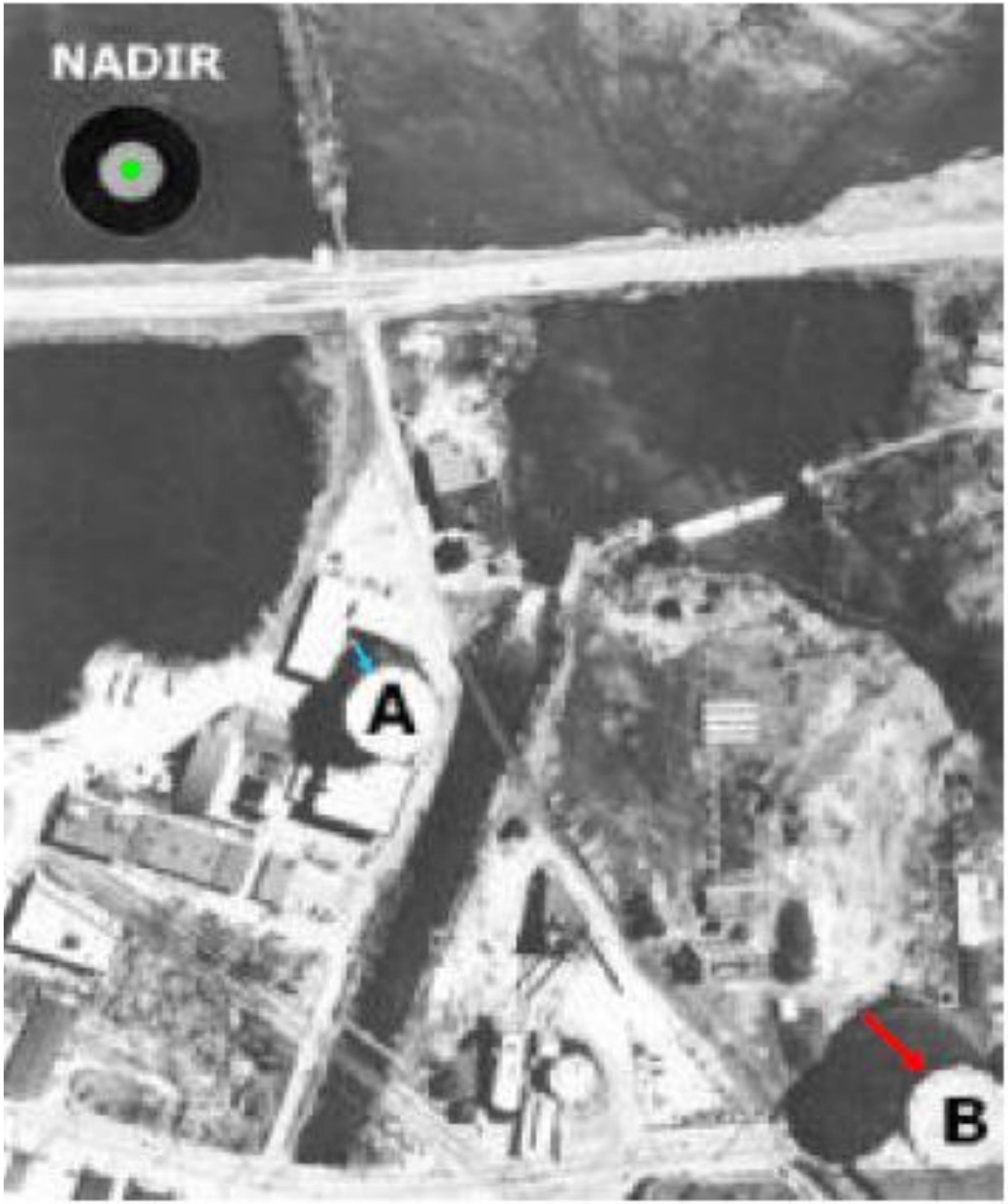
Relief Displacement on a Vertical Photograph

- 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.
- The displacement is from the photgraphic nadir point. In a vertical photo, the displacement is from the principal point, which is the nadir in this case.
- Photographic Nadir point is where the vertical from the Exposure Station intersects the photograph.

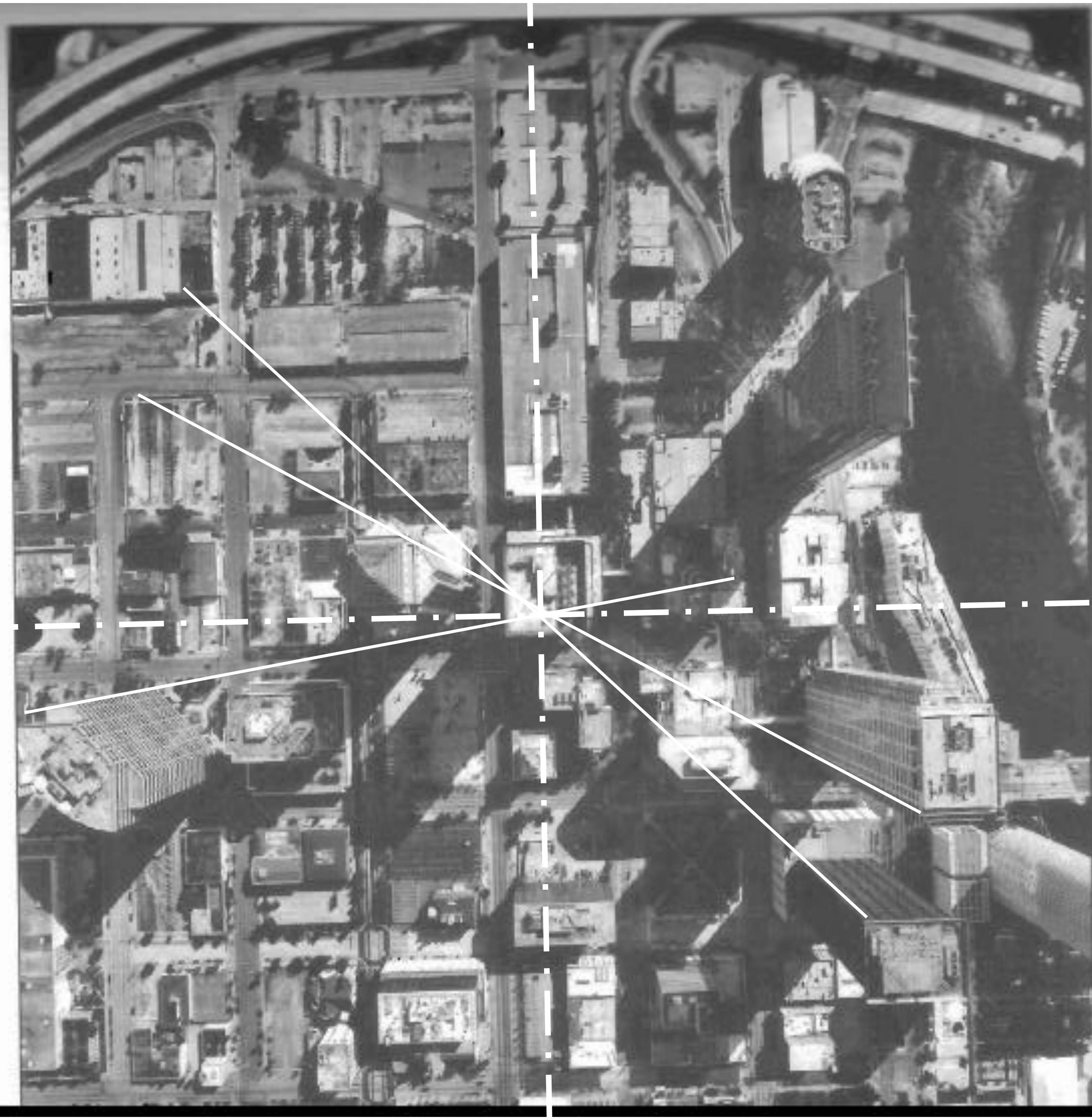
Relief displacement

Towers A and B are equally high, but placed at different distances from the nadir point, thus have different relief displacements. A tower, depicted beneath nadir point has no relief displacement





Relief displacement from Nadir (enlarged)



Relief displacement from Nadir (Center)

$r_a/R = f/H$

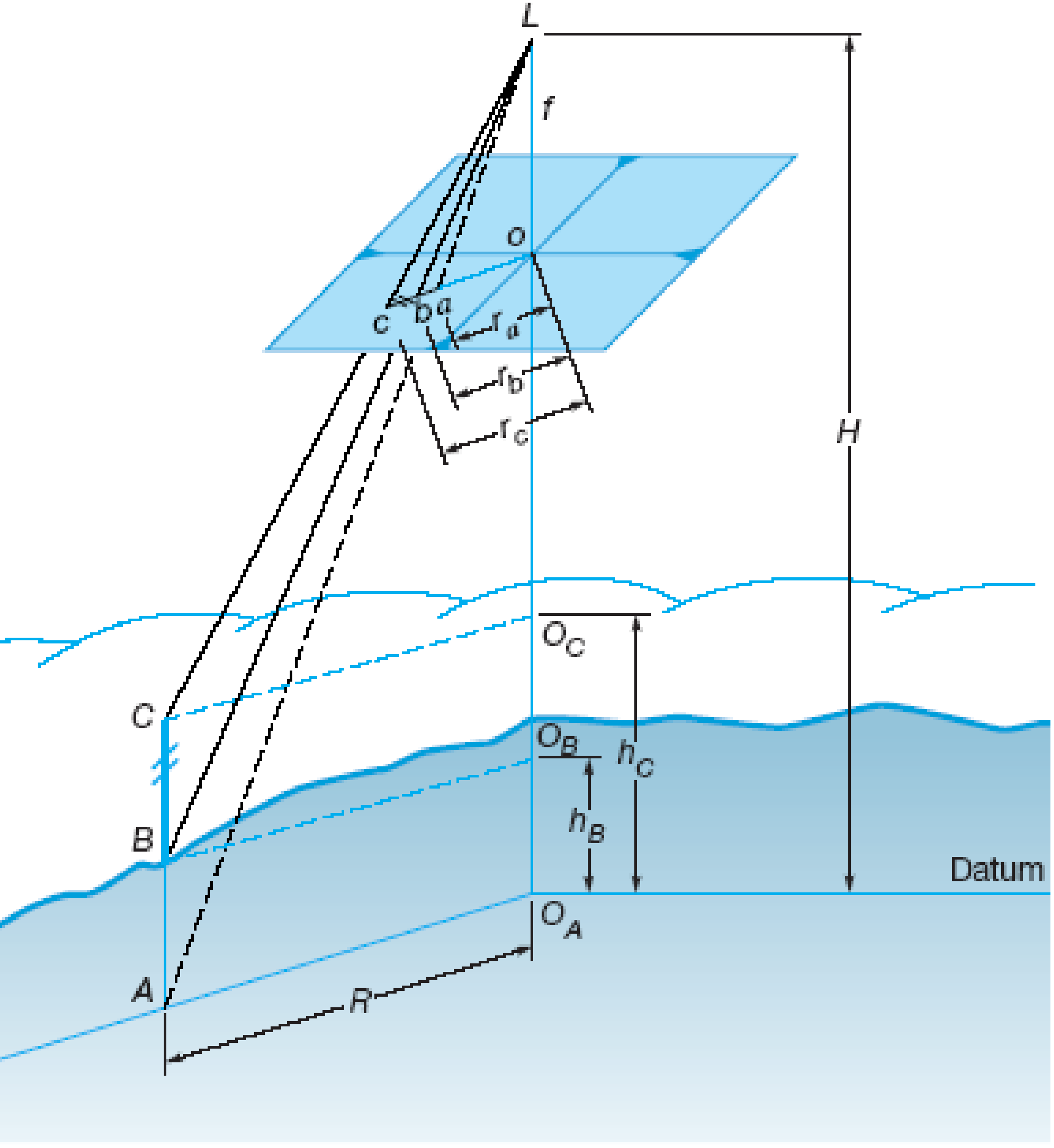


Figure 27–9 Relief displacement on a vertical photograph.

- Relief displacement (d) of a point wrt a point on the datum :

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

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.

Or, in general:

Assume that point C is vertically above B, they are shown on the photograph as (c) and (b).

Measured radial distances from the center to points c and b (r_c and r_b) , then

$d_c = r_c - r_b$ and;

$d_c = (r_c * ht_c) / (\text{flying height above ground} = H - h_b)$

Example 6-7. A vertical photograph taken from an elevation of 535 m above mean sea level (MSL) contains the image of a tall vertical radio tower. The elevation at the base of the tower is 259 m above MSL. The relief displacement *d* of the tower was measured as 54.1 mm, and the radial distance to the top of the tower from the photo center was 121.7 mm. What is the height of the tower?

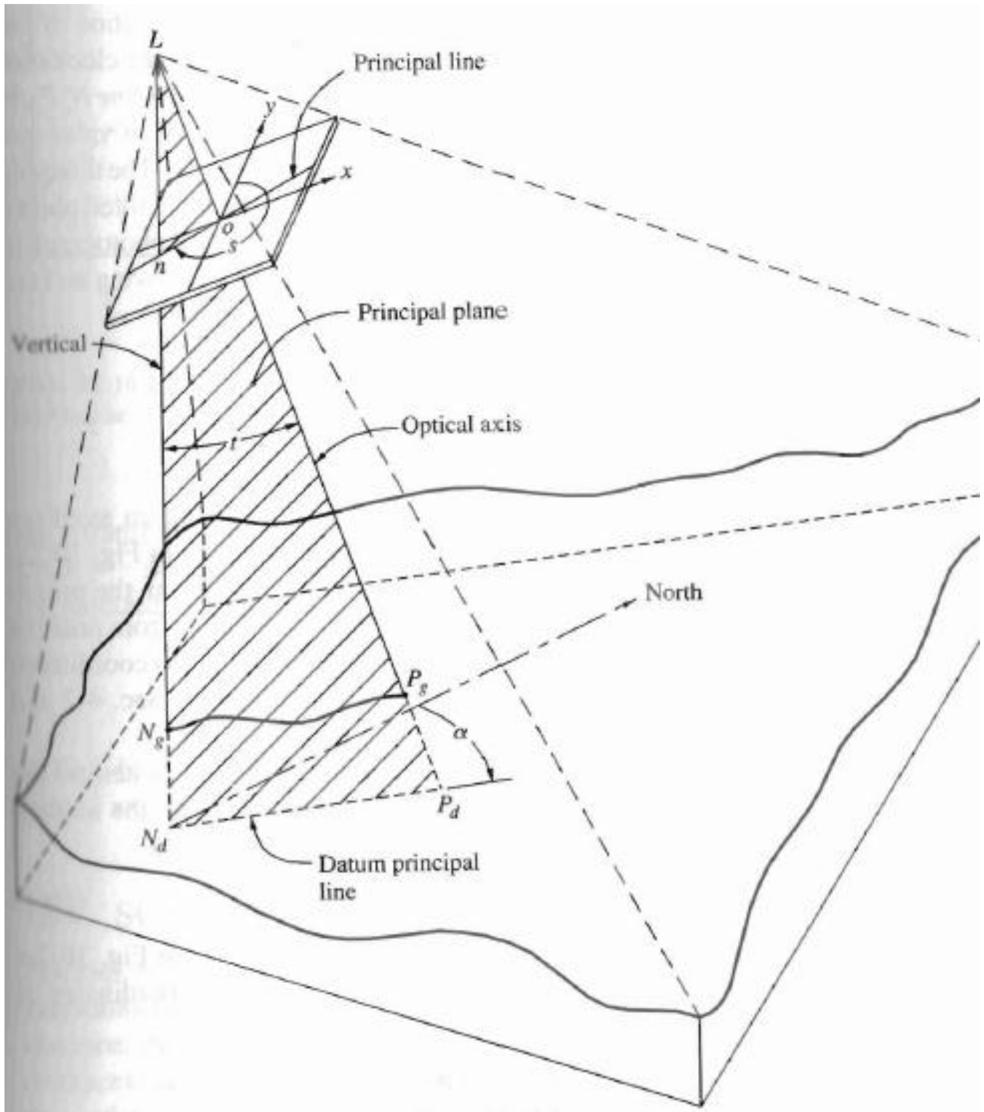
Answer:

$d = r\, h / H'$, then

$H' =$

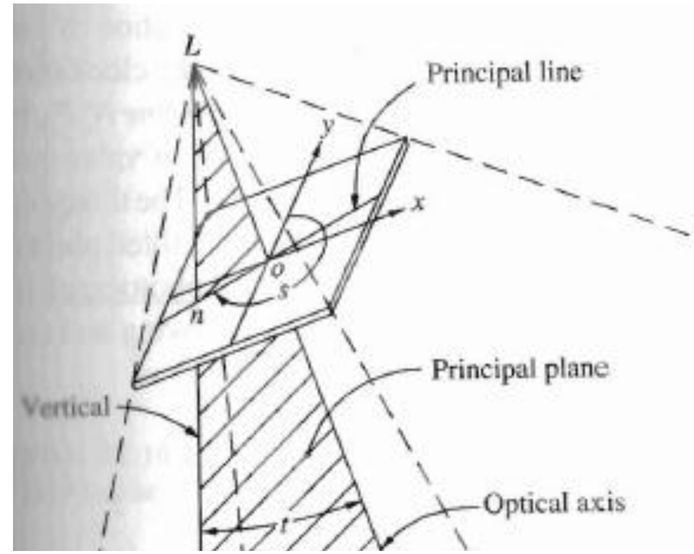
$H =$

Tilted Photographs

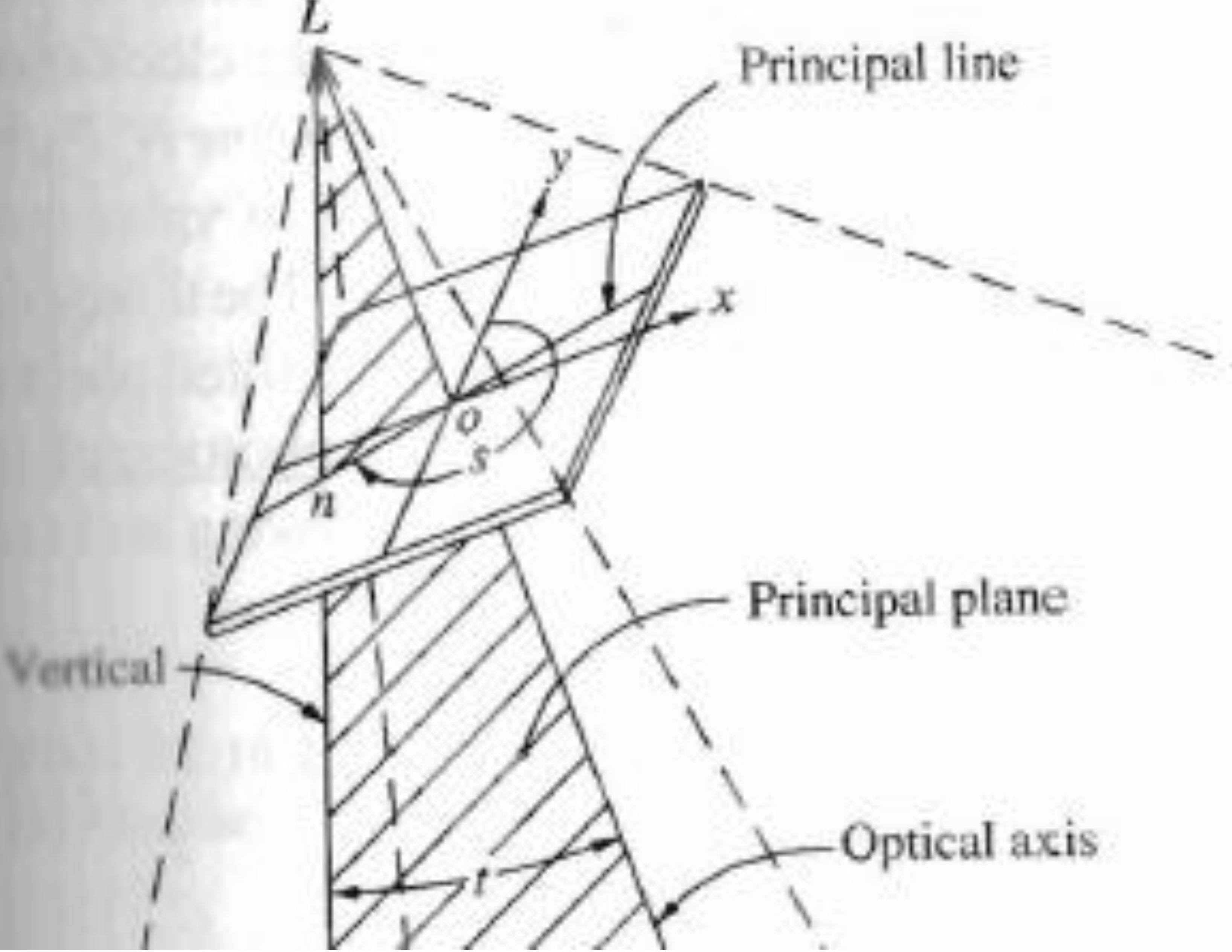


Basic elements of a tilted photographs

- The optical axis is tilted from the vertical
- Identify the following:



- t = angle of tilt between the plumb line and the optical axis L0
- *i* = the isocenter: the line bisecting the tilt angle intersects the principal line in the isocenter.
- no = the principal line joining the nadir point (n) and the principal point (0).

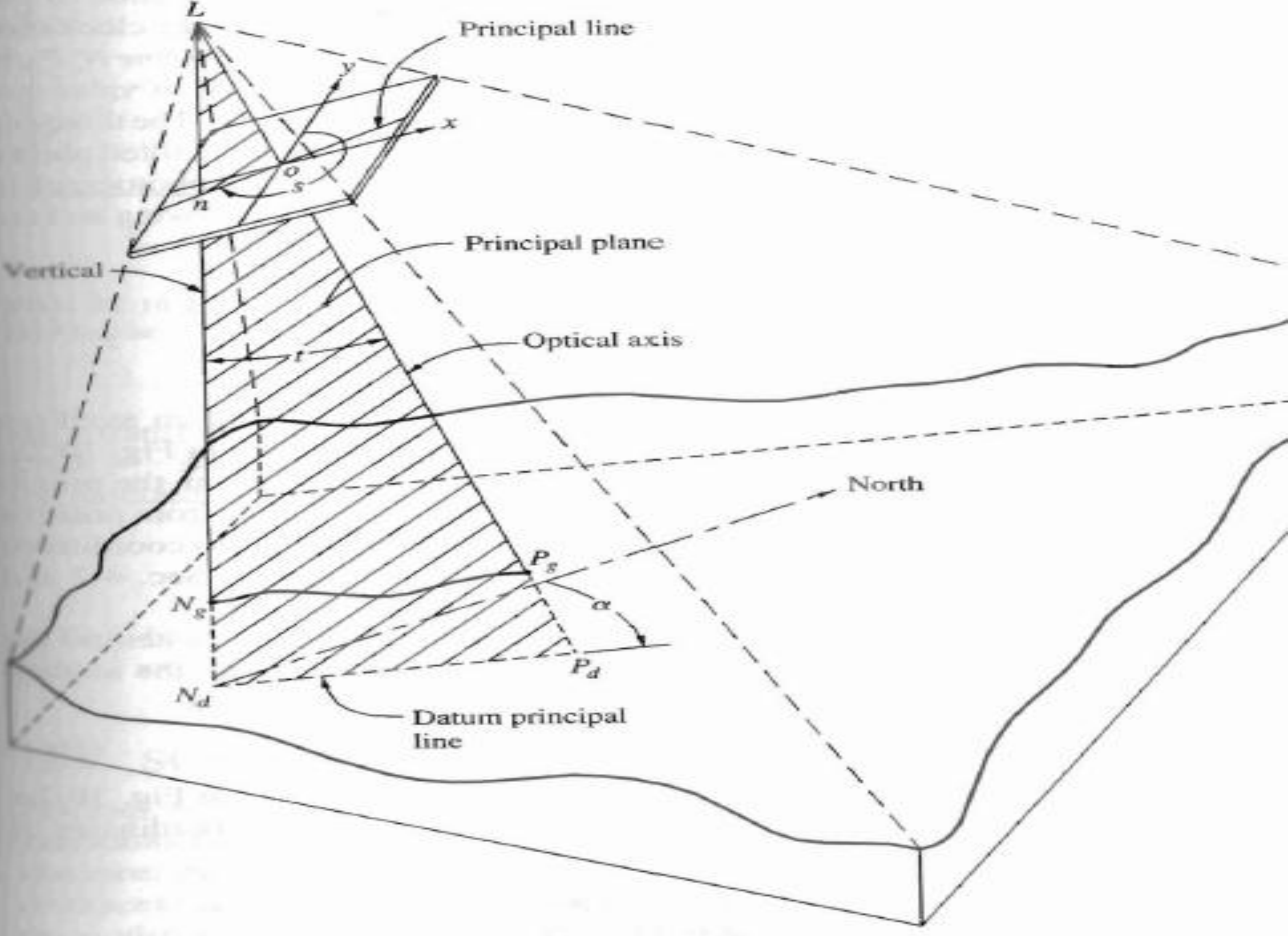

L
Principal line
y
x
o
s
n
Principal plane
Vertical
t
Optical axis

- Lno = the principal plane: it is the vertical plane containing o, L and n (shaped plane).
- *im* = axis of tilt: it is the line perpendicular to the principal line from the isocenter *i* in the plane of the photograph.
- S = the swing angle: it is the angle measured from the positive photographic y-axis clockwise to the principal line (on).
- x'y' axes are the auxiliary coordinate system of the tilted photograph where:

y' is the principal line (no).

x' is the perpendicular to y' from point *n* .

θ = the rotation angle between y and y' axes in a counterclockwise direction.



L
Principal line
y
x
o
s
n
Principal plane
Vertical
Optical axis
t
North
P_g
N_g
α
P_d
N_d
Datum principal
line

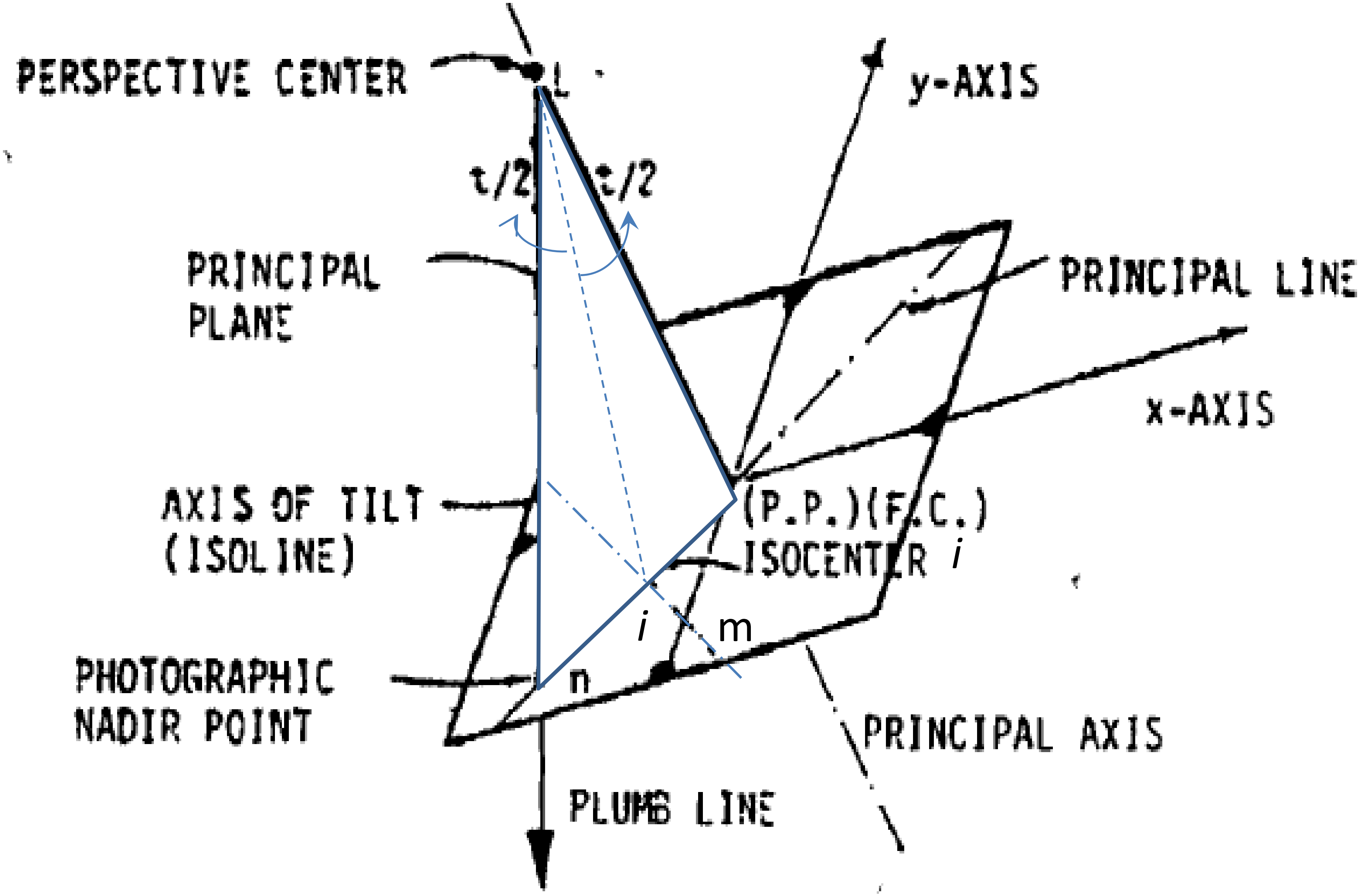
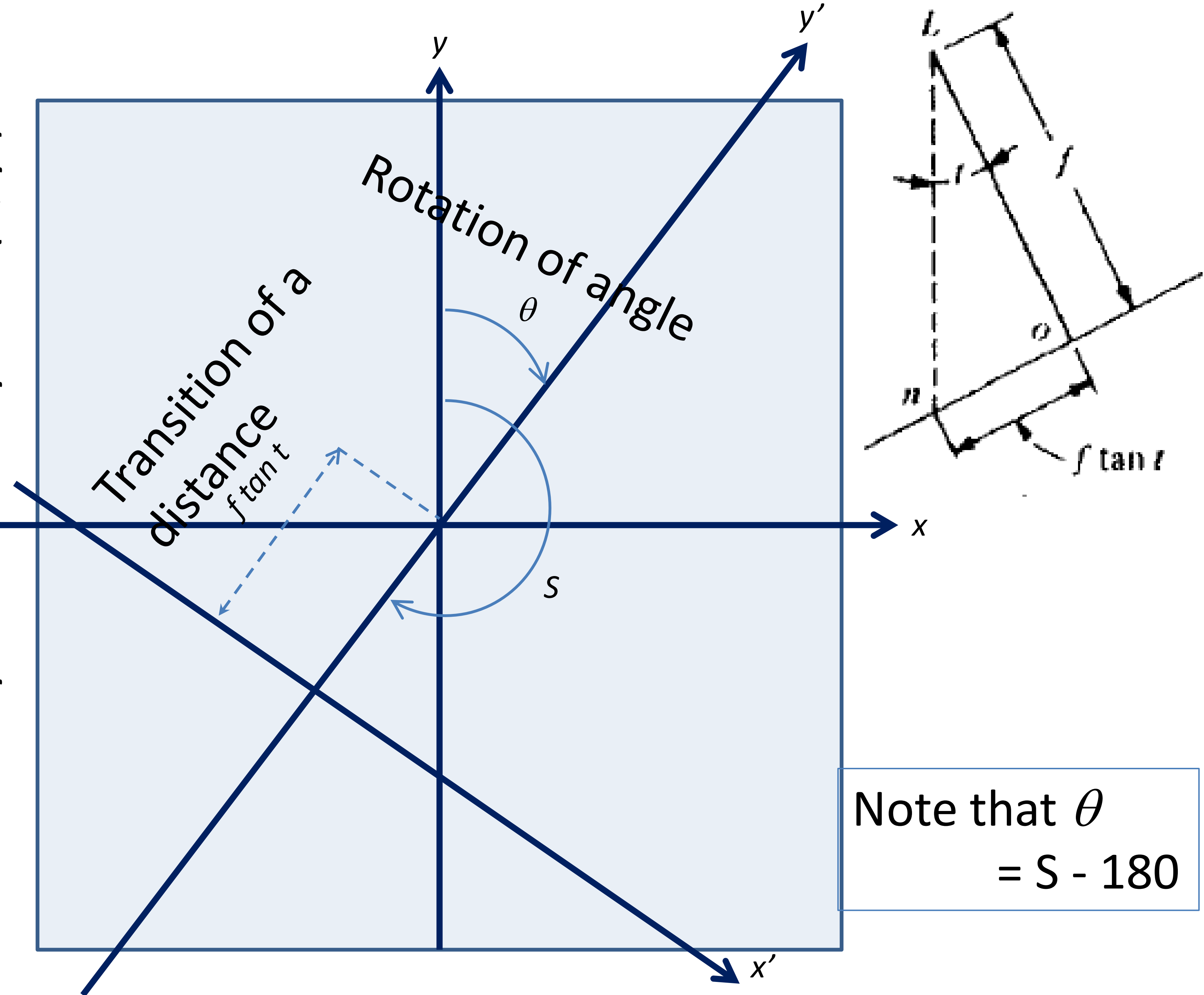


Figure (3-6) Basic elements of tilted photograph

What and why an auxiliary coordinate system?

- A step to relate photo coordinates to ground, because the photograph is tilted.
- Thus, photo and ground coordinates are not parallel any more.
- You need a system in between as a step to transfer photo coordinates to ground, specially that tilt is variable.

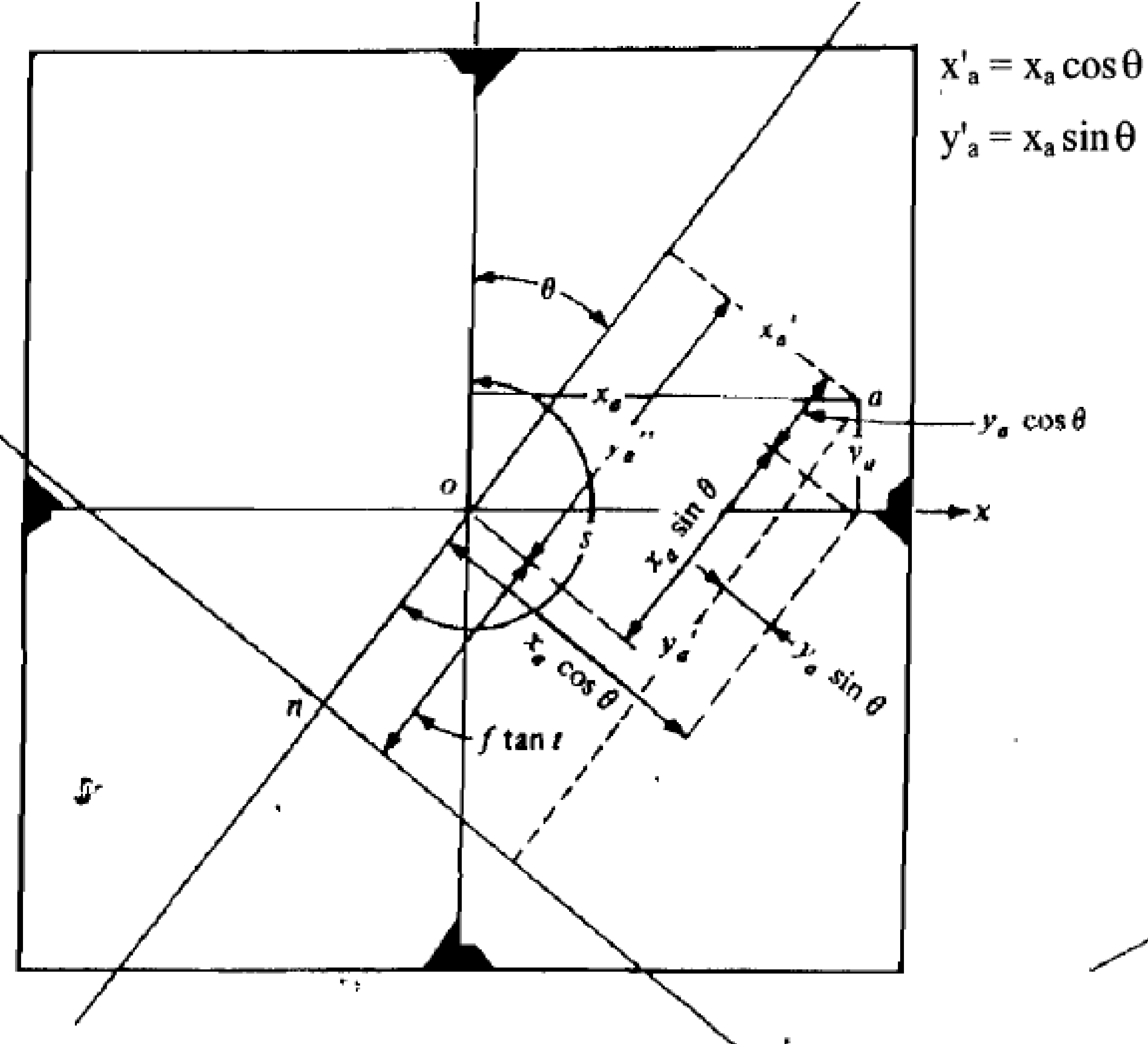
Transformation from photo coordinates (*x*, *y*) to an auxiliary coordinate system (x', y')



Note that θ = S - 180

$$x'_a = x_a \cos\theta - y_a \sin\theta$$

$$y'_a = x_a \sin\theta + y_a \cos\theta + f \tan t$$



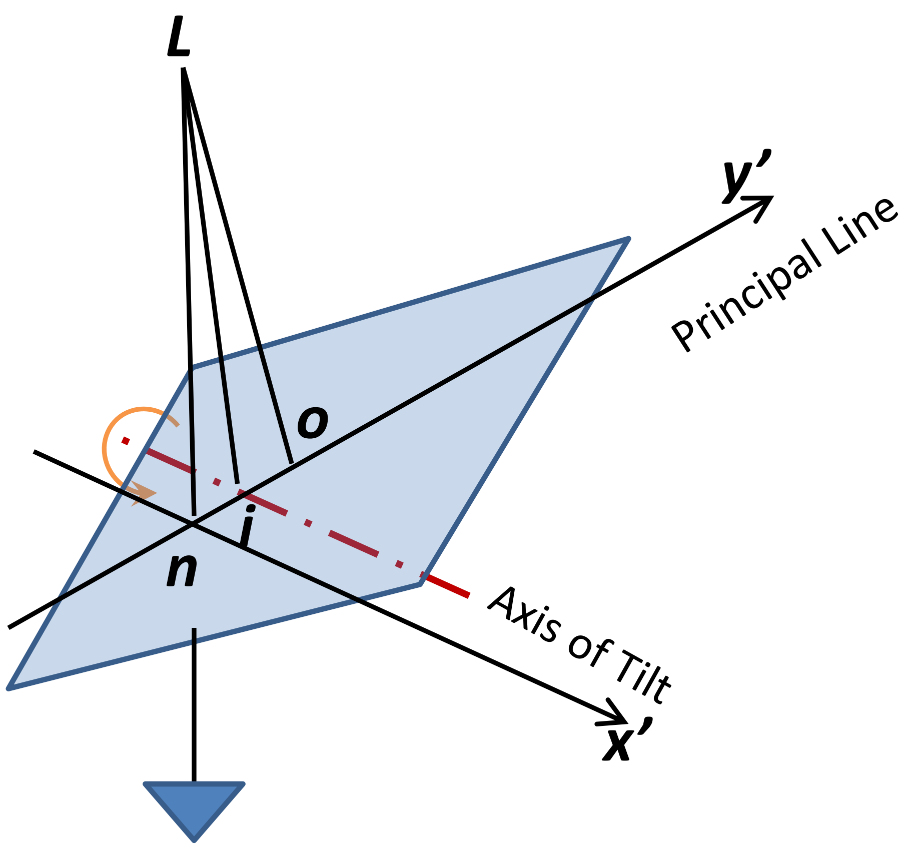
Relationship between Photo and Auxiliary coordinate system

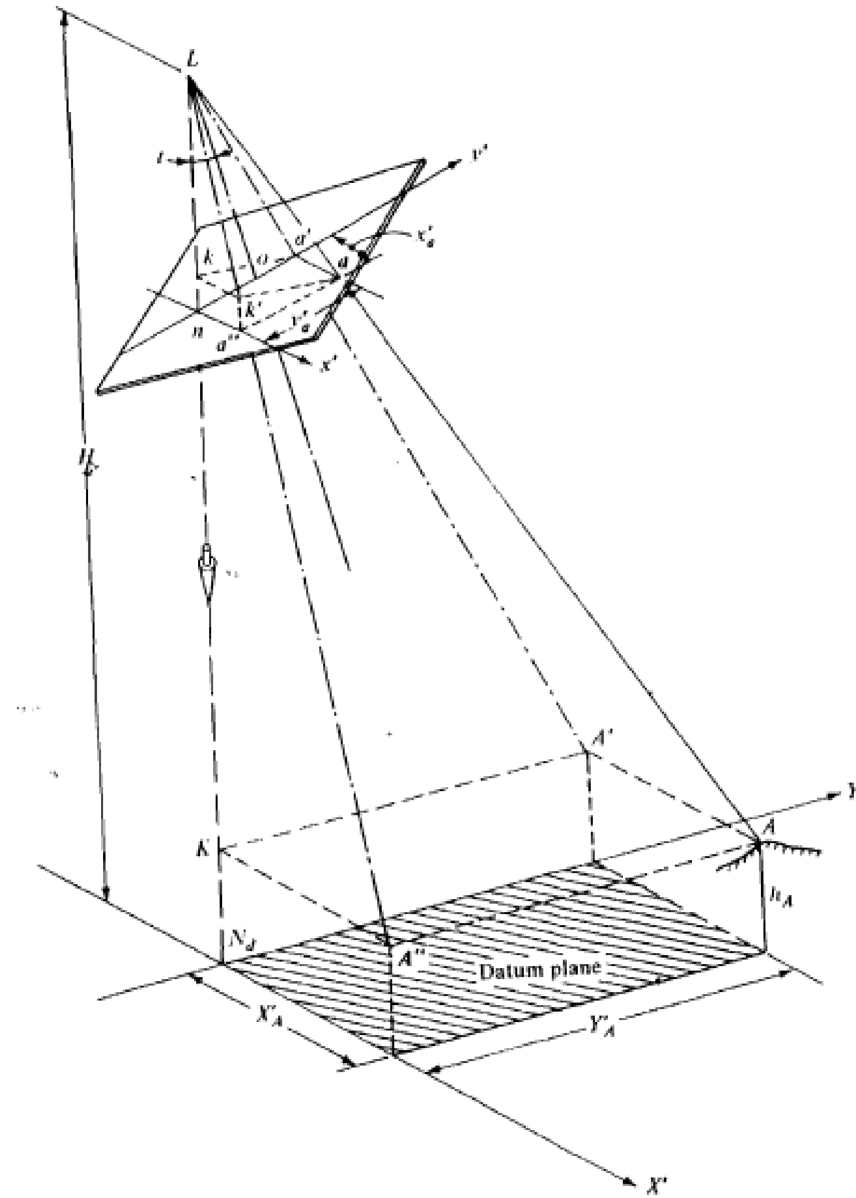
$$x'_a = x_a \cos\theta - y_a \sin\theta$$

$$y'_a = x_a \sin\theta + y_a \cos\theta + f \tan t$$

Scale of a tilted Photograph

The tilt of a photograph occurs around the axis of tilt in the direction of the principal line.

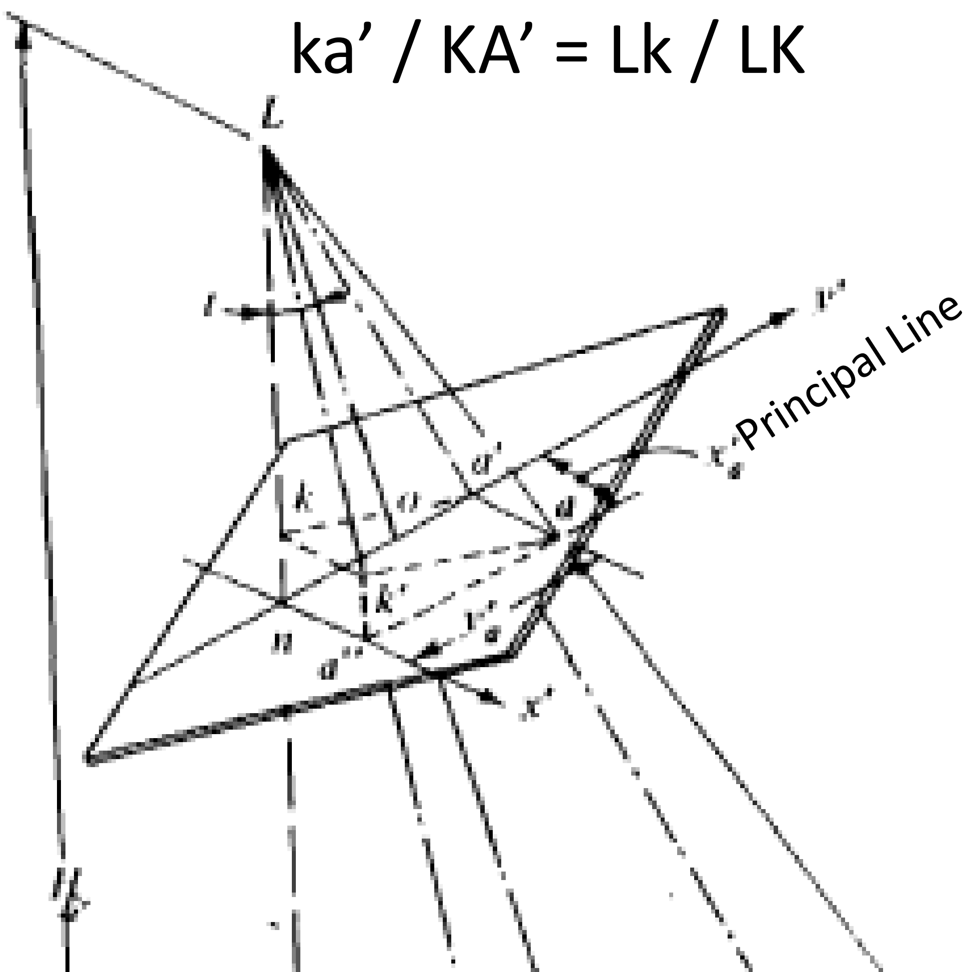


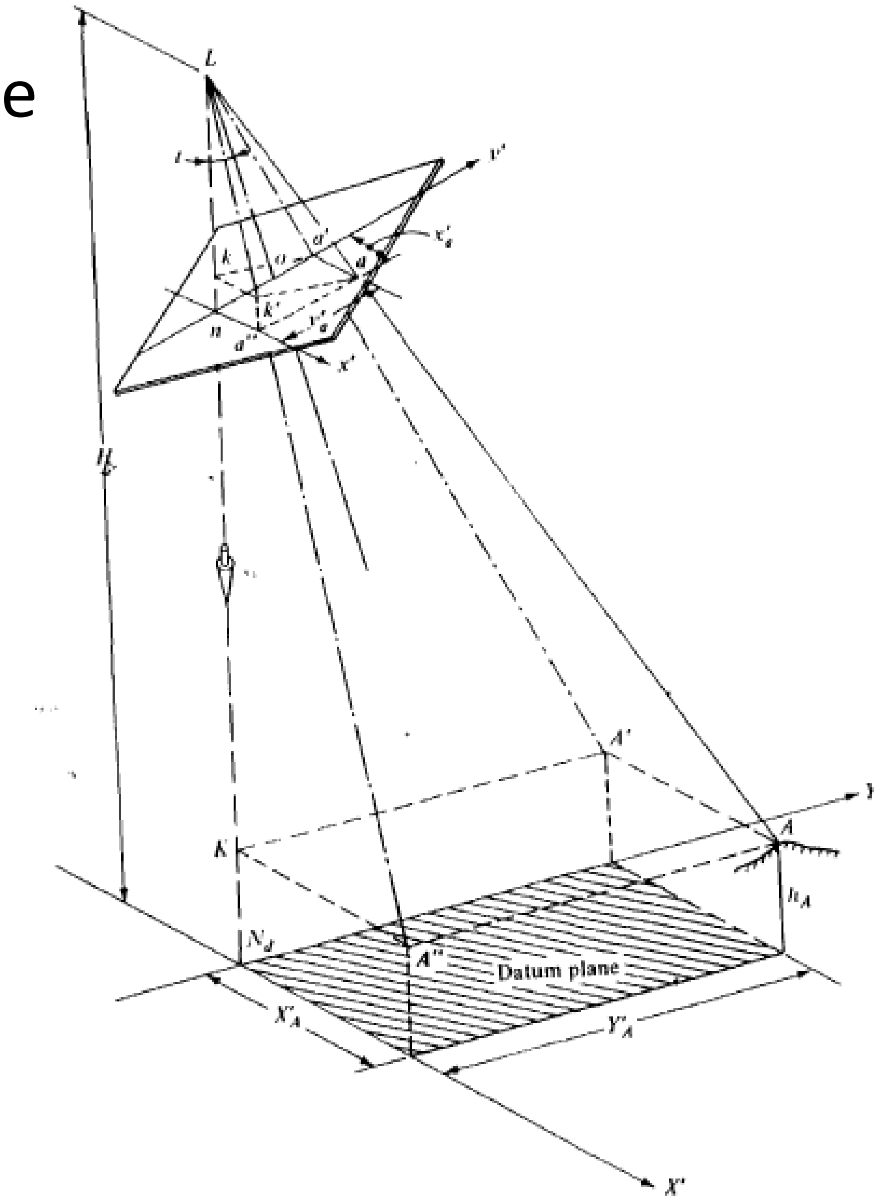


Scale of a tilted Photograph

- Scale = horizontal distance on the photo / horizontal distance on the ground =

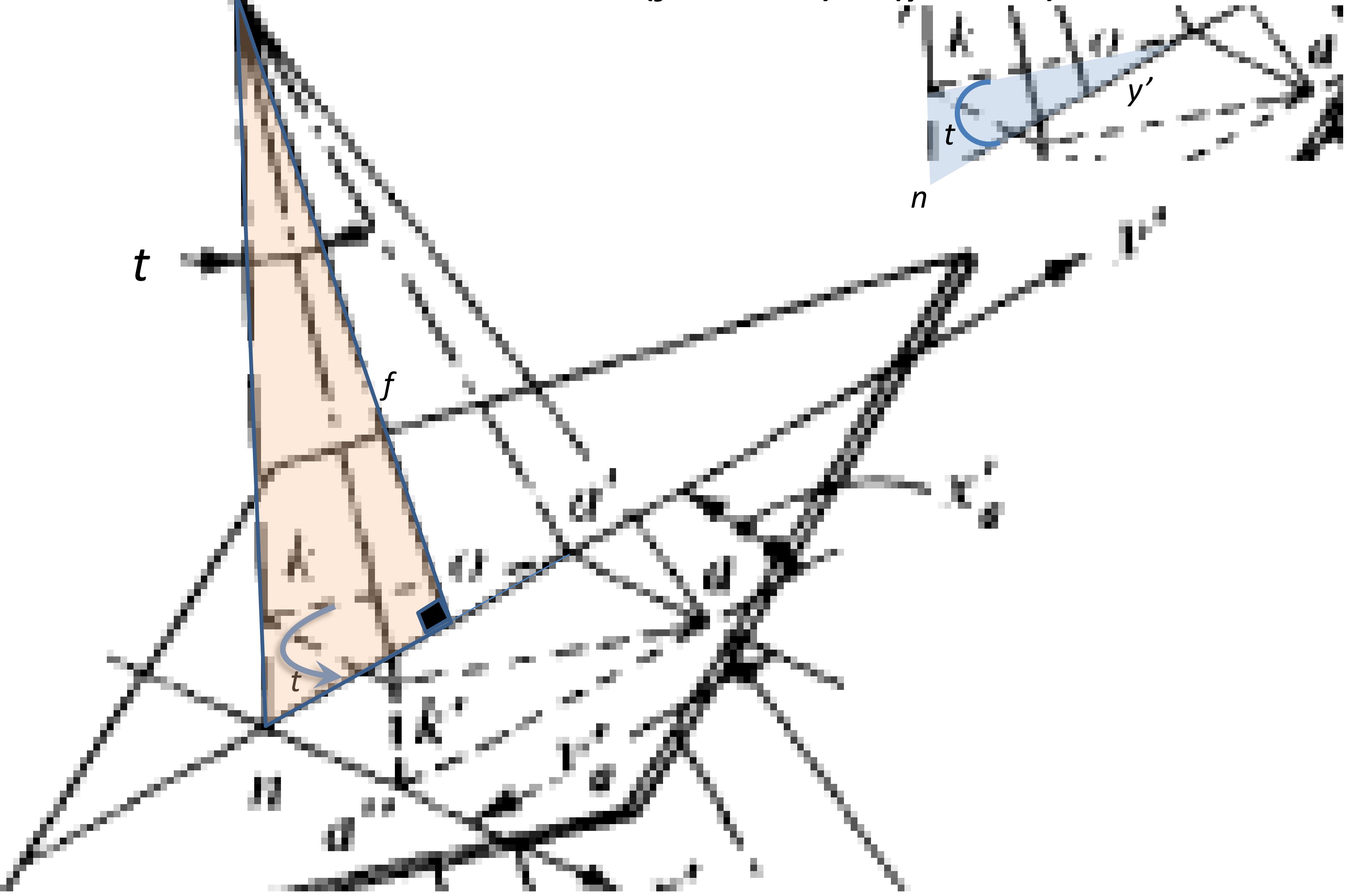
  $$ka' / KA' = Lk / LK$$





S = Lk / LK, but:

Lk = Ln – nK = *(f /cost t) – (y’ sin t), and*

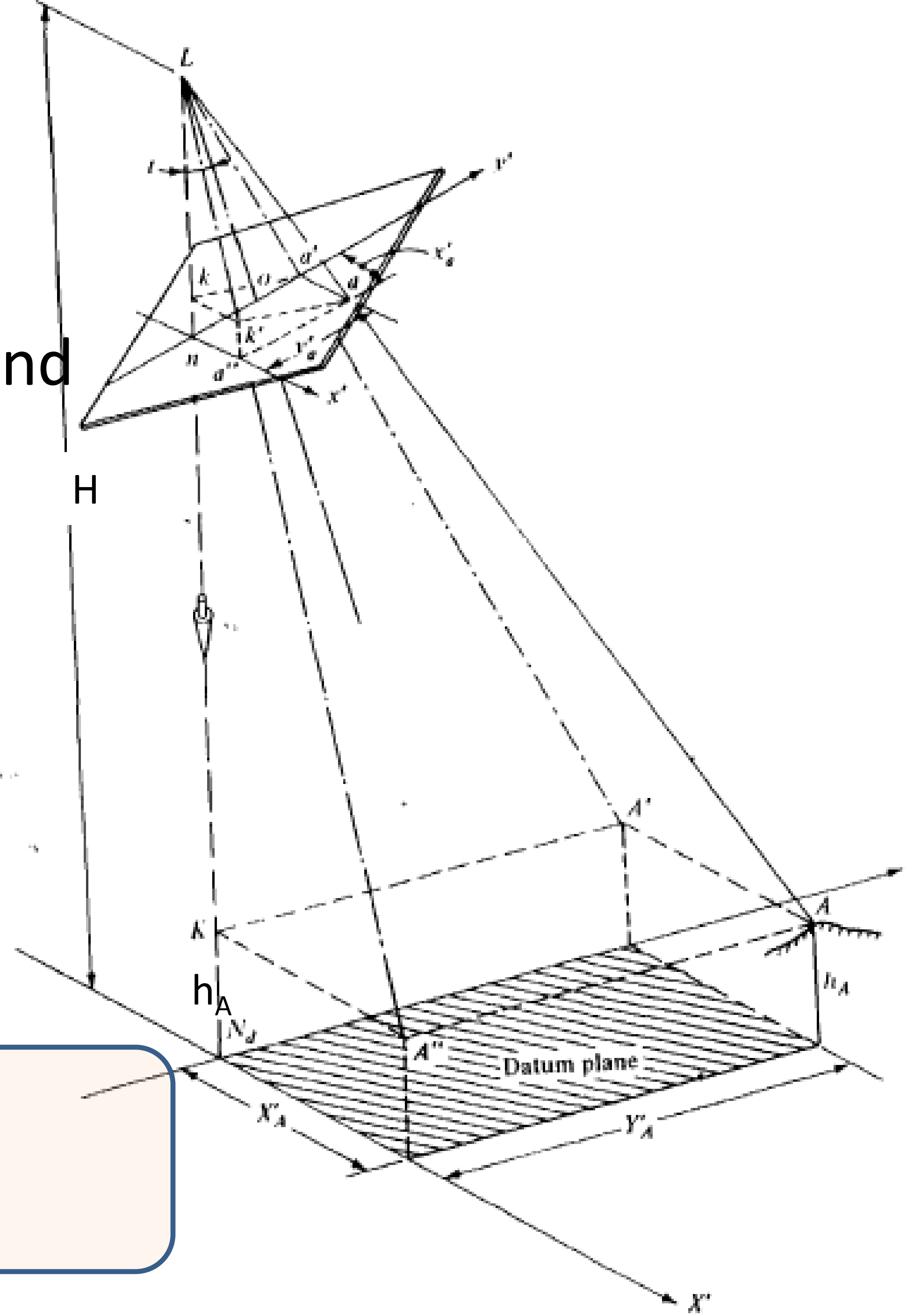


Also,

$LK = H - h_A$

$\quad = $ flying height above ground

Then:



Scale of a tilted photograph

$S_A = f(\sec t) - y' \sin t \,/\, (H-h_A)$

Example

Example 3-1:

A tilted Photo is taken with a 6 inch focal length camera from a flying height of 8200 feet Tilt and swing angles are 3° 30° and 218° respectively. Point (A) has an elevation of 1435 feet and its image coordinates are xa = -2 85 inch. ya 3.43 inch . What is the scale at point (a) ?

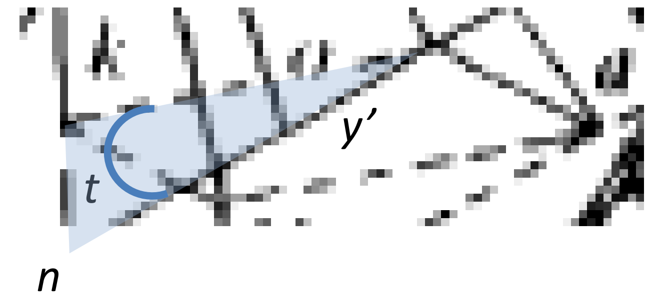
Solution

$\theta =$

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

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



- 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,
- $Y' = y'\cos t / S$

Example

Example 3-1:

A tilted Photo is taken with a 6 inch focal length camera from a flying height of 8200 feet Tilt and swing angles are 3^{0} 30^{0} and 218^{0} respectively. Point (A) has an elevation of 1435 feet and its image coordinates are xa = -2 85 inch. ya 3.43 inch . What is the scale at point (a) ?

If the image coordinates of another point (b) are xb = 3.09 inch, yb 1 .78 inch. and the elevation of (B) is 1587 feet .calculate ground coordinates of (A) and (B).