UNIT- 4

Photogrammetry Surveying

Unit Specifies

Through this unit, we have discussed the following aspects:

- Types of photographs and their utility
- Various technical terms used in photogrammetry
- Determination of scale, and relief displacement
- Determination of height of various points through Parallax Bar observations
- Determination of various parameters from tilted photographs
- Digital photogrammetry and its utility
- Requirement of aerial-triangulation
- Exercises for computation of 3-D coordinates using photogrammetric measurements

In this unit, the utility and advantages of aerial photogrammetry for data collection are discussed. The characteristics of each types of photographs are given. The relationships to determine the scale and relief displacement would help in computing various essential parameters and removal of relief displacement errors. Questions of short and long answer types following lower and higher order of Bloom's taxonomy, assignments through a number of numerical problems, a list of references and suggested readings are given in the unit so that the students can go through them for practice.

Rationale

This unit on Photogrammetric surveying would help the students to acquire knowledge about the types of photographs and their utility in data collection and mapping. It explains the characteristics of vertical aerial photographs and tilted photographs. Relationships are derived for the determination of scale of photograph as well coordinates of points. The concept of stereovision and its utility in generating 3-D model as well determination of height of various points are covered to develop a better understanding of subject matter. Some related problems are given which can help further for getting a clear idea of the concern topics on photogrammetry. Some explanation of tilted photograph will further enhance the knowledge about their uses. Digital photographs can be analysed through the use of photogrammetric software, so a brief description of some photogrammetric software is also presented. The photographs are often used in large numbers, therefore the concept of mosaic and aerial triangulation is also given.

Pre-Requisite

Mathematics: geometry and trigonometry

Unit Outcomes

List of outcomes of this unit is as follows:

U4-O1: Describe various types of photographs and their uses
U4-O2: Describe the essential components and characteristics of vertical aerial photographs
U4-O3: Realize the role of parallax in stereo vertical aerial photographs for computation of height of various points
U4-O4: Explain the role of tilted aerial photographs and digital aerial photographs
U4-O5: Apply the parameters to generate 3-D coordinates of points

Unit-4 Outcomes	**Expected Mapping with Programme Outcomes** *(1- Weak correlation; 2- Medium correlation; 3- Strong correlation)*					
	CO-1	**CO-2**	**CO-3**	**CO-4**	**CO-5**	**CO-6**
U4-O1	2	1	2	3	1	2
U4-O2	2	2	3	1	3	-
U4-O3	3	2	2	3	1	2
U4-O4	3	3	2	2	1	-
U4-O5	2	2	3	1	-	2

4.1 Introduction

The name "*photogrammetry*" is derived from the three Greek words *phot* which means light, *gramma* which means letter or something drawn, and *metrein*, the noun of measure. The photogrammetry is defined as *the art, science and technology of obtaining reliable information about physical objects on the earth's surface and its environment, through processes of recording, measuring, and interpreting photographic images.* It derives information from the photographs, and transforms this data into meaningful results and thematic maps.

Photogrammetry discipline, like other disciplines, is constantly changing and developing. Presently, it is dependent on developments in data products, computer software and semi-auto or automatic processing methods. The computers and software are greatly impacting the developments in photogrammetry, shifting from analog to analytical and digital photogrammetric methods. Images used in photogrammetry are captured from a special (metric) camera, or from digital sensors, mounted usually on aerial platforms or drones. These images can also be recorded from a device mounted on a tripod kept on the ground, called *terrestrial images*. Photogrammetry requires certain skills, techniques and judgments to be made for taking reliable measurements on aerial photographs (both hardcopy and digital images).

The acquisition of photographs consists of project planning, image acquisition, image processing, and derivation of results. The end product from the photogrammetric process can be the coordinates of individual points, a graphical representation of the ground surface (topographic map, thematic map, etc.), or a rectified image with map-like characteristics (ortho-photos) or a digital elevation model (DEM) or digital maps. The most common use of aerial photographs is the creation of base maps for various applications, selection of ground control points (GCPs), and ground truth verification. Large-scale mapping using photogrammetry provides a cost-effective and faster approach for applications, such as urban planning, forestry, agriculture, natural resources planning, terrain analysis, road alignment, infrastructural development, etc. Aerial photographs have also been successfully used to create 3-D model of various ground features for the purpose of planning, visualisation and measurement. The 3-D mapping requires viewing the area from two different camera angles, thereby recreating the similar conditions for 3D model in software environment, as it existed at the time of photography.

Modern photogrammetry also includes airborne and terrestrial based LiDAR (light detection and ranging) data. The LiDAR data acquired from both approaches are being used for large number of applications. With good lighting and atmospheric conditions, good quality and better contrast photographs can be acquired for various mapping purposes, but if vegetation or high-rise structures are present in the area, LiDAR data may be an excellent source of input data for detailed and accurate interpretation below the vegetation cover. More recently, aerial photographs have also been acquired from a drone for creation of large scale maps.

4.2 Historical Developments

The conception of using photographs for purposes of measurement appears to have been originated with the experiments of Aime Laussedat of the Corps of the French Army, who in 1851 produced the first measuring camera image for its application to topography. The first known aerial photograph was taken in 1858 by a French photographer and balloonist, Gaspar Felix Tournachon, known as *Nadar*. It was a view of the French village of Petit-Becetre taken from a tethered hot-air balloon, 80 m above the ground (Figure 4.1). In 1858, Laussedat, Meydenbauer in Germany carried out the first experiment in making the critical measurements of architectural details on the basis of two photographs of the building.

Figure 4.1 (left) Nadar "elevating photography to the condition of art", caricature by Honoré Daunier. Published in Le Boulevard 25th May, 1862. (center) Nadar's earliest surviving aerial image, taken above Paris in 1866. (right) Boston from a tethered balloon, 13th October, 1860, by James Wallace Black.

Later, besides hot air balloons, kites, pigeons and rockets have been used which carried cameras into space for taking air-photographs. In 1882, the English meteorologist, E. D. Archibald was among the first to take photographs from kites, and then in 1889, Arthur Batut took aerial photographs from a kite, in Labruguiere, France. The first aerial photograph from a rocket mounted camera was taken by the Swedish inventor, Alfred Nobel in 1897. He is best known now-a-days for the Nobel prize. In 1903, Julius Neubranner designed a tiny breast-mounted camera for carrier pigeons.

The first successful aerial photography from an airplane piloted by Wilbur Wright was taken in 1909 by L.P. Bonvillain who took motion pictures of the military field at Centocelli, near Rome. During World War I (1914-1918). The battle maps used by both sides were created from these aerial photographs. After the war, the aerial photographs were used for civilian purposes. Sherman Fairchild took a series of overlapping photographs and made an aerial map of Manhattan Island. Along with his successful development of aerial camera, Fairchild also designed and built airplanes with high-wings and stable platform to take aerial photographs. His cameras were carried on Apollo-15, 16 and 17 to map the moon surface.

Since year 1950s, the development of the photogrammetry went through four major phases, as briefly explained below as well as shown in Figure 4.2.

(a) Graphical photogrammetry: This was the first phase which gave rise to new inventions and applications, followed by many experiments and investigations.

(b) Analogue photogrammetry: This was the second phase of the era of analogue photogrammetry (1900 to 1960), which led to the invention of analogue rectification and stereo-plotting instruments. During this phase, airplanes and cameras were extensively used in the World War II (1939-1945), and established aerial survey techniques for military operations. It further gave rise to new developments, such as application of radio control to photo flight navigation, and new wide-angle lenses & devices to acquire true vertical photographs. Photogrammetry thus became a popular surveying and mapping method, and several optical or mechanical and electronic components for modeling and processing as well as to reconstruct the 3D geometry from stereo-photographs. Major output during this phase was topographic maps.

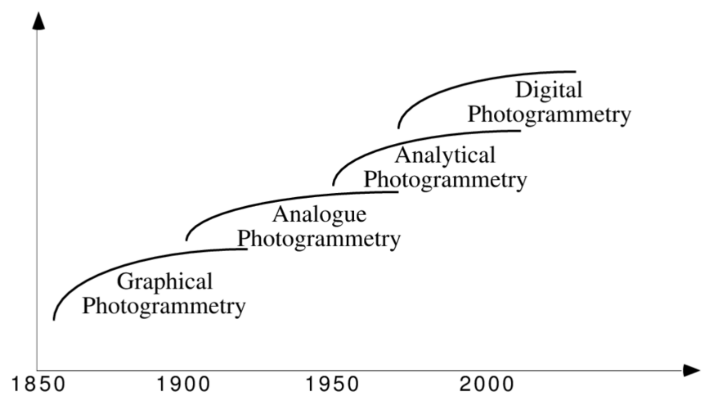

Figure 4.2 Major phases of development of photogrammetry

(c) Analytical photogrammetry: In 1950s, third phase began with the use of computers; and thus analytical photogrammetry was developed for accurate photogrammetric measurements. Aerial triangulation was improved greatly, and the analytical plotters developed in 1970s. Computer replaced the expensive optical or mechanical instruments. The resulting devices were digital/analogue hybrids which used mathematical modeling assisted with digital processing. In this mode, the image coordinates were obtained using mono-comparators or stereo-comparators, and further processing was done through computer. Images in hard copy form (e.g., on film) were used in both the above methods, but the output was in digital form.

(d) Digital photogrammetry: The fourth development phase is the digital photogrammetry phase. Digital photogrammetry, also called *softcopy photogrammetry*, requires digital images that are processed through a computer. With the availability of images with high resolution digital scanners and digital cameras, digital images are processed using photogrammetric software employing the same analytical principles for modeling. Hence, digital methods use strengths of both analytical and image processing methods for analysis and stereo-plotting works (Grave, 1996). The output from this is in digital form: Digital Elevation Model (DEM), digital maps, digital orthophotos, etc. Digital photography is used for a diverse set of commercial, industrial, agricultural, governmental and private applications. The main advantage to work in digital environment is huge saving in time and cost to derive the useful results, and using the digital output as input into other analysis systems, such as GIS (Hassani and Carswell, 1992).

Table 4.1 shows a comparison of photogrammetric techniques used.

Table 4.1 A comparison of various photogrammetric techniques (file:///C:/Users/user/Downloads/8435637.pdf)

Characteristics	**Analog**	**Analytic**	**Digital**
Image	Film	Film	Pixels
Plotter	Analog	Analytical	Computer
Model Construc.	Mechanical	mechanic/computer	Computer
Stereo Viewing	Optical	Optical	Varies
Output	Mech./CAD	Mech./CAD	CAD
Aerotriangulation	Very limited	On/Off Line	Semi-automatic
Orthophoto	Very limited	Unavailable	Automatic
Limitations	Focal length Film Format	Film format	None
Accuracy	Average up to ±15 μm	Very high up to ±3 μm	Same as scanning accuracy
Cost	Very high	Very high	Reasonable to high

4.3 Types of Aerial Photographs

There are two main types of images in photogrammetry. Photographs are taken with either **aerial** camera mounted in an aircraft or with terrestrial camera mounted on a tripod on the ground. Aerial camera in aircraft is usually pointing vertically down towards the ground, while in terrestrial photogrammetry it is pointing near horizontal.

(a) Aerial photographs

Aerial photographs which are normally used for mapping and photo-interpretation can be classified into two main categories *viz.*, vertical and tilted photographs.

(i) Vertical aerial photographs

An aerial photograph taken with the camera axis held in a vertical or nearly vertical position is classified as vertical photograph (Figure 4.3a). A tilt of camera axis up to ±3º from vertical line is acceptable. When the geometry of a vertical photograph is considered, the photograph is assumed to be taken with the optical axis truly vertical.

(ii) Tilted photographs

Sometimes due to unavoidable conditions (e.g., strong winds), the camera axis is unintentionally tilted more than 3˚ from the vertical. The resulting photograph is called tilted photograph (Wolf, 1980). The tilted photographs may further be classified in two categories *viz*., low oblique and high oblique photographs.

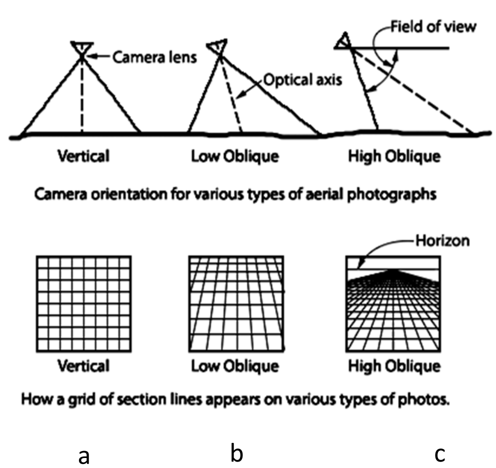

Figure 4.3 Vertical, low oblique and high oblique photographs *(ASPRS, 1980)*

Low oblique photographs**:** An aerial photograph taken with an intentional tilt of camera axis 15° to 30° from the vertical axis is called as low oblique photograph (Figure 4.3b). This kind of photographs is often used in reconnaissance surveys of the area as measurements can't be made directly on such photographs.

High oblique photographs**:** A photograph in which the apparent horizon appears is termed as high oblique photograph. Apparent horizon is the line in which the Earth appears to meet the sky as visible from the aerial exposure station. The high oblique photographs are obtained when the camera axis is intentionally inclined about 60° from the vertical axis (Figure 4.3c). Such photographs are useful for mapping the international boundary and extracting the details of the territory on other side as well as military applications.

(b) Terrestrial or Close-range photographs
Terrestrial or close-range photographs are taken when the camera, either hand-held or tripod mounted, is located on or near the ground. For a detailed mapping of the feature/object, the camera is set up close to the object and photographs are taken. The output may be photographs or non-topographic products, like 3D models, measurements, or point clouds. Figure 4.4 shows the close range or terrestrial photographs of a 3D building taken from three locations of camera, to determine the precise coordinates of corners or to recreate a 3D model.

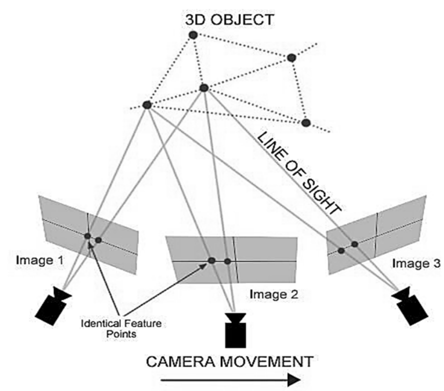

Figure 4.4 Terrestrial or close-range photographs

Close-range photogrammetry has been applied for precise deformation measurements in industrial and engineering applications. There are many uses of terrestrial or close-range photogrammetry, such as 3D modeling of objects, monitoring of dam structures, buildings, structures, towers, or movie sets, architectural restoration, preserving the cultural heritage, location of monuments, medical imaging for forensic sciences and reconstructive surgery, facial reconstruction studies, structural stability studies of bridges and hydro-electric dams, earth-works, stock-piles, automobile industry, shipping industry, antenna calibration, study of traffic accidents and crime scenes by police departments, etc.

4.4 Applications of Photogrammetry
Photogrammetry has been used in several areas. Some applications are given below.

Mapping: The biggest and largest application of photogrammetry is in the field of mapping various features and preparation of various thematic maps, including topographic maps. The 3D maps can easily be created with stereo-photographs. Photographs have also been used as ground reference data for the analysis of remote sensing images.

Geology: They are used for mapping structural geology, faults, folds, lineaments, analysis of thermal patterns on Earth's surface, geomorphological investigations.

Forestry: Forest cover mapping can be carried out using the aerial photographs. Timber inventories, biomass estimation and forest types mapping have also been undertaken by these photographs.

Agriculture: Mapping soil type, soil conservation, crop planting, crop types, crop disease, crop-acreage estimation have become easy with the aerial photographs. Landuse mapping has been the most popular applications of photogrammetry so far.

Design and construction: Site planning and route alignment studies can be undertaken using photogrammetry. Photographs have been used in design and construction of dams, bridges, transmission lines, railway lines, roads, etc. They are very much useful in planning the growth of cities, new highway locations, detailed design of construction, planning of civic amenities, etc.

Cadastre: Aerial photographs have been successfully used for the determination of land boundaries for assessment of area and associated taxes. Large scale cadastral maps are prepared for re-appropriation of land.

Exploration: They are used for various exploratory jobs, such as oil or mineral exploration.

Military intelligence: The photographs are being used for reconnaissance survey, study of terrain conditions and topography, deployment of forces, planning manoeuvres, planning of operation, etc.

Medicine and surgery: Photogrammetry is used in stereoscopic measurements of human body, x-ray photogrammetry in location of foreign material in body and location and examinations of fractures and grooves, bio-stereometrics, etc.

Miscellaneous: Crime detection, traffic studies, oceanography, meteorological observations, architectural and archaeological surveys, planning new infrastructure, etc.

4.5 Advantages and Disadvantages of Photogrammetry

The advantages of photogrammetry over the traditional ground surveying are numerous. The photographs provide an economical and efficient way of mapping a large area, no site access issues, provide a permanent record of features at that instant of time; this is especially useful in rapidly changing sites, such as mines, quarries and landfills. However, there are some disadvantages also (Garg, 2019). A summary of the advantages and disadvantages is given below:

Advantages:

1. It provides a permanent pictorial record of the area that existed at the time of aerial photography.
2. It covers a large area; hence mapping is economical than the traditional survey methods.
3. It is cost-effective, providing high level of accuracy.
4. It provides a bird's eye view of the area, and thus helps in easy identification of both topographic and cultural features.

5. It is particularly suitable for areas that are unsafe, hazardous, and difficult access. Photogrammetry is an ideal surveying method for toxic areas where the safety of ground surveying staff is important.
6. It can effectively be used in the office for detail mapping of several features, thus minimizes the field work.
7. The sequential photographs of the same area may be used for monitoring the area.
8. If area has to be updated after some time, the latest photographs can be used to update new or missing information, and therefore there is no need to map the entire area again.
9. The use of digital photographs ensures total flexibility of scale of mapping.
10. The coordinates of every point in the mapped area can be determined with no extra cost.
11. It requires less manual effort for mapping the area.

Disadvantages:

1. Processing and analysis of aerial photographs require experienced technical manpower.
2. Photographic coverage requires advance flight planning as well as specialised equipment and aircraft.
3. Atmospheric conditions (winds, clouds, haze etc.) may affect the flight plan as well as quality of aerial photographs.
4. Seasonal conditions, i.e., snow cover will affect the photographs and obstruct the features.
5. The ground information hidden by high-rise buildings or dense tree canopies, and roads hidden by trees on both sides, cannot be mapped accurately.
6. Accuracy of contours and cross sections will depend on the accuracy of 3D models generation from stereo-photographs which is a factor of scale of photographs and number of ground control points (GCPs) used for creating the 3D model.
7. Aerial photography is expensive for developing countries, like India, particularly if repetitive coverage of an area is required for large scale mapping and monitoring purposes.
8. For sensitive areas or restricted areas, aerial photography may not be allowed.

4.6 Comparison of Aerial Photograph with Map

The basic geometry of a map and an aerial photograph is different, as listed in Table 4.2. Aerial photographs cannot be directly used as maps, as vertical aerial photographs do not have a uniform scale throughout and their projection system is also different. In addition, relief displacement and distortions are present on aerial photographs. Figure 4.5 shows the B&W aerial photographs and corresponding topographic map of the area. The photograph needs to be transformed from perspective projection to the orthometric view before it can be used as map. Such transformation will yield ortho-photo which can replace a map. Details of transformation of aerial photographs into ortho-photos are given in Moffit and Mikhail, (1980).

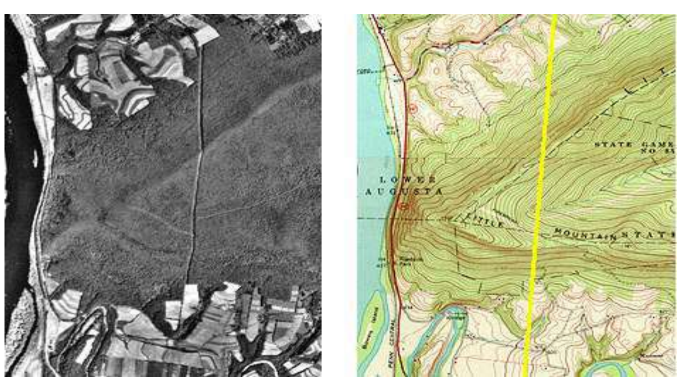

Figure 4.5 Aerial photograph and corresponding topographic map

Table 4.2 Difference between an aerial photograph and a map

S.No.	Aerial photograph	Map
1	It is based on a central or perspective projection.	It is based on an orthogonal projection.
2	It is a real image of the ground.	It is an abstract representation of the ground. Legend is needed to read it.
3	The objects and features are represented in their true shapes and sizes.	The features are generally represented symbolically with different symbols and not with their actual sizes.
4	The scale of the photograph is not uniform throughout.	The scale of a map is uniform throughout.
5	An aerial photograph has geometric distortion that increases towards the edges of the photograph.	A map is a geometrically correct representation of the Earth surface projected.
6	Relief displacement error is present	No such error is present
7	In absence of a legend, it is comparatively difficult to read a photograph and identify the objects.	Objects/features are shown in Legend with different symbols and colours, which make it easy to read and identify them.
8	Aerial photography can be carried out for inaccessible and hazardous areas.	The mapping of inaccessible and hazardous areas is very difficult.

4.7 Flight Planning

Acquisition of aerial photographs requires details of flight planning. Now-a-days, many digital cameras are used to capture aerial digital images. The photographic format of each photo is 23 cm x 23 cm. Acquisition of photographs requires thorough planning prior to flying to capture photographs of the project site. The project area is marked on the topographic map to study the elevation range as well as the cultural and natural features present in the area. In India, aerial photos are taken in the air by the authorised agency of Govt. of India, *viz.* Survey of India (SoI), Dehradun, and National Remote Sensing Centre (NRSC) Hyderabad. Users make a request to these agencies to obtain aerial photographs either from the archive or flying afresh through the area, on payment basis, subject to clearance from the Ministry.

It is required to know the extent of area, and decide on the scale of photographs. Also the focal length of the camera lens, size and shape of the area to be photographed, amount of end lap and side lap, relief displacement, tilt angle of photographs, drift angle and ground speed of aircraft are determined. Knowing the scale and focal length and average elevation (above *msl*) of the terrain, flying height of the aircraft can be determined. The scale and flying height are inter-related to each other (Moffit and Mikhail, 1980); higher the flying height, smaller the scale and larger the area covered. The number of flight lines, their locations, spacing between them (air-base), and their orientation are computed in advance which would depend on the characteristics of the area to be photographed. Other specifications to be known include area covered by one photograph, number of photographs taken in each flight line, total number of photographs, weather and meteorological conditions etc. Clouds in the photographs are undesirable, therefore, a clear sunny day with least wind is considered to be ideal for taking air-photos.

The vertical photographs are usually taken by a series of parallel flight lines (Figure 4.6); these lines are normally taken along the longer dimension of the area (l_1). After finishing capturing of photographs along first flight line, the aircraft takes a semi-circular turn (outside the project area) to enter into second flight line of area and continues in the similar manner till the entire area is covered, as shown in Figure. The flight line directions are generally planned in East-West or North-South direction. The land limitations, such as mountain range, lake, and sea-side may also affect planning of the flight line directions, and under such situations, flight lines are planed parallel to these details.

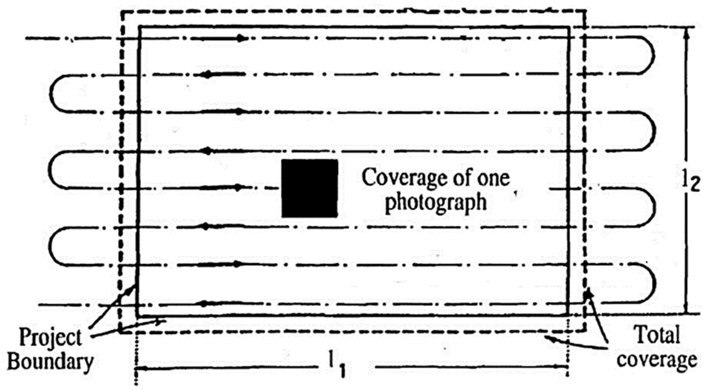

Figure 4.6 Route in flight planning

The aircraft speed is controlled in such a way that the required forward or end overlap is maintained for all the photographs. Overlapping photographs of the ground are taken as the aircraft moves along a defined flight path (Figure 4.7). Flying at a slower speed will allow for a better turning radius. Best speed is one where lift and drag are equal, making it most efficient. The airbase or the distance between two successive aircraft locations that satisfies the amount of required end overlap is computed (Moffit and Mekhail, 1980). Once the airbase is determined and the aircraft speed is decided upon, the time between two successive exposures can be computed.

Strong winds can affect the direction of aircraft. ***Drift*** is the lateral shift of the aircraft from the flight lines that may be caused by the blowing wind or the pilot error. So, a good practice is to capture the photographs on a sunny day with no wind. Taking aerial photography in urban territories is better at midday, when shadows are shortest. ***Crab*** is the angle formed between flight line and the edges of the photographs in the direction of flight. It occurs when the aircraft is not oriented with the flight line. It reduces the effective width of photographic coverage (Kraus, 1994).

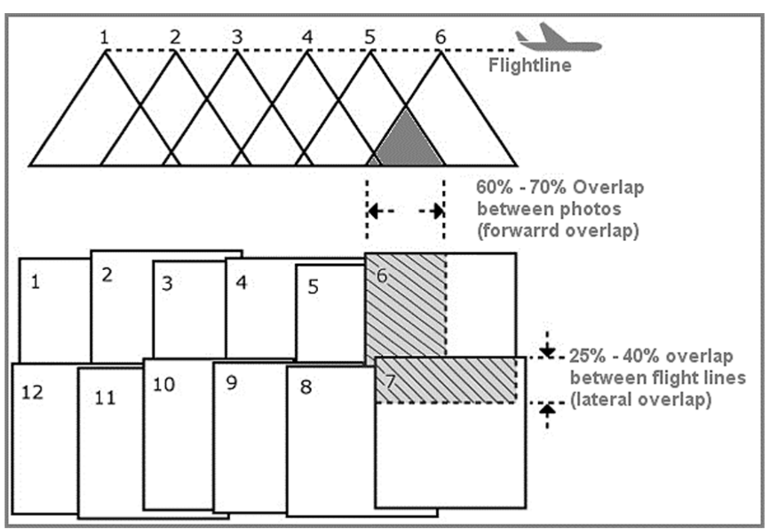

Figure 4.7 Photography during a flight planning (Source: ASPRS, 1980)

The following are the considerations in flight planning:

1. Mark the flight plan on a map, and compute the length (L) and width (W) of the area.
2. Plan and establish the ground control points.
3. Compute the scale of photograph using the relationship:
   $S_{avg} = f / (H - h_{avg})$ (4.1)
4. Compute the coverage on the ground by one photo (*A*).
5. Compute the flight lines spacing:
   (D) = Photo coverage (*A*) * (100 – amount of side lap) /100 (4.2)
6. Calculate the number of flight lines:
   $N_1 = (W / D) + 1$ (4.3)
7. Always round-off the number of flight lines, i.e., 8.4 becomes 9, as we don't want to lose any small are uncovered.
8. Select the first flight line along North-South or East-West boundary of the area.
9. Compute the distance between two consecutive photos (or airbase B):
   B = Image coverage (*A*) * ((100 – amount of end lap) /100) (4.4)
10. The camera exposes the next photo when aircraft has moved a distance equal to airbase. If the aircraft speed is (*v*), the time (*t*) taken between two consecutive photos:
    t = Air-base (B) / Aircraft speed (*v*) (4.5)
11. Number of images per flight line (N_2) = $(L / B) + 1$.
12. Always round up the number of photos, i.e., 25.3 becomes 26.
13. Add two images at the beginning of flight line and two at the end of flight (to ensure continuous stereo coverage), i.e., additional 4 images for each flight line are taken. So, number of images per flight line:
    $= (L / B) + 1 + 4$ (4.6)
14. Total number of images for the project = $N_1 \times N_2$.
15. Estimate the cost of the project.

4.8 Technical Terms in Aerial Photogrammetry

Exposure station: Location of an aircraft in the air at the time of taking a photograph is called exposure station (e.g., 1,2, 3, etc., in Figure 4.7).

Air-base or Camera base: The distance between two successive exposure stations along a flight line is called the air-base or camera base (e.g., 1-2, 2-3 etc., in Figure 4.7).

Perspective centre: The point of origin or termination of bundles of perspective light rays is called the perspective centre (Figure 4.8).

Perspective (Central) projection: All the projecting rays by a camera lens pass through the perspective centre to form the perspective projection (Figure 4.8). An aerial photograph is based on a perspective (central) projection. Due to relief variations of the ground objects, an aerial photograph differs geometrically from the map of corresponding area.

Flight line: The flying path an aircraft takes when taking the photographs is called flight line. It represents x-axis for photographic measurements (e.g., line 1-6 in Figure 4.7), while y-axis is perpendicular to it passing through the principal point of the photograph.

Flight strip: Each flight line during photography of an area will cover some area on the ground in the form of a corridor, called a flight strip. Figure 4.7 shows two flight strips.

Strip of photographs: The number of photographs covered during a flight strip is called strip of photographs (e.g., 6 photographs in one strip in Figure 4.7).

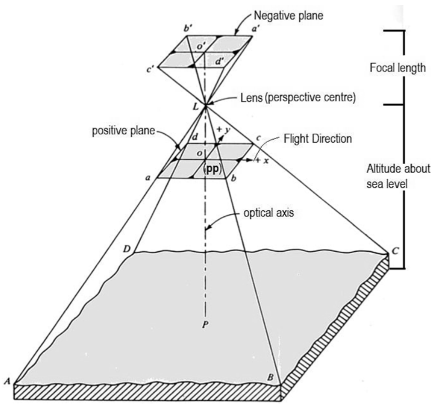

Figure 4.8 Geometry of an aerial photograph (Garg, 2019)

Total number of photographs: The total number of photographs are obtained by multiplying the number of photographs in each strip by the number of flight lines) (e.g., 6x2= 12 photographs in Figure 4.7).

Flying height: The height at which the aircraft flies (altitude of aircraft above mean sea level) when the photographs were taken is known as the flying height (Figure 4.8). It has a direct relationship with the photographic scale; higher the flying height, smaller the scale. Flying height is always known prior to flying to the area.

Plumb line: It is a vertical line from the exposure station, indicating the direction of gravity. In coincides with the optical axis of the camera lens in case of a truly vertical photograph (Figure 4.8).

Camera axis: The camera axis represents the optical axis. It is a line passing through center of camera lens perpendicular both to camera plate (Negative) and photographic plane (Positive) (Figure 4.8).

Focal length: Distance from the optical centre of the lens to the focal plane, when the camera is focussed at infinity, is called the focal length of camera lens (Figure 4.8). Its value is known, as it is supplied by the manufacturer of camera.

Ground nadir: The point on the ground vertically beneath the perspective centres of the camera lens, denoted by letter P (Figure 4.8).

Fiducial marks: Four index marks, which are shown at the edge or corners of the photographs, are called the fiducial marks (Figure 4.9). These are used for determining the principal point of the photograph.

Fiducial axes: Straight lines joining the opposite fiducial marks on a photograph are called fiducial axes (Figure 4.9).

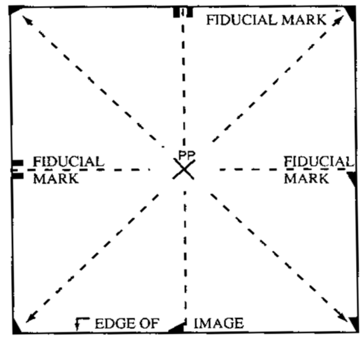

Figure 4.9 Fiducial marks on the photograph

Principal point (PP): The geometric centre of an aerial photograph, located at the intersection of lines drawn between the opposite fiducial marks. is called the principal point (Figure 4.9).

Conjugate principal point (CPP): The principal point (PP) from one photo transferred onto adjacent photo along the flight line is called the CPP.

Photograph centre: The point on the photograph that is located at the intersection of the fiducial axes is called the photographic centre. In a perfectly adjusted camera, the photograph centre and the principal point are identical (Figure 4.9).

Photographic nadir: The point on the photograph which corresponds to the ground nadir, denoted by letter *n*. The point on the photograph at which a vertical line (plumb line) from the perspective centre to the ground nadir intersects the photograph, is called photographic nadir.

Overlap: The common region (expressed as a percentage) between two photographs is called overlap. The overlap between two successive aerial photographs in the same flight line is called *longitudinal overlap* or *forward overlap* or *end lap*, and the overlap between photographs in adjacent parallel flight lines is called the *lateral overlap* or *side lap* (Figure 4.7). The amount of end lap is kept a minimum of 60%, which is useful to generate 3D view of the common area between the photographs. The lateral overlap or sidelap is kept between 25-40%, which is used to create a mosaic of the area.

Superlap: The common overlap between three successive photographs is called superlap. It means that a photograph with 70% overlap will have 40% superlap region.

Mosaic: The process of seamlessly joining a series of overlapping air photos together to form one large image, is called a mosaic. It is created to view and analyse the large area.

Stereo-pair: Two successive photographs taken during a flight line with sufficient overlap is called a stereo-pair.

Stereo-model: In two successive photographs, the overlapping part can be utilized for stereo measurements. The stereo-pair is used to create a stereo model that can be seen in 3D using a stereoscope device.

Parallax: The apparent displacement of the position of an object with respect to a reference point, caused by a shift in the point of observation, is known as parallax.

Floating mark: It is a mark (dot or cross), associated with parallax bar or stereometers or stereoscopic plotting machines, seen as occupying a position in the 3-D space formed by the stereoscopic fusion of a stereo-pair, and used as a reference mark in examining or measuring the stereo-model.

Scale: The ratio of a distance on a photograph or map to its corresponding distance on the ground is called scale. Scale may be expressed as a ratio (1:25,000), a fraction (1/25,000), or equivalence (1 cm = 250m).

Photo-interpretation: An act of identifying the objects from images and judging their relative significance is called photo-interpretation.

Control points: The reference points precisely located on both the ground and the photo whose three-dimensional coordinates are known, are called as control points.

Orthogonal projection: Maps are based on orthogonal (parallel) projections where the projecting rays are perpendicular to the line on the ground. The advantage of this projection is that the distances, angles or areas on the plane are independent of the elevation differences of the objects, and these measurements compare well with the actual ground.

Ortho-photos: An ortho-photo is an aerial photograph that is rectified by combining photogrammetric principles with Digital Elevation Model (DEM) data. An aerial photograph does not have a constant scale throughout the photograph, whereas the scale is uniform throughout in an ortho-photo, and hence it can be used as an alternate to a map.

Angle of tilt: The angle at the perspective center between the photograph perpendicular and the plumb line is called angle of tilt. It is present in case of tilted photographs (Figure 4.10).

Isocentre: The point on the tilted photograph where the bisector of the angle of tilt (t) strikes the photograph (located in the principal plane as well as on the principal line), is called isocentre (Figure 4.10). It is denoted by letter *i*. The isocenter is a unique point common to the plane of the tilted photograph, its principal plane, and the plane of the assumed truly vertical photograph taken from the same camera station and having an equal principal distance (i.e., the isocenter is located at the intersection of three planes).

Principal line: The line on the tilted photograph which passes through the principal point and the nadir point (and the "isocentre"), is called the principle line (Figure 4.10).

Principal plane: The vertical plane through the perspective centre containing the photograph perpendicular and the nadir point (and the "isocentre") is called the principal plane.

Azimuth: The horizontal angle measured clockwise about the ground nadir from a reference plane (usually the north meridian) to the principal plane. The azimuth of a photograph is the ground-survey direction of tilt, while swing is the direction of tilt with respect to the photograph axes.

Swing: The angle about the principal point of a tilted photograph, measured clockwise from the positive y-axis to the principal line at the nadir point, is called swing. It is denoted by letter *s*. Swing also refers to rotation of the photograph (or photo-coordinate system) around the photograph perpendicular (or photograph z-axis). In air navigation, swing represents aircraft rotation about the aircraft's vertical axis and is referred to as ‘yaw’ or ‘crab’.

Tilt displacement: It is the displacement of images on a tilted photograph is radially outward (inward) with respect to the isocenter if the images are on the low (high) side of the isometric parallel. The ‘low’ side of a tilted photograph is the side closer to ground.

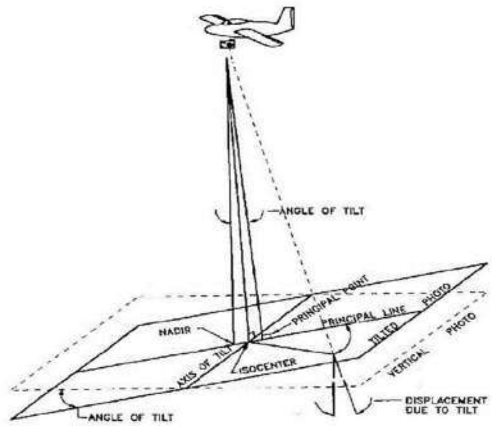

Figure 4.10 Representation of a titled photo

4.9 Scale of a Vertical Photograph

The scale is a ratio of the distance between two objects on the photograph to the distance between the same points on the ground. In Figure 4.11, if *A* and B are the ground points and a and b are their corresponding images on the photograph, O is the exposure station, *f* is the focal length, and *H* is the flying height above ground, the scale *S* of the vertical photograph is computed as:

$$Scale \quad S = \frac{\text{Map distance}}{\text{Ground distance}} = \frac{ab}{AB}$$

Considering the isosceles triangles Oab and OAB, we can write:

$$S = \frac{ab}{AB} = \frac{f}{H} \quad (4.7)$$

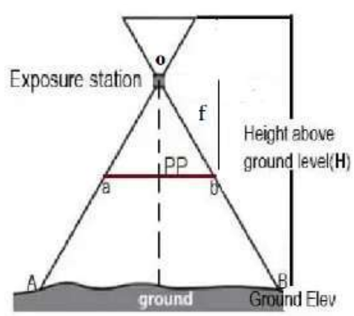

Figure 4.11 Scale of a vertical photograph in a flat terrain

So, the scale is the ratio of focal length and flying height of the aircraft. It is directly proportional to focal length of camera lens and inversely proportional to the flying height.

This relationship is valid when the ground is assumed to be flat. But the ground is always undulating with some amount of relief. In case of undulating ground, the scale is computed as:

In Figure 4.12, four point on the ground A, B, C and D, having different elevations with mean sea level are shown. The photograph is taken from an exposure station L with a camera having *f* focal length and from a flying height H above mean sea level. Let us consider two points *A* and *B* having elevation h_a and h_b, respectively, above the mean sea level.

The scale of the photograph at point *A* may be written (using two similar triangles Lao and LAO_A) as:

$$S = \frac{ao}{AO_A} = \frac{Lo}{LO_A} = \frac{f}{H - h_A}$$

(4.8)

Similarly, the scale of photograph at point B will be (using two similar triangles Lbo and LBO_B):

$$S = \frac{bo}{BO_B} = \frac{Lo}{LO_B} = \frac{f}{H - h_B} \tag{4.9}$$

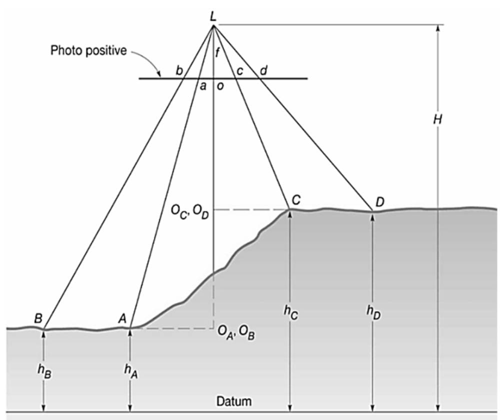

Figure 4.12 Scale of a vertical photograph in an undulating terrain (*Schenk, 2005*)

Scale at ground points *C* and *D* can also be computed in a similar manner. Hence, it is observed from the above relationship that the scale of a vertical photograph varies at different points depending on their elevations, as *f* and *H* will be same for all the points in a given photograph. If all the points within a photograph are situated at the same elevation, the scale will be constant and uniform throughout. But in general, there is a height variation in the terrain, so scale of the photograph will vary from ground point to point. If the average elevation of the area is h_{av}, a more generalised relationship to compute the average scale S_{av} of photograph having points at different elevations may be written as:

$$S_{av} - \frac{f}{H - h_{av}} \tag{4.10}$$

A more general expression for the scale may be written as-

$$S = \frac{f}{H - h} \tag{4.11}$$

So, photographic scale is directly proportional to focal length of the camera lens. When a camera with larger focal length is used, a larger scale is obtained, and vice versa. It also varies inversely with the flying height; scale decreases as the flying height increases and vice versa.