Earth observation and aerial surveys

RICS guidance note, 6th edition, global

RICS professional standards and guidance

RICS guidance notes

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Key terminology

The following key terms are commonly used in the earth observation and aerial imagery sector. A full glossary can be found in Appendix C.

Accuracy	The degree to which a set of independent measurements are free from defects, consistent with a standard rule.
Aerial photography	Photographs taken from an aerial vantage point.
Earth observation	The process of capturing data about the earth's physical, chemical and biological systems using remote sensing technologies including surveying techniques and the collection, analysis and presentation of the data.
Hyperspectral imagery	An imaging technique operating across the visible and non-visible parts of the electromagnetic spectrum, typically generating 500 separate spectral bands for in-depth analysis.
LiDAR	Light detection and ranging.
Multispectral imagery	Imagery captured using sensors operating outside the visible part of the electromagnetic spectrum.
Resolution	A measure of the level of detail that can be detected.
Thermal imagery	Imagery created from detecting and recording the infrared part of the electromagnetic spectrum.

1 Introduction

Earth observation and aerial surveys are used to capture, store and process reflected and emitted radiation from the earth's surface. The techniques employed include aerial photography, light detection and ranging (LiDAR) and hyperspectral, multispectral and thermal imaging systems. Survey instruments are typically carried by satellites, fixed wing aircraft, helicopters and increasingly by unmanned aerial vehicles (UAVs).

Earth observation and aerial survey data are used to help understand climate change, develop smart cities and contribute to the development of digital twins, improving the efficiency of the construction industry and infrastructure sector. Specific applications include:

- national mapping
- cadastral mapping
- transportation infrastructure
- asset management
- land cover classification
- navigation and
- 3D city modelling.

Organisations are looking to the power of geospatial data to provide insight into our natural and built environments. This will enable improved management of these resources, which will in turn contribute towards a more sustainable future.

1.1 Scope

This guidance note is intended for use by land, sea, engineering and environmental professionals who are acting in an advisory capacity, and by survey-knowledgeable clients who specify their own surveys. It is also intended to be used by earth observation and aerial survey specialists.

It will help clients communicate their goals, and what they expect to receive in terms of:

- types of data
- accuracy
- resolution
- survey detail and
- final deliverables.

It will help both parties clarify issues such as project constraints and timescales.

This guidance note incorporates a full revision of *Vertical aerial photography and digital imagery* (5th edition), RICS guidance note. New sections on LiDAR and hyperspectral, multispectral and thermal imaging systems have been added.

The following topics are covered in this guidance note:

- sections 2–3: pre-project considerations, including the different data capture platforms available and planning requirements
- sections 4–7: the techniques of aerial photography, LiDAR, sensing in the non-visible part of the electromagnetic spectrum and earth observation and
- section 8: future developments in earth observation and aerial survey techniques.

This guidance note also contains sample specifications, an accuracy and resolution table that combines information about each technique and an expanded glossary in the appendices.

1.2 Effective date

This guidance note is effective three months from publication.

2 Data capture platform

2.1 Data type

The starting point when commissioning earth observation or aerial survey data is to consider what the data will be used for. In many cases, this will be self-evident, for example:

- national mapping
- heritage recording
- forestry
- land classification
- rail transportation or
- precision agriculture.

The use case for the aerial survey will determine the type of data that will be most appropriate:

- **Aerial photography** is the most common type of data as it aligns most closely with the client's view of reality, with features such as trees and buildings instantly recognisable, albeit from a different perspective. The science of photogrammetry was built around the use of stereo aerial photography from which precise measurements can be made, increasing the utility of aerial photography as an aerial survey technique. Today, dense image matching photogrammetric techniques are also used, particularly using photography captured from UAV platforms.
- **LiDAR** is a good source of height information and has found numerous applications in modelling the built and natural environments.
- **Multispectral, hyperspectral and thermal data**, sensing outside of the visible part of the electromagnetic spectrum, are particularly useful in detecting the health of different plant species.

It is frequently the case that more than one data type is commissioned to meet a particular use case. For example, aerial photography and LiDAR are frequently commissioned together, with the photography providing a view of reality and the LiDAR data the third dimension. Another common combination is aerial photography and hyperspectral imagery, with the latter used to accurately determine plant species.

2.2 Accuracy and resolution

The accuracy of an aerial survey is traditionally expressed by specifying an absolute root mean square error (RMSE) for the positioning of the survey data. Ground checkpoints should be used as an independent check on the mapping accuracy (see section 3.4).

The resolution of aerial photography and multispectral, thermal and hyperspectral imagery is expressed as a ground sampled distance (GSD). The resolution of a LiDAR survey is expressed as the number of points recorded per square metre on the ground, or points per square metre (ppm^2).

Higher resolution imagery enables more detail to be observed within the scene and thus finer detail to be mapped. GSD is not synonymous with accuracy, but an aerial survey cannot be more accurate than the GSD.

It is important to specify realistic accuracy and resolution requirements that are appropriate for the use case of the aerial survey. This can directly influence the cost of a project. To achieve both a highly accurate and high-resolution dataset:

- specialist (and therefore more expensive) sensors and workflows should be employed
- data should be captured at as low an altitude as possible, which increases the number of flight lines, time in the air and therefore cost and
- a coordinated ground control survey is required, further increasing costs.

Over-specifying a survey can bring about undue cost. For instance, there would be little advantage in specifying high accuracies for a land cover classification of a river basin.

Appendix B contains a combined accuracy and resolution table for each data capture platform.

2.3 Project extent

The project extent will influence the choice of data capture platform. The basic premise is that large project areas are captured more efficiently at higher altitudes and at higher data capture speeds:

- **Satellite-based sensors** are best for capturing areas of hundreds of thousands of square kilometres.
- **Fixed wing aircraft** can efficiently capture projects in the tens of thousands of square kilometres. They can carry larger and more complex instrumentation, such as a large format camera and a gyro-stabilised mount, so they can therefore achieve better system accuracy and resolution relative to the flight altitude.
- **Helicopters** can fly lower and slower, are much more manoeuvrable than fixed wing aircraft and are more efficient at capturing aerial survey data along corridors such as roads or railway lines. The lower altitudes at which they can fly enable them to capture higher resolution and potentially more accurate data, even considering the limitations of their payloads.
- **UAVs** that are part of an unmanned aerial system (UAS) can carry various aerial sensors and are suited to sites of a relatively small extent in the tens of square kilometres. The recent miniaturisation of LiDAR instruments and cameras has enabled very high-resolution surveys in the order of <10mm GSD to be conducted economically over smaller sites owing to the platform's proximity to the ground, which – under standard permissions – is <400ft above ground level (AGL).

2.4 Selecting a data capture platform

The use case, project extent and data type have the biggest impact on the accuracy, resolution and data capture platform for an aerial survey. More than one platform and/or data type can be used for different use cases.

Table 1 is an example of matching data types and data capture platforms in six common use cases. In practice, there are many more successful combinations.

Use case	Project extent	Data type	Accuracy	Resolution	Data capture platform
National mapping	Large	Aerial photography	High	Medium	Fixed wing
Heritage recording	Small	Aerial photography	High	High	UAV
Forestry	Medium	LiDAR	Medium	Medium	Fixed wing
Land classification	Large	Multispectral imagery	Low	Low	Satellite
Rail transportation	Medium	LiDAR	High	High	Helicopter
Precision agriculture	Small	Multispectral imagery	High	High	UAV

Table 1: The relationship between use case, project extent, data type, accuracy, resolution, and data capture platform

2.5 Data capture platform restrictions

Each data capture platform has its own restrictions.

Satellites are on fixed, sun-synchronous orbits passing over the equator at the same time every day, which may or may not suit the project's requirements.

Fixed wing, helicopter and UAV operations are governed by two global bodies: the International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO). The European Union Aviation Safety Agency (EASA) governs operations within the EU. Practitioners should consult the national aviation organisations of their individual country for specific operational details.

For example, the Civil Aviation Authority (CAA) is the statutory body that oversees and regulates all aspects of civil aviation in the UK. Fixed wing aircraft are restricted to a height of 10,000ft in the UK, above which an aircraft with a pressurised cabin or oxygen for the flight crew can be used. Below this altitude, fixed wing aircraft must comply with restrictions on flight zones set by the CAA, which are more prevalent and restrictive around dense urban areas and sensitive sites such as prisons or airports. UAV pilots are required to hold permissions for commercial operations (PfCO) accreditation, for which mandatory training is required. The drone operators are obliged to write an operations manual that must be approved by the CAA.

Under standard permissions from the CAA, UAVs are restricted to operating outside of controlled airspace – unless they attain permission from the relevant authority – maintaining:

- a distance of 50m from people, vehicles, vessels and structures not under the control of the pilot
- a distance of 150m from crowds of 1,000 people and
- a visual line of sight at all times.

They are also restricted to a height of <400ft AGL. To operate outside of these standard permissions and to operate in congested, restricted or sensitive areas, UAV operators need to have their operational safety case approved by the CAA and possibly third parties with a legitimate interest in the activity of the flight. Clients are advised to review the operator's paperwork before commissioning a survey to check the permissions they hold. See Drones: applications and compliance for surveyors, RICS insight paper, for more information.

In the EU, EASA registration of UAV operators became mandatory on 1 July 2020. All drone operators in applicable jurisdictions operating a drone with a weight of more than 250g are required to register, as well as any drone less than 250g that is not a toy and is equipped with a sensor able to capture personal data. The registration number is required to be displayed on the drone. The training requirements and distances to which pilots can operate are set to change significantly to standardise the legislation across the EU.

3 Project planning

All aerial survey projects have some key items in common regardless of location, extent, data capture platform, type of data, ground control, accuracy or resolution. These items should be addressed systematically during the project planning stage.

In the fast-moving area of UAV surveys, the International Organization for Standardization (ISO) have developed standards covering the general specification, product systems and operational procedures.

3.1 Area of interest

The starting point for any survey should always be a geo-referenced digital file supplied by the client showing their area of interest (AOI). In many cases, this is accompanied by a specification document providing details of the target imagery GSD, accuracy requirements and the deliverable products to be created.

However, the contractor can sometimes simply be supplied with a geo-referenced AOI file and a description of the potential use case for the survey data. An experienced contractor should be able to advise on the specification of the data, the data formats, a schedule of data deliverables and the best sensor to capture the geospatial data to meet the client requirements.

3.2 Project start and end date

Every aerial survey project has a start date and an end date. There are a number of factors that influence the rate at which an aerial survey project proceeds, including:

- the prevailing weather conditions
- time of year (see section 3.3.3) and
- the limitations associated with working in congested airspace.

It is important that the client and contractor work closely to define the project start and end dates, taking these factors into consideration. The need for adherence to the contract requirements and a completion date must be tempered by the need to produce an acceptable product.

3.3 Project constraints

The project constraints listed in the following subsections should be identified and addressed at the earliest opportunity.

3.3.1 Military or civil security clearances

These may be required in order to fly over, photograph or process data of sensitive locations, or in order to operate in particular countries. In some cases, this may require an in-air observer in the aircraft during the data capture. The data captured may also need to be processed in the host country.

3.3.2 Air traffic control requirements

Some element of air traffic control is required to operate fixed wing aircraft, helicopters and UAVs in congested airspace. Permissions, which are time sensitive, may need to be applied for in advance. Permissions are more difficult to obtain around major airports or over military training areas.

3.3.3 Time of year

Flying can take place all year round. However, it is recommended to specify that the angle of the sun is at least 15° above the horizon, which, in the northern hemisphere, generally coincides with a flying season of between April and October. A sun angle of >15° is high enough to provide optimal lighting conditions; lower sun angles may result in deep shadows, particularly in urban areas or where there are considerable differences in the height of the terrain. Some clients may also specify that flying should take place during 'leaf-off' conditions, i.e. when there is minimal growth on trees, to provide better visibility of the ground beneath. The timing of this period is variable and should be subject to agreement between the client and the contractor.

Choosing the day(s) on which to fly is crucial in determining the quality of the final image. A balance should be met between flying in suboptimal conditions, risking the client rejecting the photography, and waiting too long for better conditions, lengthening the project acquisition period.

3.3.4 Tidal constraints

For coastal projects in which it is beneficial for the maximum amount of intertidal area to be exposed during the data capture period, the tide times may be a project constraint. Clients may specify set periods of time before and after low tide during when data can be captured; this is known as the tidal window.

3.3.5 Health and safety/environmental requirements

Some clients may require risk assessments to be prepared, for example for low-level flights in sensitive or congested areas, or for flights taking place during unsociable hours.

3.3.6 Special limitations

There may be flying limitations or restrictions relating to observance of religious days or for security reasons.

UAVs tend to operate at lower altitudes, and it is advisable to consider the potential for public interest in the flight scheduling. For example, if operating in the vicinity of a school, it is prudent to inform the school of the planned survey and perhaps even schedule the project for outside of school hours. See Drones: applications and compliance for surveyors, RICS insight paper, for more information.

3.4 Ground control requirements

Independent ground control points are required to support the aerial triangulation process and verify the accuracy of the final product. To be effective, these ground control points should be captured to a standard of accuracy that is three times higher than that required by the final mapping product using professional land survey techniques. Capturing the ground control points to a higher standard of accuracy enables a buffer for additional random error propagation that may occur during the triangulation and product creation process.

If very high accuracies are required that are beyond the technical limits of a global navigation satellite system (GNSS), total station and precision levelling techniques may be required. This is most commonly the case with UAV surveys on discrete sites, such as in the rail environment.

The ground control points should be specified in the coordinate system for the final imagery product output. The contractor should be able to advise on the number of verification points to be surveyed to provide adequate evidence to support the final accuracy claim.

3.4.1 Control points for imagery surveys

For all types of imagery, ground control points can either be pre-marked or captured on points of detail after the flying mission is complete.

The advantage of pre-marked points is that there will be no ambiguity in their position when they are used in the aerial triangulation process. The disadvantage of this approach is that they may have been removed before the flight mission takes place. This approach also tends to be more expensive.

Points of detail may be harder to locate or observed in error within the aerial survey data, but they can be captured in the photography soon after the mission is complete, ensuring that up-to-date points are used. Using points of detail is the most common approach.

For full ground control, on the rare occasions where direct geo-referencing of the imagery is not used, points should be positioned in the overlaps between images, every five images along the strip, depending on the terrain. Control should be placed in this manner every third strip within the block. With the use of global positioning system (GPS) and inertial measurement unit (IMU) data, the amount of control can be reduced.

It is good practice to observe two or three points in each ground control location to act as checkpoint for the verification survey or if one point becomes unsuitable to be observed. Each point should be accompanied with a detailed witness and location diagram, including a photograph of the site to aid in the identification of the point on the imagery.

See the current edition of Guidelines for the use of GNSS in surveying and mapping, RICS guidance note, for more information.

3.4.2 Control points for LiDAR surveys

For LiDAR surveys, there are two types of control points:

- ground control areas (GCAs): a grid of 121 points to validate the height of the captured data and
- ground control points (GCPs), which are captured on points of detail to validate the plan position.

GCAs and GCPs should ideally be captured in the same locality. The number of points required is dependent on the size of the AOI and the flight line configuration. Ideally, they should be no more than 10–15km apart and located under crossing flight lines if possible.

GCAs do not necessarily need to be completely flat; a slope of <10° is acceptable. They should be established on hard, smooth surfaces within the survey area, away from aerial obstructions such as tall buildings or trees. If there is space, a 5x5m grid should be established with a point roughly every 0.5m, giving a total of 121 points. If this is not possible, an appropriate shape that captures 121 height points should be chosen.

GCPs should be captured on points of detail – on hard surfaces within the project area away from overhead obstructions – that can be located within the LiDAR AOI. Suitable points are along the tops of kerb lines and road markings. 20 points per location are enough for this purpose.

3.5 Project reports

The contractor should submit a brief progress report at regular intervals on the acquisition of the data and the production of the derivative products.

This should detail:

- each flight sortie
- location
- ground control locations and
- verification of the accuracy of the survey. This is best achieved by observing additional ground control points to act as checkpoints during the verification process (see section 3.4).

Clients may also request that they are informed of progress at significant milestones, for example, immediately prior to the commencement of data acquisition, on completion of data acquisition and during the data production and deliverable stages.

The time between the data acquisition and quality acceptance by the client of the derived products should be kept to a minimum to reduce the risks involved with additional rework.

3.6 Form of contract

Where the form of contract is not specified by the client, it is recommended that this guidance note is used along with the project information requirements set out in section 1 of the current edition of Measured surveys of land, buildings and utilities, RICS guidance note. Appendix A contains sample specifications for aerial photography, LiDAR, thermal and earth observation data.

3.7 Data ownership and copyright

The client should decide whether they wish to retain the ownership and copyright of the captured data and the derived products. The options for data ownership and copyright are as follows.

- The data and products become the property of the client upon completion and final payment of the contract.
- Under an agreement with the client, the contractor has the right to resell the data under a separate agreement for royalty payments.
- The data and products remain the property and copyright of the contractor.

4 Aerial photography

Aerial survey cameras come in two forms:

- frame cameras, where the imagery is captured frame by frame in a traditional sense and
- push broom scanners (also known as along track scanners), where the image is built up line by line.

Frame cameras are the most widespread cameras used for aerial surveys.

The term ‘metric’ is used to identify a camera that has been specifically made or modified for photogrammetry. They are factory-calibrated, and the calibration parameters are used to remove distortions in the assembled digital images. This is particularly important during the data processing stages where the successful removal of image distortions will have a positive effect on the subsequent 3D photogrammetric data products. The use of a metric camera designed for photogrammetric data capture should increase the utility of the data captured.

UAVs typically utilise non-metric cameras. It is therefore important that the surveyor is sufficiently competent to correctly calibrate the camera themselves to avoid adversely affecting the achievable accuracy of a project.

4.1 Key considerations

4.1.1 Footprint area

It is recommended that the camera CCD array/lens combination is selected to minimise the number of images to cover the contract area

The size of a digital camera's charged coupled device (CCD) determines the footprint area covered by a single frame on the ground. All other factors being the same – such as the lens and the flying altitude – the larger the CCD array, the larger the camera footprint coverage. Normally, digital frame cameras use multiple CCDs in their construction and the images from the individual CCDs are ‘stitched’ together by processing software to form a larger image or footprint on the ground. A larger camera footprint requires fewer images to cover the contract area, improving the efficiency of both the data capture and subsequent data processing. Medium or small format cameras use a reduced number of CCDs, making them impractical for large survey tasks due to their smaller footprint and therefore the greater number of strips of photography required to be flown for the same area.

4.1.2 Focal length

A typical multi-purpose lens will have a focal length of up to 210mm. A shorter focal length of 80mm will cover a wider area and produce height measurements that are more precise. A longer focal length of 210mm will improve the GSD of the imagery (and reduce relief displacement in the imagery) from the same flying height. For this reason, longer focal lengths are advantageous for the capture of data in urban areas.

In the case of UAVs, a shorter focal length of between 20mm and 80mm is generally recommended because of the smaller sensor sizes available on drones compared to manned aircraft. Typically, full frame complementary metal-oxide-semiconductor (CMOS) sensors are 25 to 35mm across. However, medium format sensors are now small and light enough to be carried on a UAV. These larger focal length sensors have greater image footprints at a given GSD – leading to more efficient data capturing – and enjoy improved low-light performance.

4.1.3 GSD

The GSD of the imagery is determined by:

- the choice of camera lens focal length

- the resolution of the camera sensor and
- the altitude at which the survey is flown.

The relationship between focal length, GSD, flying height and coverage is explored in Table 2.

Focal length (mm)	120	120	210	210	120
GSD (m)	0.10	0.05	0.05	0.10	0.09
Flying height (m)	3,000	1,500	2,625	5,250	2,625
Cross-track coverage (m)	2,646	1,323	1,323	2,646	2,315
Along-track coverage (m)	1,700	850	850	1,700	1,487
Footprint (km^2)	4.50	1.12	1.12	4.50	3.44

Table 2: Relationship between focal length, GSD, flying height and coverage

Halving the GSD and maintaining the focal length will reduce the flying height and consequently the footprint of a single image by a factor of four. This in turn will increase the number of flight lines and time in the air.

Increasing the focal length will enable the GSD and image coverage to be maintained while flying at a higher height, improving data capture efficiency.

Long focal length lenses are suited for data capture at higher altitudes, with maximum efficiency. Shorter focal lengths will provide wider coverage from the same altitude, but not necessarily an improved GSD.

It is normal for imagery output to be quoted as a GSD rather than the traditional photographic scale.

4.1.4 Restriction of image movement

Restricting the amount of image movement during exposure and keeping the camera as level as possible during random instances of air turbulence can significantly improve the image quality, particularly at large scales. The image movement is determined by:

- the speed of the aircraft
- the camera exposure time and
- the GSD of the imagery.

Image movement should not exceed 25µm over three or more consecutive exposures. This requires the use of a camera with:

- forward motion compensation (FMC) and
- a gyro-stabilised mount during turbulent conditions.

FMC, offered by most current air survey cameras, is a digital compensation technique that reduces the amount of the image movement due to the speed of the aircraft over the ground in the direction of flight.

Gyro-stabilised camera mounts are designed to reduce camera tilts and sudden rotations along three axes and are frequently controlled using GNSS and IMU data. Maintaining the camera in a flat and level position less than 2° from the horizontal is desirable. An occasional exposure with up to 4° may be permitted, provided the minimum forward and lateral overlaps are maintained (see section 4.2.2). Rotation in the z-axis (known as crab) should not exceed 5° as measured between the direction of flight and a line parallel to the image frame.

The contractor should select the equipment necessary to provide the product quality required under the flying conditions at the time of photography.

4.1.5 Directly geo-referencing aerial imagery

Using GNSS coupled with an IMU during the capture of vertical and oblique aerial imagery significantly increases the utility of that imagery. GNSS and IMU systems enable significant savings to be made in the amount of ground control and aerial triangulation effort required to provide accurate positioning of imagery both for subsequent mapping projects (see section 4.4.6) and to produce orthophotography (see section 4.4.4).

These systems usually require access to GNSS base station data, which can either be captured specifically for the project or data that comes from a continuously operating network. However, companies specialising in navigation are now developing solutions to remove errors resulting from orbital and atmospheric delays without the need for base stations.[3]

Evidence should be provided by the contractor that the GNSS and associated IMU and camera are calibrated on a test area at regular intervals. This is particularly true where the camera components have been removed and reinstalled on the aerial platform. The calibration procedure calculates the angular misalignments, which are then applied to the data when producing positioning and exterior orientation files.

The collection and supply of GNSS/IMU data is considered a standard practice. The camera positions can be outputted in the coordinate system of the client's choice.

4.1.6 Calibration

Each camera lens unit to be used on the contract should be calibrated, cleaned, tested and certified by the camera manufacturer or by a calibration centre that is recognised internationally or approved by the camera manufacturer. This should be carried out less than two years prior to the date of the photography. The two-year period is in recognition of the fact that modern lenses remain stable and that the cost of an annual recalibration in countries without local laboratories may be considered excessive.

The calibration certificate should contain the following information:

- name and address of the calibration centre and name of authorised signatory
- date of calibration
- camera manufacturer's serial number of the lens unit
- calibrated focal length of the lens unit in accordance with the manufacturer's recommendations and
- radial and tangential distortion parameters in micrometres. The measured distortion should fall within the limit defined by the manufacturer for the lens type.

If the contractor becomes aware of anything that may affect the calibration of the camera, the client should be informed immediately.

Digital cameras are calibrated and 'electronically adjusted' by the manufacturer to bring the system to a 'zero' state or within the manufactured tolerances as stated on the calibration certificate. The calibration data file produced during the calibration process is used in the first stages of image data processing. This data file would not normally be provided to the client unless the supply of raw data is specified as part of the contract.

Consumer-grade cameras should be calibrated as above where possible. However, camera self-calibration methods do exist, particularly for short focal length configurations, based on the analysis of imagery captured coincidently with the project data. Frequently, structure from motion (SfM) algorithms favoured by cameras carried by UAV platforms incorporate some elements of camera calibration.

4.2 Flying and coverage

4.2.1 Flight lines

Nadir (near-vertical) photography should be flown in approximately straight and level runs (strips) to achieve full stereoscopic coverage. There is little cost saving to be obtained by reducing the overlaps between exposures to a minimum. Full stereoscopic coverage will maximise opportunities for future use of the data.

Oblique photography should also be flown in approximately straight and level runs to achieve full coverage of the contract area. Modern aerial camera equipment can capture nadir photography simultaneously with oblique imagery. Commonly, four oblique cameras are employed, two along the flight line and two additional cameras either side, inclined at 45°. Care should be taken where a nadir camera is flown simultaneously with oblique cameras to ensure that the resulting coverage is compatible.

Contractors commonly prepare flight lines that are aligned either east-west or north-south, unless the client has a specific request for the orientation of the photography, or a more suitable flight line orientation is dictated by:

- the terrain
- air traffic control restrictions
- the avoidance of secure sites or
- the capture of tidal areas.

Coverage of corridor features such as for transport infrastructure can be achieved with the use of additional flight lines to capture the bends in the most economical manner.

Oblique projects are also frequently planned either in a north/south or an east/west direction, rather than ‘off-grid’. This means that every spot has coverage from the north-, south-, east- and west-facing cameras, with the camera direction and compass points being maintained.

Once the minimum number of runs required to cover the target area has been calculated, taking account of the terrain, the spacing between flight lines may be adjusted to increase and equalise the lateral overlap between each run.

There should be no duplicate run/strip or frame numbers. The sequence should be maintained even if the target area is subsequently flown in several missions.

Flight plans may be reused where there is a requirement for an ongoing repeat or monitoring survey.

4.2.2 Overlap

Forward overlap is required to ensure adequate formation of stereoscopic coverage. Lateral overlap (sidelap) is required only to ensure that no areas are missed between adjacent flying strips, and to tie adjacent strips together.

The forward overlap between successive exposures in each run is usually between 60% and 80%. The sidelap between adjacent strips is normally between 15% and 40% for flying heights greater than 1,500m AGL, increasing to between 20% and 40% for lower flying heights. An allowance of ±5% of the selected overlap is permissible.

In urban areas with high-rise buildings, a forward overlap of 80% and a sidelap of 30% is normally used. By increasing the coverage, each tall building will appear in more frames, thus increasing the choice of images that show the building to appear vertical. Exceptionally, the sidelap may be increased to 60% (along with a forward overlap of 80%) by clients who intend to use the imagery to produce 3D city models.

In coastal areas where a run crosses the shoreline, the forward overlap can be increased to 90%. The increase in overlap should include at least three photo centres over land.

In mountainous areas, where it is impossible to maintain the usual sidelap requirements, short infill runs should be flown, parallel to and between the main runs, to fill the gaps. Where ground heights within the area of overlap vary by more than 10% of the flying height, a reasonable variation in the stated overlaps is permitted, provided the forward overlap does not fall below the selected percentage and the sidelap does not fall below 10% or exceed 45%.

In oblique imagery, overlaps are not as crucial as stereo imagery is not expected. However, oblique imagery is still planned with some overlaps to ensure full coverage over the contract area.

Push broom imagery sensors acquire multiple strips of images simultaneously (forward, nadir and backward) as opposed to operating via a series of separate exposures. Stereo viewing is derived from the fixed geometry of the sensor. Scanner-based imagery must therefore be flown in a continuous swathe with a minimum of 20% sidelap (25% in elevated or urban areas).

4.2.3 Acceptable quality limits

The following list is intended to act as a set of acceptable quality limits (AQLs) to provide guidance on the subjective topic of image quality. The prevailing weather and atmospheric conditions, which are outside of the control of the contractor, are the most important factors that affect the image quality, and therefore the AQLs. The client and contractor should work closely together to ensure a mutually acceptable result. These guidance notes apply equally to nadir imagery and oblique imagery.

- The photography should be taken at any solar altitude above 15°, unless special restrictions are included.
- The imagery should be sharp.
- There should be minimal flare from expanses of glass, water or cars.
- Colour and light balance should be uniform.
- Contrast should be consistent across the block of imagery.
- There should be a good match between flight runs and adjacent images.
- The photography should only be flown in conditions where the visibility does not significantly impair the image quality and detail is not lost because of rain, atmospheric haze, dust, smoke or any other conditions detrimental to the photographic image.
- The photography should be substantially free of cloud, dense shadow, or smoke. Isolated areas of cloud, dense shadow or smoke should not be cause for rejection of the photography, provided the intended use is not impaired. Typical tolerances for cloud and cloud shadows may be less than 5% for a single image and 1% over a contiguous block of images.
- The photography should conform to any specific radiometric values specified by the client, including:
  - mean histogram luminosity values
  - mean of the individual colour bands or
  - standard deviation for each colour band.

4.3 Aerial photography accuracy and resolution table

The relationship between aerial photography scale, GSD, mapping scale and potential photogrammetric accuracies is well known. Table 3 has been reproduced from the previous edition of this guidance note.

Photo scale	GSD	Mapping scale	Horizontal RMSE	Vertical RMSE
1:3000	4cm	1:500	+/- 0.100m	+/- 0.050m
1:5000	7.5cm	1:1250	+/- 0.225m	+/- 0.125m
1:10000	15cm	1:2500	+/- 0.500m	+/- 0.250m

Table 3: Relationship between photo scale, GSD, mapping scale and potential photogrammetric mapping accuracy

The following table is an expanded version of Table 3 that includes high-altitude fixed wing aerial photography, photography captured from a helicopter and photography captured from UAVs.

It is worth noting that Table 4 is based on high-end equipment on the market today and that many factors may affect accuracy and resolution. Therefore, the values quoted can only be referenced as achievable.

Platform	Height AGL		Achievable accuracy (m) (RMSE figures, at 1 sigma)		Achievable resolution – GSD (m)
	m	Ft	Plan X,Y	Height Z	
UAV	30	100	+/- 0.01	+/- 0.015	0.005
UAV	122	400	+/- 0.04	+/- 0.06	0.02
Helicopter	319	1,047	+/- 0.05	+/- 0.03	0.02
Helicopter	638	2,093	+/- 0.10	+/- 0.05	0.04
Fixed wing	1,200	3,937	+/- 0.10	+/- 0.05	0.04
Fixed wing	2,250	7,382	+/- 0.19	+/- 0.09	0.08
Fixed wing	4,500	14,764	+/- 0.38	+/- 0.19	0.15
Fixed wing	7,500	24,606	+/- 0.63	+/- 0.31	0.25

Table 4: Achievable accuracy and resolution values for aerial photography

The UAV flying altitude of 400ft represents the highest altitude at which a UAV can be operated in the UK without the approval of an operational safety case.

For comparison purposes, Table 4 is based on a camera focal length of 120mm for the fixed wing aircraft, an 80mm lens on a helicopter-based medium format camera system and a 35mm UAV camera lens. The miniaturisation of camera technologies has meant that medium format cameras (with a focal length of around 80mm) are now small and light enough to be carried on UAV platforms.

Table 4 shows that mapping accuracies of 2.5 to 3x the GSD can be achieved horizontally and 1.25 to 2x vertically. This range in values is a reflection on the quality of the camera and navigation equipment that can currently by carried by each platform.

When using dense image matching photogrammetric techniques, a well-known rule of thumb for calculating likely achievable relative accuracies is:

Plan = 1 to 2x GSD

Height = 2 to 3x GSD

Similarly, the absolute accuracy follows a similar pattern in which horizontal accuracy is better than vertical accuracy (in contrast to the pattern shown in Table 4). Dense image matching processing is particularly popular with UAV workflows as it is more forgiving on external camera geometry.[4]

The accuracy achieved at an altitude of 1,200m is roughly equivalent to band G in the survey detail accuracy band table given in section 2.3 of the current edition of the RICS guidance note Measured surveys of land buildings and utilities. Altitudes of 2,250 and 4,500m are roughly equivalent to bands H and I.

4.4 Digital imagery deliverables and products

4.4.1 Digital imagery

The contractor may supply all stereo digital imagery upon request, which enables the client to take advantage of any future improvements in image processing techniques.

The client may specify the image format, image compression and data transfer medium. Stereo imagery data can require large volumes of space, so clients are likely to specify a format that can be easily incorporated into their archive system.

It is rare that stereo imagery is supplied without the accompanying positional information, derived from a GNSS/IMU navigation system. As a minimum, for each image, this should consist of:

- a unique run and frame number
- easting, northing and height position and the three photogrammetric camera rotations – omega, phi and kappa – in the client's choice of coordinate system.

The accompanying positional information is frequently used to georeference the imagery to meet the client's requirements. This should be simply supplied in a text file or database format.

4.4.2 Metadata

The data should be accompanied by metadata that describes the instruments used to capture the data and any processing applied. The following international standards are relevant to documenting metadata for imagery:

- ISO 19115-1:2014, Geographic information – Metadata – Part 1: Fundamentals
- ISO 19115-2:2019, Geographic information – Metadata – Part 2: Extensions for acquisitions and processing and
- ISO/TS 19115-3:2016, Geographic information – Metadata – Part 3: XML schema implementation for fundamental concepts.

Metadata should be made available to client organisations for onward supply to their customers. It may be specified for digital imagery or for any other digital imagery products described in the following sections.

Metadata standards are normally specified by the client organisation. Positional data derived from a GNSS/IMU navigation system is a good example of metadata.

Other examples of metadata are:

- date and time flown
- GPS time
- geographic reference
- flying height
- coordinate system
- resolution
- file size

- camera system
- oblique image orientation and
- date of production.

4.4.3 Stereo imagery

Digital stereo imagery is a raw product used to produce more complex geospatial data. This can in turn provide insight into the business proposition for which the imagery was commissioned. For example, supplying imagery with geo-referenced coordinates enables basic plan measurements to be taken and exploited for numerous applications.

Aerial photography can be used to form stereoscopic models, which are created using a mathematical model to replicate the geometry of the image at the time it was captured. This produces a precise geographical location for each individual image at the time of exposure. The position of each image is described using three coordinates (easting, northing, height) and three rotations (omega, phi, and kappa) around the three principal camera axes.

Aerial triangulation can then be used to view the stereoscopic models in 3D. This is a technique in which the imagery is tied together, geo-referenced and verified against independently captured ground control points, within a rigorous least squares adjustment model. The result is a 3D coordinate for every pixel in the image, enabling 3D measurements to be taken from the imagery.

The completion of a rigorous aerial triangulation process significantly increases the utility of the imagery. It provides the basis to:

- create orthophotography (see section 4.4.4)
- generate digital terrain models (DTMs) and digital surface models (DSMs) (see section 4.4.5)
- extract 3D mapping data (see section 4.4.6) and
- create additional specialist products such as:
    - 3D building modelling
    - tree mapping and
    - line of sight analysis.

There are other less rigorous methods of achieving the same result, such as SfM and simultaneous localisation and mapping. These methods are favoured by aerial survey methods that use very small cameras on smaller aerial platforms such as UAVs.

4.4.4 Orthophotos

Orthophotos are true-to-scale 2D images. A DTM is used to remove the effects of the aerial camera geometry, tips or tilts in the imagery and the effects of relief displacement. They can be created in any common imagery format and in any specified coordinate system. The measurement of a distance in the image, such as a road width, will be replicated in the terrain, making them an indispensable tool for a wide range of applications.

4.4.5 Digital terrain/surface models

A terrain model is a digital representation of the ground surface defined by 3D points. Terrain models can be automatically generated from stereo photography. The modelling software takes advantage of the mathematical model established during the aerial triangulation process to calculate a 3D coordinate for each pixel in the stereo imagery.

There are two types of terrain model:

- DTMs, for all points located on the ground and under trees and bridges and
- DSMs, which include all surface features such as the tops of tree canopies and buildings.

Terrain models are used for wide-ranging applications such as:

- 3D city modelling
- 3D visualisation
- forest management
- road, rail, and energy sector engineering
- the management of flood risk and
- preventing coastal erosion.

4.4.6 Mapping

Mapping is a traditional application of aerial imagery. Stereoscopic models have a long history of being used to update vector databases for national mapping companies and for engineering applications, among others. Where the third dimension is not required, orthophotos have been successfully employed for map update tasks and land use classification.

5 LiDAR

LiDAR instruments are active sensors that emit and receive a laser pulse from an aerial platform, deducing ranges or distances to the terrain by measuring the time taken for the laser pulse to return. Coupled with GNSS/IMU technologies, these ranges are used to compute the 3D position of each laser pulse, forming a LiDAR point cloud (see section 5.4.1) that accurately depicts the terrain below the sensor. Modern LiDAR sensors carry a medium format RGB camera, enabling imagery to be captured simultaneously.

LiDAR technologies have established themselves as the predominant method of obtaining accurate 3D data from aerial surveys and offer advantages over photogrammetric methods such as the ability to capture data at night, during the winter, under trees and irrespective of solar angle.

Bathymetric LiDAR systems are equipped with a laser (frequently referred to as a green laser) operating at wavelengths capable of penetrating inshore waters down to depths of approximately 40m. The result is an accurate 3D model of the sea floor.

Developments in LiDAR technology are underway: Geiger mode LiDAR (GML), single photon LiDAR (SPL) and flash LiDAR are examples of developments that are currently being refined.[5] GML and SPL LiDAR have a sensor design that is based on a focal plane array of pixels, as opposed to the single pixel that is used in traditional LiDAR technology, known as linear LiDAR. These technologies divide a single pulse into hundreds of thousands of sub-pulses, providing potentially higher point densities. GML and SPL also require less laser energy, enabling them to be flown at higher altitudes while maintaining point densities and reducing costs. Flash LiDAR, while offering higher point densities, is a relatively high energy system, making it more suitable for low altitude applications. It is unclear whether any of these developments will gain the market penetration that linear LiDAR currently enjoys; linear LiDAR still offers advantages in vegetation penetration and accuracy.

5.1 Key considerations

5.1.1 Point density

Laser point density is a key metric when commissioning LiDAR data. Expressed simply as the number of points per metre squared (ppm^2), laser point density is a measure of the spatial resolution of the LiDAR data. The higher the point density, the higher the spatial resolution, and therefore the more detail that will be visible in the data.

The point density is dependent on the laser pulse rate frequency (PRF, also known as the pulse repetition rate or PRR) and the flying speed. These two variables control the rate of data capture. The PRF is simply the number of times the laser fires every second. The higher the PRF, the higher the achievable point densities. High specification lasers can fire at a rate of 2MHz. Slowing down the flying speed of the aircraft will increase the point densities that can be achieved. The flying speed should be slow enough to meet the requirements of the specification, but fast enough to maintain an efficient number of flying hours.

The scan rate is the rate at which the data is captured as the laser is directed back and forth (with the use of a mirror), perpendicular to the direction of travel of the aircraft over the terrain. It is not uncommon for the scan rates of high-end systems to operate up to 600 lines/sec. The scan rate controls the laser point spacing along the aircraft path.

Point density is also influenced by the terrain itself. Areas of water will absorb the laser energy, recording very few points. Vegetation will also absorb a larger amount of the laser energy than manmade surfaces. It is not uncommon for LiDAR specifications to specify point densities and accuracy requirements with respect to hard surfaces.

The choice of LiDAR system should be determined by the eventual use for which the data is being commissioned. For example, a flood risk analysis on a large river catchment may require a point density of around 8ppm². This type of project is better suited to the larger LiDAR instruments, where the laser is powerful enough to provide an adequate number of returns from high altitudes, keeping flying time to a minimum and reducing cost. Corridor engineering applications such as for road, rail and power line corridors tend to be much smaller but require higher point densities. LiDAR instruments that are 'eye safe' at low altitudes are more suitable for this type of work.

5.1.2 Footprint area

Data coverage is influenced by:

- the instrument laser scan angle
- the laser power level and
- the flying altitude above the terrain.

More powerful lasers can operate at higher altitudes. The laser scan angle, also referred to as the field of view (FOV) of the instrument, controls the footprint of the laser data capture area on the ground. An FOV of 60° refers to 30° of coverage either side of a nadir line drawn directly below the aircraft. As the altitude increases, the footprint on the ground increases and the point density decreases, as shown in Table 5.

Coverage		Point density			Output	
FOV (°)	Flying height (m)	PRF (Hz)	Scan rate (lines/sec)	Aircraft velocity (km)	Point density ppm²	Capture rate (km²/sec)
60	1,300	1×10^6	200	160	8.1	0.12
30	1,300	1×10^6	200	160	17.4	0.06
30	2,800	1×10^6	200	160	8.1	0.12
60	1,300	1×10^6	200	125	10.4	0.1
60	1,300	1.25×10^6	200	125	12.9	0.1

Table 5: Relationship between FOV, flying height, PRF, scan rate, aircraft velocity, point density and capture rate.

Reducing the LiDAR footprint on the ground by decreasing the FOV will increase the point density if the laser is fired at the same rate and the aircraft speed is maintained. This will also reduce the capture rate, as less terrain will be covered in the same time period. Increasing or decreasing the flying height while maintaining the FOV will influence the coverage area.

An increased point density can be achieved by simply slowing down the aircraft velocity at the expense of reducing the capture rate. Increasing the PRF will also improve the point density while maintaining the capture speed.

5.1.3 Directly geo-referencing LiDAR imagery

LiDAR data is scanned line by line as opposed to being captured in a single frame. The scanner head position should be accurately directly geo-referenced. All LiDAR instruments should have an integrated GNSS/IMU navigation system.

The location of each individual laser pulse at the time of capture is described using three coordinates (easting, northing and height) and three rotations (omega, phi and kappa) around the three principal instrument axes. These systems do require access to GNSS base station data, which can either be data that is captured specifically for the project or data that comes from a continuously operating network.

The camera positions can be output in the coordinate system of the client's choice.

A LiDAR system should also be calibrated after a new installation or at a regular interval of one month during a large project. The calibration procedure involves a special calibration flight at two different altitudes.

The calibration flight is used to deduce the angular difference between the LiDAR sensor and the aircraft coordinate systems to ensure alignment. This provides the angular misalignments, which are then applied to the LiDAR data when producing the laser point cloud (see section 5.4.1).

Ground control points are not normally required for this procedure but are useful for quality control of the captured data. Evidence should be provided by the contractor that the GNSS and associated IMU are calibrated on a test area at regular intervals. This is particularly true when the LiDAR components have been removed and reinstalled on the aerial platform.

5.1.4 Calibration

The LiDAR unit should have a factory calibration certificate, valid for a two-year period, prepared by the instrument manufacturer. Several internal sensor parameters should be measured and compared against the values at the time of manufacture. The sensor model should be adjusted accordingly to maintain its accuracy.

5.2 Flying and coverage

5.2.1 Flight lines and overlap

Professional flight planning software is used by contractors to consider all the factors affecting point density and will enable coverage of the client's AOI in as few flight lines as possible. The flight planning is completed using an underlying DTM, which takes into consideration the effects of the local topography of the area.

Flight line planning for LiDAR sensors follow the same principles as those for vertical aerial photography detailed in section 4.2.1. The best results are achieved by organising the coverage of an area in straight flight lines that are as level as possible. Coverage of corridor features such as for transport infrastructure can be achieved via the use of additional flight lines to capture the bends in the most economical manner.

Overlaps between flight lines are usually at between 15% and 35% and are necessary to ensure that there are no gaps. Cross strips are also frequently flown to assist in the data processing by tying blocks of flight lines together.

5.2.2 Acceptable quality limits

The following list is intended to act as a set of AQLs to provide guidance on the subjective topic of LiDAR data quality. The prevailing weather and atmospheric conditions, which are outside of the control of the contractor, are the most important factors that affect the data quality, and therefore the AQLs. The client and contractor should work closely together to ensure a mutually acceptable result.

- Point density and point cloud accuracy specifications should be met.
- Full coverage should be achieved.
- There should be a good match between flight runs.
- The LiDAR should only be flown in good conditions, in the absence of rain, cloud, atmospheric haze, snow and flooding.
- The LiDAR may be flown at any time when the weather conditions are suitable to achieve the specified standards of data quality, except where special time constraints are defined.

The intended use of the LiDAR may impose limitations upon times of flying. See project constraints in section 3.3.

5.3 LiDAR accuracy and resolution table

Preparation of Table 6 is based on the American Society for Photogrammetry and Remote Sensing (ASPRS) document: ASPRS Positional Accuracy Standards for Digital Geospatial Data, edition 1, version 1.0., 2014, pg. A7.

The accuracy values in the table are dependent on:

- the flying altitude and
- the GNSS positional and IMU angular rotation errors of the equipment used.

Laser ranging and timing errors are also considered.[6] Many other factors may also affect accuracy and resolution. Therefore, the values quoted can only be referenced as achievable.

Platform	Height AGL		Achievable accuracy RMSE (m)		Achievable resolution (ppm²)
	m	Ft	Plan X,Y	Height Z	
UAV	30	100	+/- 0.019	+/- 0.012	140
UAV	122	400	+/- 0.06	+/- 0.05	51
Helicopter	260	853	+/- 0.03	+/- 0.03	100
Helicopter	400	1,312	+/- 0.04	+/- 0.03	48
Fixed wing	500	1,640	+/- 0.04	+/- 0.03	30
Fixed wing	725	2,379	+/- 0.06	+/- 0.04	20
Fixed wing	1,300	4,265	+/- 0.10	+/- 0.05	8
Fixed wing	2,600	8,530	+/- 0.20	+/- 0.10	2
Fixed wing	5,000	16,404	+/- 0.39	+/- 0.15	1

Table 6: Achievable accuracy and resolution values for LiDAR sensors

The UAV flying altitude of 400ft represents the highest altitude at which a UAV can be operated in the UK without the approval of an operational safety case.

For comparison purposes, the LiDAR FOV was maintained at 60°, keeping a high degree of coverage. LiDAR resolutions were calculated from first principles. The laser PRF values vary with altitude as lasers with a high PRF capability currently tend to be larger and heavier and can therefore only be carried by fixed wing and helicopter platforms. The differences in platform velocity at different altitudes were also considered when calculating the LiDAR resolution.

5.4 LiDAR deliverables and products

5.4.1 LiDAR point cloud

The basic deliverable is the LiDAR point cloud, which is made up of individual laser data points that are fully geo-referenced in 3D in the client's choice of coordinate system and usually cut into 1km squares.

LAS – or the compressed version, LAZ – is the most frequently used format for LiDAR data. It is an internationally used standard format, maintained by the ASPRS, which facilitates data classification and storage of metadata.[7]

The client may specify the data format, data compression and data transfer medium. As with aerial photography, LiDAR data at high point densities can require large volumes of space, so clients are likely to specify a format that can be easily incorporated into their archive system.

5.4.2 Metadata

Metadata may be specified for LiDAR or for any other LiDAR products as described in the following sections.

The LiDAR LAS format promotes the easy management and exchange of metadata. Examples within this format are:

- date and time flown
- GPS time
- geographic reference
- flying height
- coordinate system
- scan angle
- number of laser returns and
- laser intensity.

5.4.3 Digital terrain/surface models

The LiDAR point cloud can be processed to extract a ground class and a second class containing all points above the ground. The ground class can be extracted separately to create a DTM of the AOI. A DSM can be created by combining the ground class and the above ground class into a single file.

5.4.4 Classified point clouds

Classified point clouds further categorise the data into separate groups. The points above the ground, for example, can be classified into:

- buildings
- hard surfaces
- lampposts
- power supply lines and
- areas of low, medium and high vegetation.

It is also common to remove temporary movable objects such as cars and classify these as noise. This enables further specialist analysis of the data. The LAS format sets out several standard classes within this specification.

Where an RGB camera has been flown simultaneously with a LiDAR instrument, it is possible to assign the RGB colour value from the camera to each individual LiDAR point in the point cloud. These colourised point clouds offer a more realistic representation of the AOI.

5.4.5 Mapping

Topographic mapping in 3D vector format can be extracted from LiDAR point clouds. The linework is digitised from the data in 2D, frequently with the use of a simultaneously captured imagery layer. Heights are then assigned to the 2D feature strings by draping the linework onto the 3D point cloud. This approach has been successful for high accuracy engineering applications.

6 Hyperspectral, multispectral and thermal imaging sensors

Aerial survey sensors operating in the non-visible parts of the electromagnetic spectrum offer a rich source of data from which to extract information through sophisticated spectral analysis. When using these sensors, the emphasis tends to be on identification and the condition of features, rather than their absolute position. These sensors broadly fall into three categories: thermal, multispectral and hyperspectral. In recent years, the use of UAVs for precision agriculture has been an important factor in driving the development of small format multispectral and hyperspectral cameras.

Thermal imaging

Thermal cameras operate in the infrared part of the spectrum at wavelengths of 4–12μ microns. They can sense heat energy emitted, reflected or transmitted by an object. A good quality, well-calibrated sensor can have a measurement accuracy of +/- 1°C. They have found applications in the power industry and in housing energy efficiency surveys.

Multispectral imaging

Multispectral cameras typically sense in between three and ten separate bands, depending on the application of the data. Band-pass filters are used to filter out unwanted frequencies. A common configuration is the use of three bands (visible green, visible red and a near infrared band), which finds applications in determining plant and soil water saturation.

The processing of multispectral data can be very complex and requires the specialist knowledge of a spectral analyst.

Hyperspectral imaging

Hyperspectral sensors have the broadest spectral range of all non-visible sensors. A high-quality instrument can typically sense from 380 to 2,500nm, from the visible near infrared (VNIR) to the short-wave infrared (SWIR) parts of the electromagnetic spectrum.

These instruments are also characterised by the large number of spectral bands that they can use to separate the data, typically more than 500. With such a rich data source, the applications are bespoke, numerous and varied, including:

- the detection of invasive plant and insect species
- precision agriculture and
- the detection of minerals.

As for multispectral sensors, the processing and manipulation of this data requires the specialist knowledge of a spectral analyst.

6.1 Key considerations

6.1.1 GSD

GSD is a key metric specified by the contractor when commissioning hyperspectral, multispectral or thermal imaging projects. As for aerial imagery, the GSD of any hyperspectral, multispectral or thermal imaging mission is determined by the flying altitude, the dimensions of the camera sensor chip and the lens. However, when using hyperspectral, multispectral and thermal imaging sensors, improving the spatial and spectral resolution can increase the amount of noise in the signal. It is therefore not uncommon for GSDs of 0.5m or even 1m to be used, with the emphasis on feature identification and condition.

6.1.2 Directly geo-referencing hyperspectral, multispectral and thermal imagery

Hyperspectral, multispectral and thermal imaging sensors are passive sensors, relying on radiation from the sun reaching the camera head, or in the case of a thermal sensor, being emitted from the target. Both push broom and frame sensors are available, although push broom sensors are becoming less common.

They do rely on an accurate GNSS/IMU navigation system to directly geo-reference the imagery, similar to the systems described in sections 4.1.5 for aerial photography and 5.1.3 for LiDAR sensors.

It may be necessary to document the sensor models used to transform coordinates on the sensor device to coordinates on the earth's surface. Should a requirement arise to document the sensor models, the following specifications may be used to describe them:

- OGC 12-000, OGC® SensorML: Model and XML Encoding Standard and
- OGC 17-011r2, JSON Encoding Rules SWE Common/SensorML.

6.1.3 Calibration

Hyperspectral, multispectral and thermal imaging sensors are sensitive precision instruments. The quality of the data captured is very dependent on ensuring that the instruments are calibrated regularly according to the instrument manufacturer's guidelines.

As with aerial photographic cameras and LiDAR sensors, a calibration flight is necessary every time the instrument is installed in a new aircraft to establish the relationship between the sensor and the aircraft coordinate system.

6.2 Flying and coverage

6.2.1 Flight lines and overlap

As with LiDAR imagery, professional flight planning software is used by contractors.

Flight line planning for hyperspectral, multispectral or thermal imaging sensors follow the same principles as for vertical aerial photography detailed in section 4.2.1.

Overlaps between flight lines usually at between 15% and 35% are necessary to ensure that there are no gaps.

6.2.2 Flight times

Thermal imagery does not rely on the capture of the visible parts of the electromagnetic spectrum, and therefore it can be captured at night. Indeed, this is recommended, because air temperatures are cooler and more stable at night, meaning differences in temperature are easier to detect. Thermal imagery is frequently commissioned during the winter period for the same reasons.

Multispectral imagery is frequently commissioned for the study of vegetation health and land use cover and as such it is usually flown during the main part of the flying season when the vegetation is in full bloom.

Hyperspectral imaging sensors require the best conditions possible to detect enough energy to produce good quality results. This usually means operation with a high solar angle in bright sunshine and cloudless skies. The presence of a significant amount of moisture in the air will affect the returns in the SWIR part of the electromagnetic spectrum.

6.2.3 Acceptable quality limits

The following list is intended to act as a set of AQLs to provide guidance on the subjective topic of image quality. The client and contractor should work closely together to ensure a mutually acceptable result.

- Geospatial and spectral resolution specifications should be met.
- Full coverage should be achieved.
- There should be a good match between flight runs and adjacent images.
- Hyperspectral, multispectral and thermal sensors should only be flown in good conditions, in the absence of rain, cloud, atmospheric haze, snow and flooding.
- Hyperspectral sensors are particularly sensitive to moisture in the atmosphere and should only be flown in bright sunshine and cloudless skies.

The intended use of the data may impose limitations upon times of flying. See project constraints in section 3.3.

6.3 Hyperspectral, multispectral and thermal imagery accuracy and resolution table

The emphasis of aerial surveys operating in the non-visible part of the electromagnetic spectrum has been on feature identification and condition.

Table 7 was prepared from first principles focusing on the achievable spectral resolutions.

Platform	Height AGL		Achievable resolution – GSD (m)		
	m	Ft	Thermal	Multispectral	Hyperspectral
UAV	30	100	0.07	0.01	0.02
UAV	122	400	0.28	0.06	0.08
Helicopter	270	886	0.05	0.14	0.19
Fixed wing	500	1,640	0.10	0.25	0.36
Fixed wing	1,000	3,281	0.20	0.50	0.71
Fixed wing	2,000	6,562	0.40	1.00	1.43
Fixed wing	3,000	9,842	0.60	1.50	2.14

Table 7: Achievable resolution values for thermal, multispectral and hyperspectral imagery

The UAV flying altitude of 400ft represents the highest altitude at which a UAV can be operated in the UK without the approval of an operational safety case.

6.4 Hyperspectral, multispectral and thermal imagery products

6.4.1 Thermal imagery

The most common product created from thermal imagery is an orthorectified mosaic created from the individually captured thermal images. In a mosaic, the individual pixels have values that reflect the relative temperatures across the AOI. The orthorectification process ensures that accurate measurements are possible from the imagery.

Thermal imagery has found applications in monitoring energy usage over wide areas and pinpointing inefficient assets such as individual buildings and pipelines.

6.4.2 Multispectral imagery

The simplest products created from multispectral imagery are three- and four-band orthorectified images. Colour infrared (CIR) photography combines the red and green visible bands with the infrared part of the spectrum. Intense reds in this imagery are associated with healthy vegetation showing fast growth rates. Four-band imagery – combining the visible red, green and blue bands with the near infrared (NIR) band – has all the benefits of traditional imagery, with the additional advantage that the NIR band can be used for vegetation studies.

Products created from ten-band multispectral cameras are much more complex to create. The successful analysis of this data relies on the creation of a spectral signature of the landscape feature in the terrain that the user wishes to detect.

A spectral signature is the variation in the electromagnetic reflectance of a homogeneous target across several different wavelengths. Spectral signatures are unique responses for each land cover classification, such as sand, roads, cereals, grassland, moorland, or forestry. They are created using a combination of multispectral observations from the camera and observations on the ground, known as ‘ground truth’ observations. Using a predefined spectral signature, an automatic classification is run on the imagery to identify the target object, such as the area of cereals under cultivation.

6.4.3 Hyperspectral imagery

The principles behind hyperspectral imagery classification are the same as for multispectral imagery in that a spectral signature is used to classify and extract the landscape feature under study.

Hyperspectral data is captured in a wide range of the electromagnetic spectrum (2,120nm) that is split into over 500 individual spectral bands; this improves the precision and the number of data processing possibilities. However, a lot more effort and attention are required when completing the ‘ground truth’ observations, which should include handheld spectrometer observations.

In the more traditional area of vegetation analysis, hyperspectral imaging has the potential of not just being able to identify cereals but also to differentiate between wheat and barley, for example.

Hyperspectral imaging has found applications in:

- invasive species detection
- forestry inventories
- the estimation of soil water content
- geological applications and
- mineral exploration.

7 Earth observation

Earth observation from satellite platforms offers the advantage of covering large areas, up to 1,000,000km^2 every day.

Sensors on-board satellite platforms tend to have either a push broom scanner, also known as an along track scanner, or a whisk broom scanner, also known as an across track scanner. Both types of scanner can produce both mono and stereo imagery. Whisk broom scanners have a greater number of moving parts, which tend to make the design of these instruments heavier, more expensive, and more prone to wearing out than their push broom counterparts. However, the whisk broom design does have the potential to offer a better spatial resolution.

Scanner-based imagery must be flown in a continuous swathe with a minimum of 20% overlap (25% in elevated or urban areas).

The key decision is whether the imagery specification can be met by the supply of tasked imagery, to be captured at some point in the future, or from previously captured imagery from the existing archives of satellite imagery providers. With tasked imagery, the same point on the earth's surface can potentially be revisited daily, offering monitoring solutions as well as applications in mapping, change detection and responding to environmental disasters.

7.1 Types of imagery

Visible, radar, and multispectral sensors are the most common sensors employed from satellite platforms. It is common for individual satellites to carry multiple sensors, including panchromatic, RGB and NIR sensors and additional multispectral options.

Radar imaging relies on an active sensor, emitting electromagnetic radio waves. Unlike optical methods that measure the wave amplitude, radar sensors measure the phase of the backscattered radio waves and can therefore operate in the dark and in all weather conditions.

Modern satellite sensors offer spatial resolutions of between 0.35m and 1.5m GSD for panchromatic sensors and from 1m to 6m GSD in the multispectral bands.

7.2 Flying and coverage

7.2.1 Satellite orbits

Earth observation satellites typically operate in sun synchronous geostationary or polar orbits. Geostationary orbits are at altitudes of approximately 36,000km, where the satellites take approximately 24 hours to orbit the earth. This enables continent-wide areas to be monitored continuously for environmental conditions or weather patterns.

Polar orbits are the most common orbits for remote sensing applications. In a polar orbit, the satellites pass over the earth's polar regions within 20° to 30° of the poles. Typically passing over the polar regions several times a day, they are at an altitude of between 200 and 1,000km from the earth's surface. The cameras onboard the satellites can be tasked with capturing either nadir imagery or off-nadir imagery.

When using off-nadir imagery, the imagery sensor is rotated so that it views the AOI from the side, rather than waiting until the satellite is directly overhead. This reduces the length of time that will elapse between observations, known as the satellite revisit time. However, because of the greater distance between the sensor and the surface of the earth, off-nadir imagery results in poorer resolution than nadir imagery.

7.2.2 Acceptable quality limits

The following list is intended to act as a set of AQLs to provide guidance on the subjective topic of image quality. The client and contractor should work closely together to ensure a mutually acceptable result.

- The specified coverage and imagery accuracy requirements should be met.
- The imagery should be sharp.
- Colour, contrast and light balance should be uniform across the whole AOI. This is particularly true for stereo photography.
- The time lapse between stereo pairs should not be too great to affect the quality of the stereo models.
- The imagery should only be accepted if it is substantially free of cloud, dust, atmospheric haze dense shadow or smoke. Isolated areas of cloud, dense shadow or smoke should not be cause for rejection of the imagery provided the intended use is not impaired. Typical tolerances for cloud and cloud shadows may be less than 5% or 10% in a single image.
- The photography should conform to any specific radiometric values specified by the client, including:
  - mean histogram luminosity values
  - mean of the individual colour bands and
  - standard deviation for each colour band.

The photography may be captured at any time when the weather conditions are suitable to achieve the specified standards of image quality, except where special time constraints are defined.

Earth observation satellites operate on specific orbits and cross the equator at the same time every day. It is therefore not possible to capture data over a target at a specific time of day. The intended use of the imagery may impose limitations upon times of capture. For earth observation imagery, it is common to specify winter or seasonal imagery capture, acquiring photographs when trees are not in leaf, or during a part of the growing season.

7.3 Earth observation accuracy and resolution table

Table 8 shows the achievable accuracy and resolution values for visible satellite imagery.

Platform	**Height AGL**		**Achievable accuracy (m) (RMSE figures, at 1 sigma)**		**Achievable resolution – GSD (m)**
	m	**Ft**	**Plan X,Y**	**Height Z**	
Satellite imagery	450– 770 km	279– 478 mi	3–4m (CE90)	3–4m (LE90)	0.35– 0.8

Table 8: Achievable accuracy and resolution values for satellite imagery

Achievable accuracies are quoted as circular and linear errors, at the 90% confidence level.

Table 9 shows the achievable resolution values for satellite imagery outside of the visible spectrum.

Platform	**Height AGL**		**Achievable resolution – GSD (m)**	
	m	**Ft**	**Multispectral**	**Hyperspectral**
Satellite hyperspectral and multispectral imagery	450 –770 km	279–478 mi	1–6	1.25–3.7

Table 9: Achievable resolution values for hyperspectral and multispectral satellite imagery

7.4 Satellite imagery products

7.4.1 Stereo imagery

Imagery from satellite platforms can be formed into stereo models. These are created from pairs of images captured from the same orbit at different times and the associated camera model and geo-referencing information. Using this imagery requires specialist software with advanced image processing and photogrammetric tools.

Stereo imagery finds applications in the creation of DTMs, DSMs, mapping and 3D visualisation.

7.4.2 Orthophotos

Imagery providers frequently offer processed imagery in the form of orthophotos, where the rectification to create the true-to-scale 2D imagery has already been completed.

They can be created in any common imagery format, in any specified coordinate system. The measurement of a distance on the image such as a road width will be replicated in the terrain, making them an indispensable tool for a wide range of applications.

7.4.3 Multispectral and hyperspectral imagery

Multispectral and hyperspectral imagery from satellite platforms offer the same set of products as from an aerial platform, (see sections 6.4.2 and 6.4.3) with the obvious advantage of potentially a much larger area of coverage captured in a shorter time span.

As well as the traditional three- and four-band orthorectified products, modern satellite multispectral sensors tend to offer a wider range of spectral bands than their aerial counterparts, which can be automatically classified in the same way using a spectral signature.

It is particularly important to verify the accuracy of the spectral analysis with ground truth observations.

7.4.4 Radar

Radar imaging has the advantage of the ability to operate at night, through thin cloud and thick vegetation layers.

Radar imaging has found applications in digital elevation model (DEM) generation, structural monitoring of dams, buildings and bridges as well as in land management, monitoring subsidence and detecting changes such as deforestation.

Interferometric synthetic aperture radar is a technique that uses pairs of radar images to generate maps of surface deformations. These are generated by the analysis of the differences of the waves returning to the satellite or aircraft-based instrument.

8 Future developments

8.1 Sensor miniaturisation

UAVs have gained acceptance in the aerial survey industry due to the improvement in their ability to carry more complex survey grade sensors. The trend of miniaturisation of navigation and LiDAR sensors for UAV deployment is set to continue.

8.2 Sensor fusion

Along with the trend of sensor miniaturisation has come the reality of sensor fusion, where aerial survey instruments incorporate more than one data type. A common option is the combination of nadir and oblique cameras with a high-powered LiDAR sensor in the same instrument. The flying advantages are clear: three data types are captured on a single mission, each co-registered with the others using the same navigation dataset.[8]

This multi-sensor approach also offers advantages during the data processing stage, with the combination of dense point cloud DSM generation fused with LiDAR data offering better quality height and 3D modelling products.

8.3 Beyond visual line of sight operation

The development of safety cases to enable beyond visual line of sight operation (BVLOS) is another key area of development. True BVLOS flights should occur once UAVs are able to communicate autonomously with other airspace users and automatically sense and avoid other flying objects. The benefits of BVLOS will be fully realised once the flight times of UAVs are increased through improved battery technologies. This capability is expected to benefit fixed wing UAVs more than multi-rotor UAVs as they have a much longer flight time.[9]

8.4 High-altitude pseudo satellites

The development of high-altitude pseudo satellites (HAPS) offer a different earth observation platform, at altitudes of between 20 and 50km AGL. These unmanned lightweight platforms use the latest in sensor miniaturisation and are powered by solar power. They have a flight endurance of three months.[10]

8.5 Developments in satellite technology

Owning and operating an earth observation satellite constellation is no longer the preserve of nation states. Modern satellite technologies are much smaller, enabling increased capture options at additional times and places and the ability to undertake repeated observation and monitoring daily.

An increased number of earth observation satellites in orbit, together with improving sensor capabilities, will increase the number of use cases from space in the future.

References

1 Drones - regulatory framework timeline, European Union Aviation Safety Agency [accessed 26 January 2021]

2 CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance, version 8, CAA, 2020 [accessed 26 January 2021]

3 Mian, O. et al, *Using the trimble post processed centrepoint RTX Fast positioning service for highly accurate UAV based mapping and surveying without GNSS reference stations*, Applanix Corporation, October 2016

4 Client guide to small unmanned aircraft surveys, The Survey Association, Issue 4, 2016 [accessed 26 January 2021]

5 King, V., What do Geiger mode and single photon mode mean for linear LiDAR?, Point of Beginning, 2016 [accessed 26 January 2021]

6 ASPRS Positional Accuracy Standards for Digital Geospatial Data, edition 1, version 1.0., 2014 [accessed 26 January 2021]

7 LAS specification 1.4 - R14, ASPRS, 2019 [accessed 26 January 2021]

8 Future technologies review, Geospatial Commission, 2019 [accessed 26 January 2021]

9 Beyond Visual Line of Sight in Non-Segregated Airspace, version 2, CAA Innovation Hub, 2020 [accessed 26 January 2021]

10 'Zephyr', Airbus [accessed 26 January 2021]

Further reading

Association of Remotely Piloted Aircraft Systems UK (ARPAS-UK) [accessed 26 January 2021]

Client guide to achievable accuracies from aerial photogrammetric systems, The Survey Association, Issue 5, 2019 [accessed 26 January 2021]

Client guide to aerial LiDAR surveys, The Survey Association, Issue 4, 2015 [accessed 26 January 2021]

Data as Infrastructure, supplement to October 2017 edition of *Prospect* magazine [accessed 26 January 2021]

Data for the public good, National Infrastructure Commission, 2018 [accessed 26 January 2021]

GeoBuiz 2019 Report: Geospatial Industry Outlook and Readiness Index, Geospatial Media and Communications, 2019 [accessed 26 January 2021]

Geospatial Commission, Cabinet Office [accessed 26 January 2021]

Grayson, B. et al, GPS precise point positioning for UAV photogrammetry, *The Photogrammetric Record*, volume 33, issue 164, pgs. 427–447, 2018 [accessed 26 January 2021]

May, N. et al, Point Positioning Accuracy of Airborne LiDAR systems: A Rigorous Analysis, *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, volume 36, October 2014 [accessed 26 January 2021]

OGC 12-000, OGC® SensorML: Model and XML Encoding Standard [accessed 19 January 2021]

OGC 17-011r2, JSON Encoding Rules SWE Common/SensorML [accessed 19 January 2021]

Ullrich, A. et al, *Linear LiDAR versus Geiger-mode LiDAR: Impact on data properties and data quality*, SPIE proceedings, volume 9832, 2016

Unmanned Aircraft System Operations in UK Airspace - Guidance, 8th edition, CAA, 2020 [accessed 19 January 2021]

Appendix A: Sample specifications

The following four tables are basic examples of sample specifications for aerial photography, LiDAR, thermal imagery and RGB earth observation imagery. In each case, the use case for the data is stated.

Item	Aerial photography
Use case	National mapping
Accuracy	0.4m RMSE
Resolution (GSD)	0.15m
Coverage	As per supplied digital file
Project constraints	Capture imagery at low tide
Metric camera (Y/N)	Metric camera – Y
Stereo imagery overlaps	60%
Flight line overlaps	30%
Data quality AQLs	The imagery must be sharp. Flare from large expanses of glass, water or cars must be at a minimum. Colour and light should be uniform. Contrast across the block must be consistent. There should be a good match between individual flight runs and adjacent images. The photography should only be flown in conditions where the visibility does not significantly impair the image quality and detail.
Solar angle	Above 15°
Deliverables	Orthophotos at 0.15m GSD

Table A1: Sample specification for aerial photography

Item	LiDAR
Use case	Railway engineering
Accuracy	0.04m RMSE
Coverage	As per supplied file
Project constraints	Urban area air traffic control
FOV	50°
Data quality AQLs	The LiDAR should only be flown in good conditions, in the absence of rain, cloud, atmospheric haze, snow and flooding.
Solar angle	No restriction
Point density	$48ppm^2$
Deliverables	Point cloud, DTM and DSM

Table A2: Sample specification for LiDAR

Item	Thermal imagery
Use case	Energy efficiency study
Accuracy	1m RMSE
Resolution (GSD)	0.5m
Coverage	As per supplied file
Start and end date	Winter period
Project constraints	Urban areas air traffic control
Equipment calibration records	Request instrument calibration records
Data quality AQLs	Has to be flown at 4°C, with minimum wind of 3 m/s or slower. There should have been no rain in the previous 24 hours. The flight should take place between 19:00 and 23:00.
Solar angle	No restriction
Spectral band identification	Thermal band (3.6–4.9µm)
Products/deliverables	Orthorectified thermal imagery (0.5m GSD)

Table A3: Sample specification for thermal imagery

Item	Earth observation
Use case	Land cover classification
Accuracy	<4m CE
Resolution (GSD)	0.55m
Coverage	As per supplied file
Start and end date	Summer capture
Project constraints	Capture within peak growing season
Stereo imagery overlaps	60%
Flight line overlaps	20%
Data quality AQLs	Maximum 5% cloud. Imagery to be free from dust and artefacts.
Spectral band identification	RGB imagery
Tasked imagery	Yes
Nadir angle	Better than 20°
Products/deliverables	RGB orthophotos at 0.55m GSD

Table A4: Sample specification for earth observation

Appendix B: Combined platform, altitude, data type and achievable accuracy table

The table below is an attempt to combine the detail from sections 4.3, 5.3, 6.3 and 7.3 into a single table.

Band	Platform	Height		Achievable accuracy (m) (1)		Example survey types/uses (2)
		m	Ft	Plan X,Y	Height Z	
1	UAV	30	100	0.02	0.01	• imagery and LiDAR for heritage recording and construction monitoring • multispectral imagery for precision agriculture.
2	Helicopter	319	1,047	0.05	0.03	High accuracy imagery and LiDAR for engineering design: • road • rail and • power networks.
3	Helicopter	638	2,093	0.10	0.05	Imagery and LiDAR • engineering asset management • mapping telecommunications networks.
4	Fixed wing	1,300	4,265	0.10	0.05	• BIM for infrastructure • imagery for cadastral mapping • LiDAR for forestry • multispectral for biomass mapping and monitoring the health of plants and crops • hyperspectral for tree species mapping and tracking soil moisture content.
5	Fixed wing	2,600	8,530	0.20	0.10	• imagery for urban mapping and 3D city models • imagery and LiDAR for coastal management • thermal mapping for energy efficiency surveys and detection of pollution.

6	Fixed wing	4,500	14,764	0.38	0.19	• imagery for rural mapping • imagery and LiDAR for river catchment flood risk management.
7	Fixed wing	7,500	24,606	0.63	0.31	• imagery for upland area mapping • environmental impact assessments.
8	Satellite	450–770 km	279–478 mi	3–4m (CE90)	3–4m (LE90)	• satellite imagery for land cover classification • multispectral satellite imagery for environmental monitoring and vegetation index mapping.

Table B1: Combined platform, altitude, data type and achievable accuracy table

1 Achievable accuracies are quoted in RMSE figures apart from satellite imagery, which are quoted as circular and linear errors, at a 90% confidence level.

2 The quoted achievable accuracies are not valid for the example survey types and uses utilising non-visible forms of remote sensing except for multispectral satellite imagery. Further details can be found in section 6.3.

Appendix C: Glossary

Accuracy	The degree to which a set of independent measurements are free from defects, consistent with a standard rule.
Aerial triangulation	The process by which stereo photography is tied together to form stereo models and geo-referenced to ground control points.
Active sensor	An instrument that both emits and receives reflected energy from the terrain and the responses recorded at the on-board instrument. LiDAR is an active sensor.
Aerial photography	Photographs taken from an aerial vantage point.
Ambiguity	The unknown integer number of carrier phase cycles in an unbroken set of global navigation satellite system (GNSS) measurements.
Angular misalignment	The misalignment between the survey instrument reference frame and the aircraft reference frame.
Base line	The 3D vector distance between the GNSS receiver on a moving aerial platform and a ground GNSS base station.
Civil Aviation Authority (CAA)	The government organisation responsible for all aspects of aviation in the UK.
Calibration	The procedure by which aerial survey instruments are checked and adjusted to ensure consistency of the resulting measurements.
Charged-coupled device (CCD)	An electronic chip employed in digital cameras to measure light intensity.
Circular error (CE)	A term commonly used to represent the horizontal accuracy of earth observation imagery. A value of CE (90) 5m represents a circular error where a minimum of 90% of the points measured have a horizontal error of less than 5m.
Coordinate reference system	A mathematical definition of a coordinate system, including the origin, scale, position and orientation of the reference ellipsoid.
Cross strip	A strip of aerial photography or LiDAR data flown at 90° to the main block to tie blocks of flight lines together improving block geometry.
Cycle slip	The loss of lock of the satellite signal by a GNSS receiver.
Dense image matching	A photogrammetric technique that enables the extraction of 3D surfaces from images acquired from multiple views.
European Union Aviation Safety Agency (EASA)	The European authority in aviation safety.
Elevation	The height above a defined level datum, e.g. mean sea level.
Elevation mask	The lowest elevation in degrees above the horizon at which a GNSS receiver is set to track a satellite.
Ellipsoid	In geodesy, a mathematical figure formed by revolving an ellipse about its minor axis to describe the shape of the earth. Used interchangeably with spheroid.
Ellipsoidal height	The height between a point on the ellipsoid and the topographic surface.
Ephemeris	A set of data that describes the position of a celestial object as a function of time.
Epoch	A point in time that is the reference for a set of coordinates.
Focal length	The distance between the centre of a lens and its focal point.

Forward motion compensation (FMC)	A technique used to compensate for the forward motion of an aircraft during the capture of an aerial image.
Geo-referencing	Referencing an image, point cloud, vector data or other entity by its geographical coordinates.
Geodetic datum	A precise mathematical model designed to best fit part or all of the geoid.
Geoid	The equipotential surface that most closely approximates to mean sea level. This surface is everywhere perpendicular to the force of gravity.
Geoidal separation	Difference in height between the ellipsoid and the geoid or mean sea level.
Global navigation satellite system (GNSS)	Encompasses all satellite systems that are used for navigation purposes including GPS, GLONASS, Galileo and BeiDou.
Ground resolved distance (GRD)	The minimum detectable distance between two small features on the ground.
Ground sampled distance (GSD)	The distance between the centres of two consecutive pixels on the ground. GSD is a common way to define the resolution of earth observation and aerial imagery.
Gyro-stabilised mount	An aerial camera mount that is held constantly in a horizontal position during flight using a gyroscope and an inertial measurement unit (IMU).
Hyperspectral imagery	An imaging technique operating across the visible and non-visible parts of the spectrum, typically generating 500 separate spectral bands for in-depth analysis
Inertial measurement unit (IMU)	An electronic device capable of measuring the gravitational and acceleration forces on a moving vehicle and reporting its velocity and position.
Kinematic survey	A dynamic method of GNSS positioning using carrier phase observations in which one receiver is moving (typically on an aerial platform) and one or more base station receivers are stationary.
LAS file format	A common LASer point cloud file format specified by the American Society for Photogrammetry and Remote Sensing (ASPRS). LAZ is the compressed version of the same format.
Linear error	A term commonly used to represent the vertical accuracy of earth observation imagery. A value of LE (90) 5m represents a circular error where a minimum of 90% of the points measured have a vertical error of less than 5m.
Metadata	A set of data that describes and stores information about other data.
Metric camera	A camera for which the focal length and radial and tangential distortions are known and calibrated regularly.
Mosaic	An assembly of digital images that have been carefully cut and joined to produce a composite image of an area of terrain larger than could be covered in a single aerial photograph at the same scale.
Multispectral imagery	Imagery captured using sensors operating outside the visible part of the electromagnetic spectrum.
Nadir	The point on the earth directly below the observer
Oblique photography	Aerial photography taken from an off-nadir position
Orthometric height	Height between a point on the geoid and the topographic surface, also known as mean sea level.

Orthophotography	The use of digital rectification and digital elevation models to produce an image that has a consistent scale.
Passive sensor	An instrument that receives and records reflected energy from the sun. A hyperspectral instrument is a passive sensor.
Panchromatic imagery	Images created using an imaging sensor that is sensitive to all radiation in the visible region of the spectrum.
Permission for commercial operations (PfCO)	The legal document needed to operate a drone commercially in UK airspace.
Position dilution of precision (PDOP)	A unitless scalar value expressing the relationship between the error in user position and the error in satellite position.
Photogrammetry	The science of making accurate measurements from digital imagery normally for the measurement of an object, mapping, or geographic information system (GIS) data collection.
Photogrammetric six degrees of freedom	The six values required to position a single aerial image in space – easting, northing and height, (real world coordinates) and omega, phi and kappa (rotations around the X, Y and Z axes).
Precision	The degree to which a set of independent measurements are exact and accurate.
Precise dilution of precision (PDOP)	A computed unitless scalar value which describes the geometric contribution to the uncertainty of a GNSS position solution.
Principal point	The position on the focal plane of a theoretically perfect camera where a perpendicular line passed through the perspective centre.
Point cloud	A 3D visualisation constructed from millions of geo-referenced points.
Point density	A measure of LiDAR resolution, usually expressed in points per square metre (ppm^2).
Points of detail	Points that can be identified in both the terrain and in aerial imagery for the purpose of geo-referencing the imagery or for the determination of geometric accuracy.
Polar orbit	A satellite orbit that passes within 20^o of both poles.
Pre-marked points	Points of detail that are established before the imagery is captured.
Push broom scanner	A scanning action that uses a fixed linear array of detectors located at the focal plane to build up an image line by line along the direction of flight of the aerial platform. These passive sensors acquire multiple strips of images simultaneously (forward, nadir and backward) as opposed to a series of separate exposures. Stereo imagery is collected in-track (or from the same orbit) and is derived from viewing the forward, nadir, and backward imagery in combination. A push broom scanner is also known as an along track scanner.
Radiometric	The measurement of radiant energy across the whole electromagnetic spectrum.
Relief displacement	The shift in an object's image position caused by its elevation above a particular datum. For vertical or near vertical photography, the shift occurs radially from the nadir point.
Resolution	A measure of the level of detail that can be detected.
Receiver Independent EXchange format (RINEX)	A common GNSS data file format.
Root mean square error (RMSE)	The standard deviation of the predicted errors.

Spectral signature	The variation in the electromagnetic reflectance from a homogeneous target.
Stereoscopic photography	Pairs of photographs that can give a visual impression of depth, or a 3D representation.
Sun-synchronous orbit	A satellite orbit in which the satellite passes overhead at the same local time every day, tracking the sun.
Short wave infrared (SWIR)	Part of the electromagnetic spectrum.
Tasked imagery	Earth observation imagery that is specifically targeted for the client by the satellite imagery providers to meet the client's specific requirements. The alternative is to purchase existing imagery inventory of the same area that has been routinely captured.
Tidal window	A period when the coastal tides are at their lowest, usually twice a day
Thermal imagery	Imagery created from detecting and recording the infrared part of the electromagnetic spectrum.
Unmanned aerial system (UAS)	This includes the ground control segment, the unmanned aerial vehicle (UAV) and all equipment, network, and personnel necessary to control the UAV.
Unmanned aerial vehicle (UAV)	Also known as a drone.
Virtual reference station (VRS)	A specialised processing technique that generates a virtual base station for a GNSS survey from a network of other fixed real base stations.
Whisk broom scanner	A scanning action that uses a rotating mirror to scan across the satellites track or orbit reflecting the energy emitted from the earth's surface onto a single detector. The imagery is built up one pixel at a time. Whisk broom scanners are also known as cross track scanners.
Witness diagram	A diagram used to locate a point in the terrain such as a ground control point.
World Geodetic System (1984) (WGS 84)	World Geodetic System (1984). The geocentric datum used by GNSS since January 19847. It has its own reference ellipsoid.

Acronyms

AGL	Above ground level
AOI	Area of interest
AQL	Acceptable quality limit
ASPRS	American Society for Photogrammetry and Remote Sensing
ATC	Air traffic control
BVLOS	Beyond visual line of sight
CIR	Colour infrared photography, includes the near infra-red band
DSM	Digital surface model
DTM	Digital terrain model
ETRS89	European terrestrial reference system 1989.
FOV	LiDAR field of view, usually expressed as an angle
GCA	Ground control areas
GCP	Ground control points
HAPS	High altitude pseudo satellite

InSAR	Interferometric synthetic aperture radar
ISO	International Organization for Standardization
NIR	Near infrared (part of the electromagnetic spectrum)
PRF	Pulse repetition frequency (also known as pulse repetition rate, PRR)
RADAR	Radio detection and ranging
RGB	Red, green, blue or visible imagery
SfM	Structure from motion
SLAM	Simultaneous localisation and mapping
UTC	Coordinated universal time
VNIR	Visible near infrared (part of the electromagnetic spectrum)
VTOL	Vertical take-off and Landing