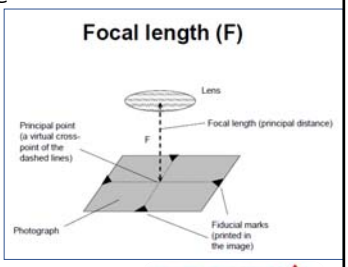
Geometry of Aerial Photographs

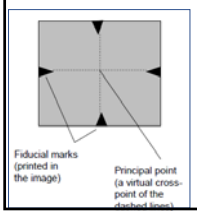
Definitions

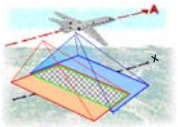
1

Photo Coordinate System

Defined by the fiducials in a film camera.
(x) axis is in direction of flight







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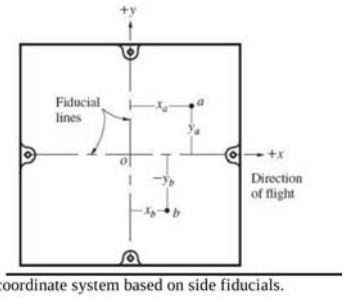

Photographic coordinate system based on side fiducials.

3

Photo Coordinates (film)

Repeated slide

- 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

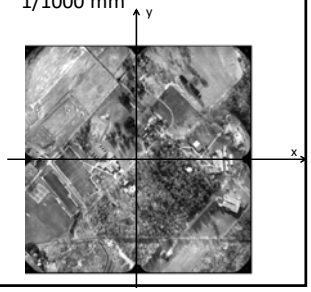

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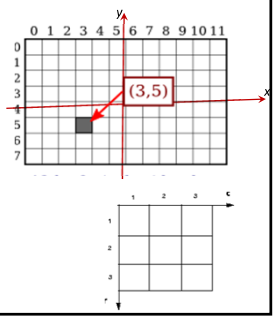
Photo Cooedinates (Digital) (x, y) and (r, c)

Repeated slide

- In a digital image, we measure rows and column locations(r, c).
- In a digital camera, the relationship between pixel locations in (r,c) and photo (x,y) at center is defined within the camera, no need for additional transformation
- In a film camera, the relationship is between photo fiducials (x,y) and ground (X, Y).
- When we scan a photo taken by a film camera, it becomes in a digital format, we measure (r,c). In this case, we need to transform (r,c) that we measure to (x,y) photo coordinates to apply the equations.
- A two-dimensional coordinate transformation from (r, c) to (x, y) is needed if the camera is not digital.



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Geometry of aerial cameras

- Identify the following:
- Photo Coordinate System(right-handed)
- L: perspective center.
- Fiducial Center F.C.: intersection of (x), and (y) axis as defined by the fiducials (in a film camera).
- 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.

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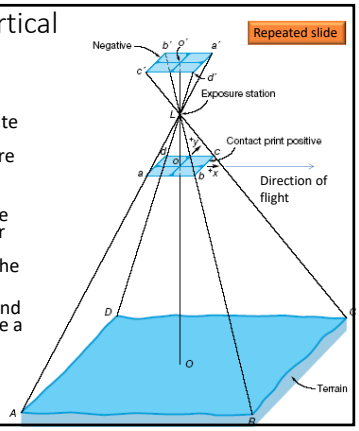
Geometry of Vertical Photographs

Repeated slide

- Define: image coordinate system (right handed), principal point, exposure station.
- If a film is used, measurements could be done using negatives or diapositives, same geometry, referred to the fiducials
- In digital images, row and columns of pixels define a coordinate system



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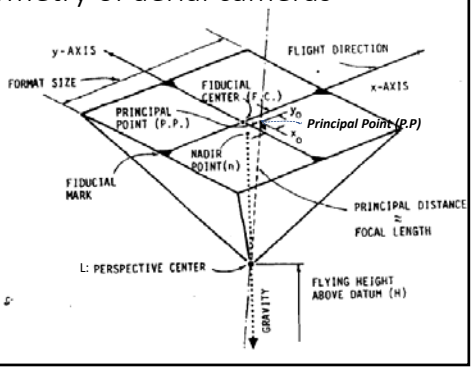
Geometry of aerial cameras

Repeated slide



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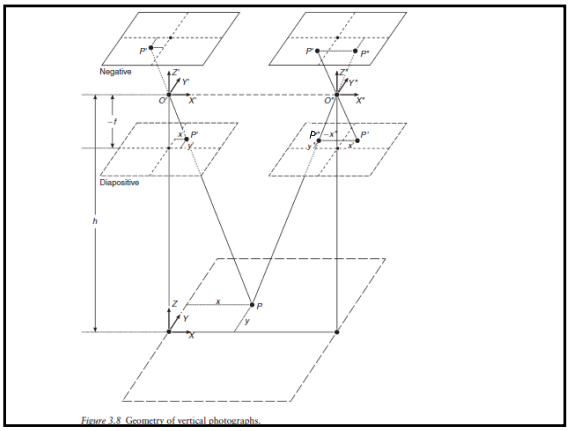

Figure 3.8 Geometry of vertical photographs.

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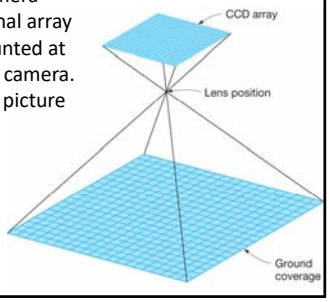
Geometry of a digital frame camera

- 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)



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Vertical Photographs

Single Photo Applications
Scale

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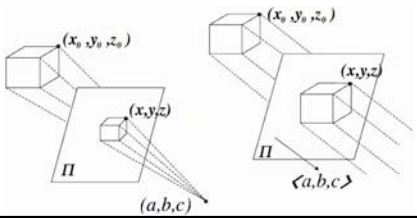
Scale of a Vertical Photograph

- Scale of a photograph is the ratio of a distance on a photo to the same distance on the ground.
- Differences between photographs and maps:
  - Projection: orthogonal or prospective
  - Scale constant on maps, but varies on photos. The closer the object to the camera (higher), the bigger it looks.



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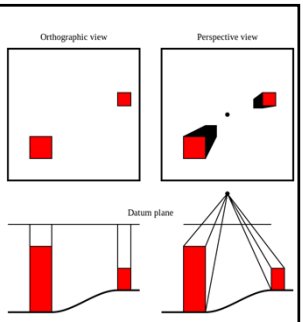
Orthophoto maps

- geometrically corrected images, can be used as maps.
- The shift in image is proportional to the relief " height" of location in a photo.
- A DTM is needed to correct "rectify" the image so that images are displaced to their corresponding location on maps.



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Orthophoto from a drone

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Orthophotos and True Orthophotos

- Orthophotos are corrected for relief of topography, top of tall structures are still shifted.
- True orthophotos are produced from multiple images to eliminate the displacement of the top of tall objects.

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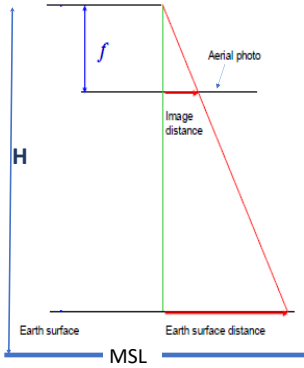
- Scale of a photograph is the ratio of a distance on a photo to the same distance on the ground.



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

(Assuming horizontal flat terrain)

$$Scale = \frac{imageDist}{surfaceDist} = \frac{f}{H\text{-}h}$$

h: ground elevation

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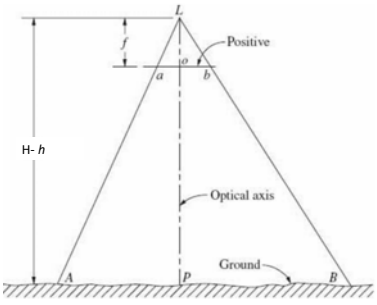

- Scale of a vertical photo of flat horizontal ground is:

S =*f* /(H-*h*)

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Aerial photograph taken at 460 m above ground, scale 1: 3,000

18

Aerial photograph taken at 910 m above ground, scale 1: 6,000

19

Aerial photograph taken at 1830 m above ground, scale 1: 12,000

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Note that all the photos are of the same area.

Aerial photograph taken at 3660 m above ground, scale 1: 24,000

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Example

A vertical aerial جويهphotograph is taken over flat terrain ارض with a 152.4 mm-focal-length camera from an altitude ارتفاع of 1830 m above ground. What is the photo scale?

- Answer:

S = 152.4 mm/ 1830 m

= 0.1524 m / 1830 m =

1: 12,000

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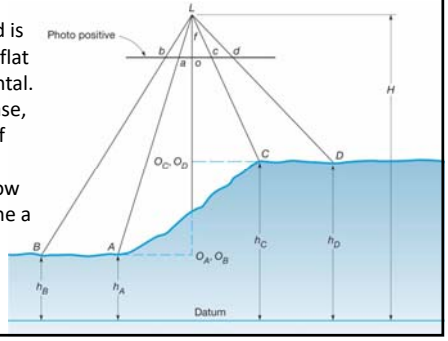
Scale of a vertical photograph over variable terrain

But, ground is not always flat and horizontal. H in that case, elevation of ground, is variable, how do we define a scale??



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Scale of a Vertical Photograph

- Definitions:

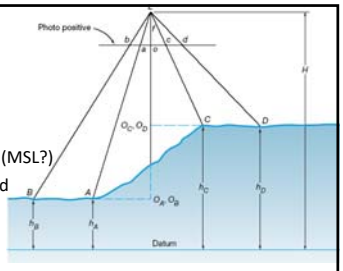
f: focal length of the camera

H: flying hight above datum (MSL?)

h: flying height above ground

- Scale (s) at any point:

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



- Average scale of a photograph:

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

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

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

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Example

Suppose that highest terrain h_1, average terrain h_{avg}, and lowest terrain h_2 of Fig. 6-3 are 610, 460, and 310 m above mean sea level, respectively. Calculate the maximum scale, minimum scale, and average scale if the flying height above mean sea level is 3000 m and the camera focal length is 152.4 mm.

Answer:

25

26

Example

On a vertical photograph the length of an airport runway measures 160 mm. On a map that is plotted at a scale of 1:24,000, the runway is measured as 103 mm. What is the scale of the photograph at runway elevation?

Answer

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Vertical Photographs

Single Photo Applications
Local Ground Coordinates

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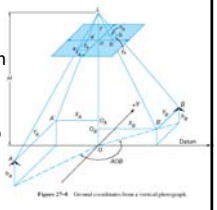
Ground Coordinates from a Single Vertical Photograph

- With a local image 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:

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

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



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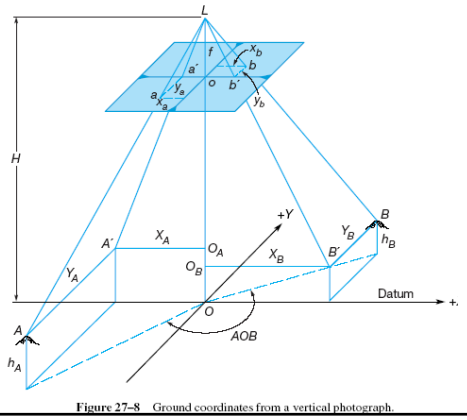

Figure 27–8 Ground coordinates from a vertical photograph.

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Example (consider answering on your own)

A vertical photograph was taken with a camera having a focal length of 152.3 mm. Ground points A and B have elevations 437.4 m and 445.3 m above sea level, respectively, and the horizontal length of line AB is 584.9 m. The images of A and B appear at a and b, and their measured photo coordinates are xa = 18.21 mm, ya = –61.32 mm, xb = 109.65 mm, and yb = –21.21 mm. Calculate the flying height of the photograph above sea level.

Answer:

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Vertical Photographs

Single Photo Applications
Relief displacement

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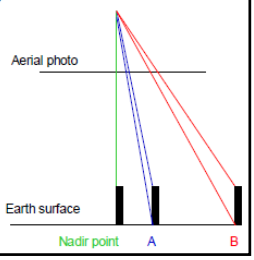
Relief displacement

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



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Relief displacement from Nadir (enlarged)

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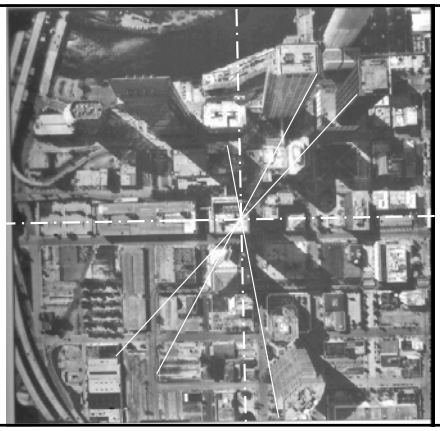

Relief displacement from Nadir (Center)

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Relief Displacement on a Vertical Photograph الازاحه بسبب الارتفاع

The shift of an image from its location as 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. الازاحه لنقطه علي الصوره من مكانها بسبب الارتفاع

- In a vertical photo, the displacement is from the principal point.

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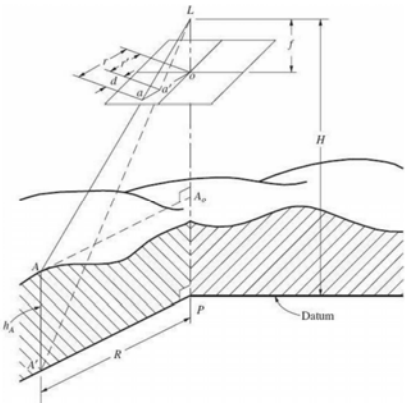
Example of geometry



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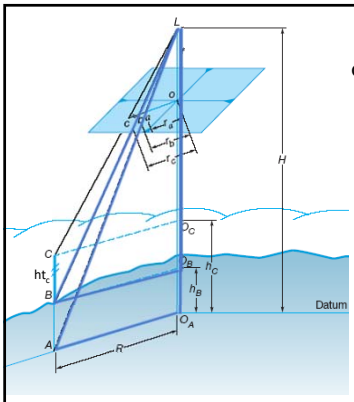

$r_a/R = f/H$

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

Similarly:

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

$\Rightarrow r_b * (H-h) = R * f$ ---(2)

Then from (1) and (2);

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

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

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

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- Relief displacement (d) of a point with respect to 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.

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Also:

$r_c/R = f/\{(H-h) - ht_c\}$

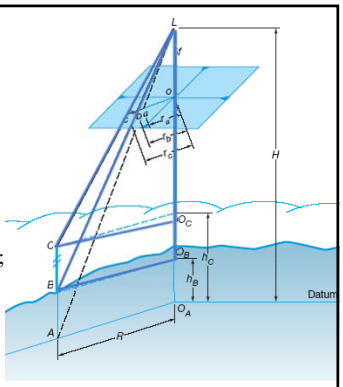
$\Rightarrow r_c * \{(H-h) - ht_c\} = R*f$ ---(3)

From (2) and (3):

$r_c * (H-h) - (r_c * ht_c) = r_b * (H-h)$ then;

$(r_c - r_b) * (H-h) = r_c\, ht_c$

$d = r_c - r_b = r_c * ht_c / (H-h)$



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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;

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

Note that relief displacement is eliminated in true ortho photos

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Example:
A vertical photograph taken from an elevation of 535 m above mean sea level (MSL) contains an 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. What is the height of the tower?

Answer:

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Vertical Photographs

Single Photo Applications
Flying Height

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Flying Height of a Vertical Photograph

- Flying height can be determined by:
  - Readings on the photos
  - Applying scale equation, if scale can be computed
    - Example: what is the flying height above datum if f=6", average elevation of ground is 900ft, scale is 1":100ft? Is it 1500'?
  - Or, if two control points appear in the photograph, solve the equation:

$L^2 = (X_B - X_A)2 + (Y_B - Y_A)^2$

then solve the same equation again replacing the ground coordinates with the photo coordinates. Get the scale.

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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:

$X_a = x_a$ * (photograph scale at a)
$Y_a = y_a$ * (photograph scale at a)

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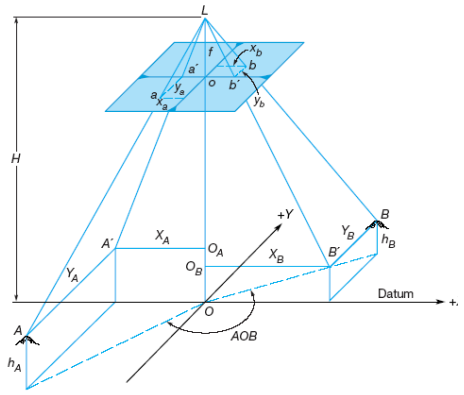

Figure 27–8 Ground coordinates from a vertical photograph.

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Tilted Photographs

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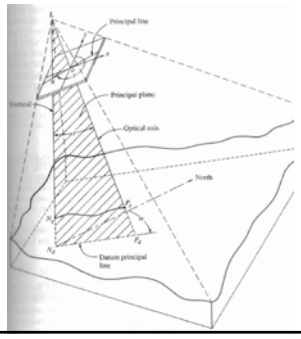
Tilted Photographs



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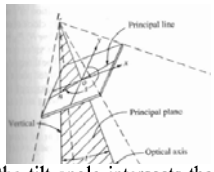
Basic elements of a tilted photographs

- 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).

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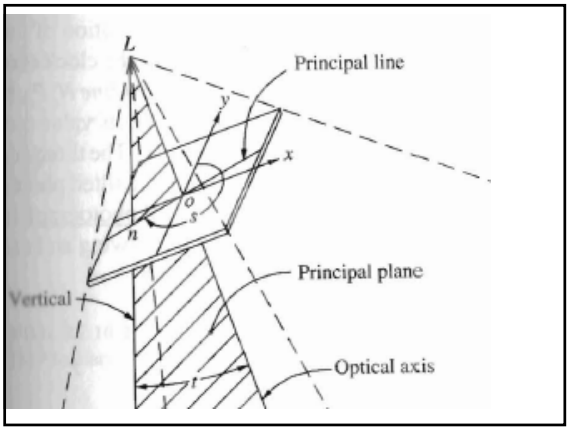

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- Lno = the principal plane: it is the vertical plane containing o, L and n (shaped plane).
- *i*m = axis of tilt: it is the line perpendicular to the principal line from the isocenter *i* in the plane of the photograph.
- S = the swing angle: it is 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.

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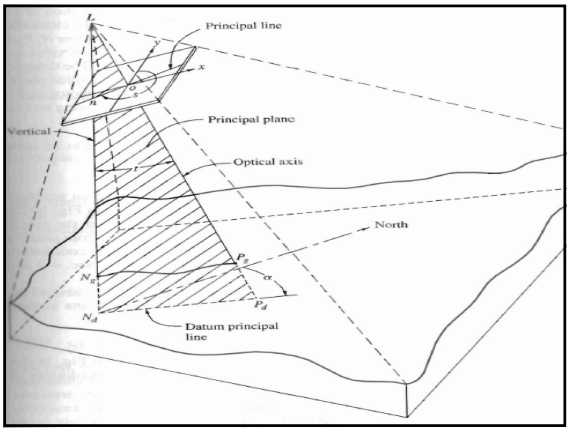

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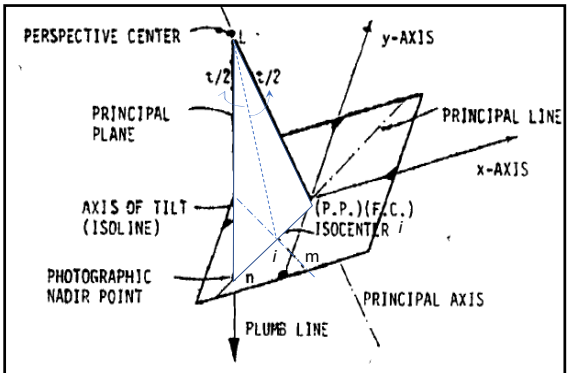

Figure (3-6) Basic elements of tilted photograph

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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.

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