3. Compiling a flight plan

3.1. Data collection

Data collection is a target-oriented activity, and after data analysis research question(s) will be answered. As a rule, data collection is inhibited by several factors, such as technology related possibilities (platforms, sensors), legislative restrictions (E.g. flight permits and no-fly zones), as well as environmental conditions (E.g. wind, light, precipitation, temperature, etc.), but also the budget and skills and abilities of the participants.

Relying on the previous, data collection needs some thorough planning and finding compromises between the needs and possibilities. Collecting the data with an UAV is generally just a part of larger (field) work that usually also includes other activities and logistics. For example, control data on the ground needs to be collected or drone battery charge organized; sometimes communication with a landowner is necessary to get the permission for accessing the survey area, etc. Thus, for us to benefit from the flight and answer the research question(s), there is a number of activities to do before and after the actual UAV flight. Tmušić *et al.* (2020) describes such workflow in form of a block diagram (see Image 19).

Image 1. An entire work flow of an UAV based mapping process, (QA – *quality assurance* (Tmušić *et al*., 2020)).

When planning fieldwork, it is reasonable to use the relative flexibility of UAV work as well as short preparation time, and choose the best moment for problem solving. Generally, the best time for 3D mapping is when the sky is under even cloud cover, because this ensures the lack of disturbing shadows or reflections. Best timing also means that seasons and phenology should be kept in mind (E.g. orchids are best identified during blooming period), or the approach should be event based (E.g.

after the first light snowfall it is possible to map relatively warmer areas also with a regular camera). Waiting for an event or special weather conditions requires that all the preparatory work has been done in beforehand, the equipment is checked and packed. Such planning is a precondition to collecting excellent data, but, on the other hand, it requires a thorough knowledge of your research object and readiness to act quickly when the opportunity comes. Sometimes, however, this means unpacking the gear without any results as well.

Compilation of **flight plan** is directly connected to drone mapping, since it enables to cover the area with data systematically and, if necessary, repeat flights using the same methodology. Flight planning presupposes compromising in, for example, the size of the survey area and spatial resolution – if we wish to have a better terrestrial spatial resolution, we cannot probably cover very large areas because we need to fly slower and on lower altitudes.

Thus, the flight plan tends to be quite specifically fashioned and compatible with a specific UAV, sensor used, specific environmental conditions and final research goal. If one of the components changes, then, as a rule, the rest of the flight plan needs to be modified as well (see chapter 4.7). The following chapter tries to disregard different constraints and restrictions and give a broader overview of the data collection process (Image 20).

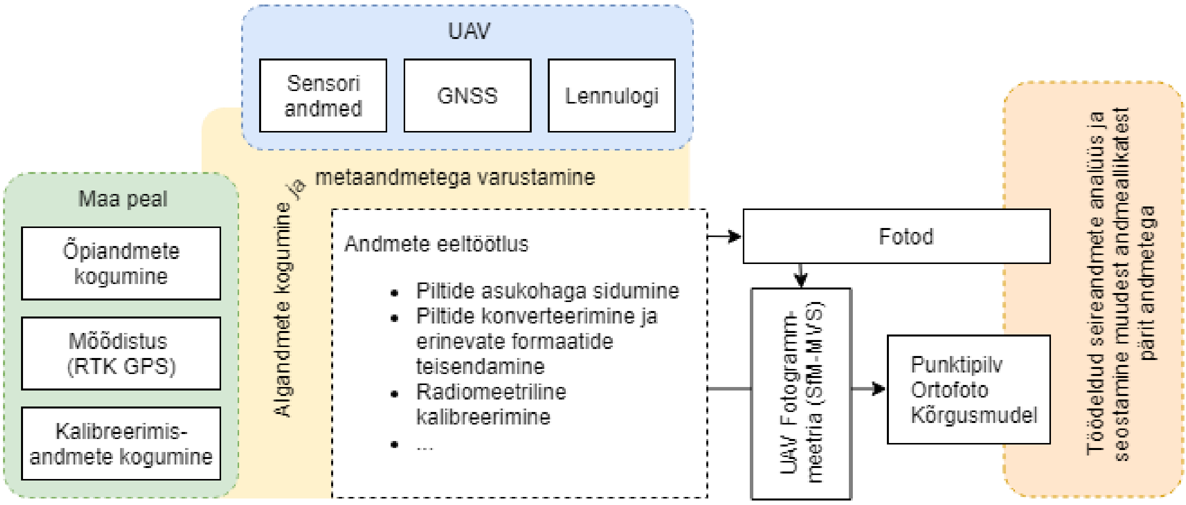

Image 2. Principle schema of a flight schedule.

When collecting data there are aspects to keep in mind that can otherwise later affect the data use:

1. Hardware used, its output and different formats;
2. Programmes used for data processing and their input;
3. Supportive monitoring on the ground and combining it with the UAV survey data: spatial binding (georeferencing), collecting learning/training data, if needed, a database allowing radiometric calibration.

In case of the two first points everything depends on the compatibility of one's output with other's input. For instance, whether the output format of the sensor/camera image is usable with the programme processing it, or it needs converting into another format; whether the camera records the complete data or we need to transfer data from a different place and align it during the post-processing phase. The third point primarily incorporates tying the data spatially i.e. georeferencing.

The following is an attempt to find answers to two questions:

- What is the best resolution (temporal, spatial, spectral) for data collection?
- How to collect data in a way that it is usable for later processing?

3.2. Data resolution

In case of drone surveillance as well as other surveillance methods, different aspects of resolution have to be carefully considered:

1. Temporal – characterises the frequency of the object surveillance;
2. Spatial – characterises the degree of detail we are able to distinguish from an object;
3. Spectral – characterises the number of spectral bands we are able to distinguish from the light reflecting from the object;
4. Radiometrical – how precisely can we distinguish and measure the intensity of radiation reaching the sensor.

The two first aspects are more or less under the control of the user, but, as said before, often compromises have to be made. The two last resolution aspects are rather determined by the parameters of the sensor and thus quite directly dependent on the budget – sensors with greater spectral and radiometric resolution are more expensive.

Temporal resolution

Drone survey flights take up certain time. If we, for example, want to cover an area with images and later use the data to create a 3D model, then in the course of flight planning we learn that in order for us to get images with necessary spatial resolution with the available drone, we will need at least 40 minutes of flight time. In addition to that, there is the exchange of batteries and data carriers, drone reset, if necessary, recalibrations, etc. Thus, the minimum surveillance interval/step with a small reserve would be 50 minutes.

Whether this step is sufficient is dependent on the research goal. It might be more than enough to map vegetation, but in case of some urgent process (E.g. monitoring a landslide or fire) it might be too long. Temporal resolution can be sped up by using several drones and sensor sets simultaneously, but this considerably rises the costs.

Temporal resolution requires considering the following:

- By increasing temporal resolution we increase the volume of data and time spent on archiving and post-processing. To economize, it is wise to choose the longest time interval/step that can still be used to answer the research question; at the same time we need to take into consideration that some fieldwork might be unsuccessful. Often the problem lies in the weather, the negative impact of which can be reduced by using a more robust drone/sensor. In comparison with photo camera, laser scanners are more reliable for 3D modelling, but also more expensive, since they are not dependent on light conditions.
- If we need to record several moments in time during a year (E.g. map the changes in the vegetation biomass), then when conducting the survey on different days, we need to think whether the changing environmental conditions during the day might influence the results of the survey. In the case above, it is recommended to conduct all surveillance flights at noon when the sun is at its highest in the sky. It is advisable to follow the phenological calendar for surveillance projects taking longer than a year.

Spatial resolution is responsible for how small the objects are that we are able to identify from the data. Spatial resolution, in turn, is dependent on the resolution of the camera/sensor, flight altitude and focal length of the lens. In order to find the combination most suitable for the task, these factors need to be juggled with when planning the flight. A rule in photo mapping is that the research object we want to distinguish later from an orthophoto must consist from at least ten pixels. For instance, if we wish to map blooms with 10 cm diameter (area ca 80 cm^2), spatial resolution needs to be between 2–3 cm per pixel. One object, thus, would consist of 9–20 pixels. Nowadays, after the camera is configured, flight planning software (see chapter 4.7) would automatically calculate ground resolution (GSD) for the set altitude.

Spectral resolution shows the number of different spectral bands or channels recording the light emanating from the object. Ideally, a sensor is picked that covers the spectral bands in which our object is as distinguishable as possible from the background, i.e. where its spectral signature is unique. For example, it is difficult to distinguish a birch from pines during mid-summer, however, in early spring or autumn when the leaves are light green or yellow, the identification is easier. In defining necessary spectral channels, we can search for help in academic literature, since a part of such time-consuming work might have been done already by somebody else. One possibility is to do some initial mapping with a hyperspectral camera that gives the richest spectral information, helping us to find spectral channels that would provide the most extensive data. Having such information enables us to choose an optimal modular multispectral camera for the task, economizing thus the volume of data and time spent for post-processing.

Radiometric resolution depends on the sensitivity of the sensor and format of data output. The sensitivity of the sensor can be slightly increased by using an electronic amplifier (E.g. in ISO RGB cameras and *gain* thermal cameras), however, it inevitably also increases the noise. Radiometric resolution is considerably affected by the choice of image format: radiometric resolution or colour depth of images in jpg-format is usually 8 bitts, meaning that, for example, the intensity of red colour can be decreased by a scale of 256-steps. If the colour depth of the raw format of the same image is, for example, 14 bitts, the intensity of red colour will be presented in a more accurate 16384-step scale. The price to be paid for such accuracy is the size of the file – raw files are multiple times larger. This results also in slower framing rate and fills data storages very quickly. If light conditions are good during shooting, and the texture of objects allows, it is reasonable to use the least compressed jpg file formats. It is only with difficult light conditions and/or extremely even objects that raw format is the most suitable one, for the quality of images then needs to be increased by post-processing, and further in photogrammetry already with the unpacked tif-images.

3.3. Metadata

In addition to the data concerning the research object, we need to collect data about data i.e. **metadata**. This is especially important in situations where surveillance data is not used immediately after the flight, or somebody else uses the data. Such extra information is sometimes of critical importance since it enables/does not enable to reuse the data (E.g. use newer methodologies to analyse the data). Metadata are all the supporting data that help us to understand and use information crucial to the survey (E.g. which spectral channel is the image from, when was it taken, who was the pilot, on what altitude and weather conditions the flight occurred, where on the ground were the control surveillance areas located, what and who was doing something there, etc.).

How, in which format and how much metadata to collect depends again on the goal. It can be predicted that the ability of data analysis will grow in the future, and therefore we must not underestimate the potential of collecting and analysing metadata. Collecting metadata is, as a rule, tedious and time consuming and such work is often avoided. What makes it easier is the fact that a large part of the work is done by our equipment (E.g. images come with time stamps, names in temporal sequences, the drone records flight logs, etc.). However, if we do not download, collect and systematize these logs it will quickly become difficult or even impossible to find and use them later.

It makes sense to deal with metadata collection and fieldwork simultaneously, that is, at the same time the data pool is created. It is necessary to download land archive the logs systematically right after the flight.

For the collection of metadata on the UAS- survey workflow, see the table by Tmušić *et al*. (2020).

Study design	Platform characteristics	Platform type
		Weight & payload capacity
		Maximum speed
		Flight height & coverage
		On-board GNSS receiver
	Sensor characteristics	Sensor type & name
		Sensor weight
	Camera settings	Pixel size
		Sensor size
		Focal length
		ISO
		Aperture
		Shutter speed
	Flight plan	GSD (cm)
		Flight hight
		Flight speed
		Forward & side image overlap
	UAS control software	Software name

	Georeferencing	Type of georeferencing
		Number of GCPs
		Arrangement of GCPs
Flight mission	Weather	Wind power&direction
		Illumination conditions
		Humidity
	Mission	Average Flying speed
		Flying time
		Flight pattern
		Camera angle
		Image format
Processing of aerial data	Geometric processing	SfM-tool name
		Final product type
		Bundle adjustment
	Radiometric processing	Signal to noise adjustment
		Radiometric resolution
		Viewing geometry
		Band configuration
		Reflectance calculation method
		Vignetting
		Motion blur
Accuracy assessment		Error measure
		Statistical value
		Error management

3.4. Compiling a flight plan

In order to fly a UAV successfully and get the necessary data with it, we need to plan the entire process stage by stage:

- **Preparing terms of reference:** this stage encompasses determining the general goal and specific sub-goals of the field work. UAV surveillance is a part of it that has to comply with other surveillance methods. A clear understanding of how we wish to process the collected data in a later phase will help to determine the methodological details of UAV surveillance. For instance, in case of photogrammetry, we need a large overlap of photos: side overlap determines the distance between flight trajectories and forward overlap determines the frequency of photographing.

- **Planning the itinerary**: when the terms of reference have been decided, as a next step we need to plan the itinerary for the UAV and identify potential dangers or restricted areas. It is especially important in case of drone plains, that, in comparison to multirotors, need much more space to manoeuvre. The itinerary is planned using waypoints that are usually connected by linear flight segments.

- **Planning of activity points:** the UAV fulfils a specific task in activity points (takes photos, focusses the camera to a concrete object, etc.). Activity points may coincide with waypoints, but may also stand alone.

- **Flight simulation**: some flight planning software (E.g. Mission Planner) allow testing the flight plan prior to the actual flight.

Compiling a flight plan should start by defining the problem that interests us and choosing the best available sensor and usage time for mapping/finding the problem. Such preparations are usually done on the basis of relevant literature, supported by consultations with an expert who knows the object well. We also need to determine the shortest possible ground sampling distance (GSD) that still allows the identification of the object. The necessary GSD determines the combination of camera and flight altitude for the flight to be performed. In case of laser scanners, we need to know the minimal point density, and in addition to decreasing flight altitude or angle, we can increase point density by flying the trajectories multiple times.

For example, an efficient use of SfM photogrammetry is preconditioned by a large overlap of photos, usually at least 70% in both side- and forward images. In case of complicated objects (semi-transparent vegetation) or cameras with lower resolution (E.g. thermal cameras) the overlap has to be up to 90%.

When flying quickly and low a problem can occur with the recording speed of the photos. To solve this the frame rate of the specific camera during which data are recorded on a memory card or any other device needs to be determined prior to the flight via camera specifications or, even better, via a test flight. Checking the recording speed becomes especially important when we wish to record large amounts of raw photos (.raw).

A rule exists for the configuration of shutter speed: the UAV must not move during the shutter speed more than half of the ground pixel size. Therefore, when flying with the speed 15 m/s with an aim to achieve pixel size 3 cm, shutter speed needs to be approx. 1/1000 seconds. For shutter speed to be that quick we need good illumination conditions, a lens with a large aperture, and/or in case of high ISO (electronic intensification of sensor signal) a camera with low noise ratio.

A software specially created for it helps to plan the flight. For example, downloadable freeware Mission Planner, that after defining the mapped area and camera, also helps to semi-automatically compile the best possible flight plan. Most of the larger UAV manufacturers have their own software for planning flights, and several flight planners integrated with SfM software (E.g. Pix4d) have been developed. Such software is generally free, or it comes along with a specific UAV.

Flight planning software generally also includes other functions: UAV configuration, pre-flight check-up, telemetric- and video connection during the flight, flight-log analysis, georeferencing photos, flight simulator, etc. (Image 23).

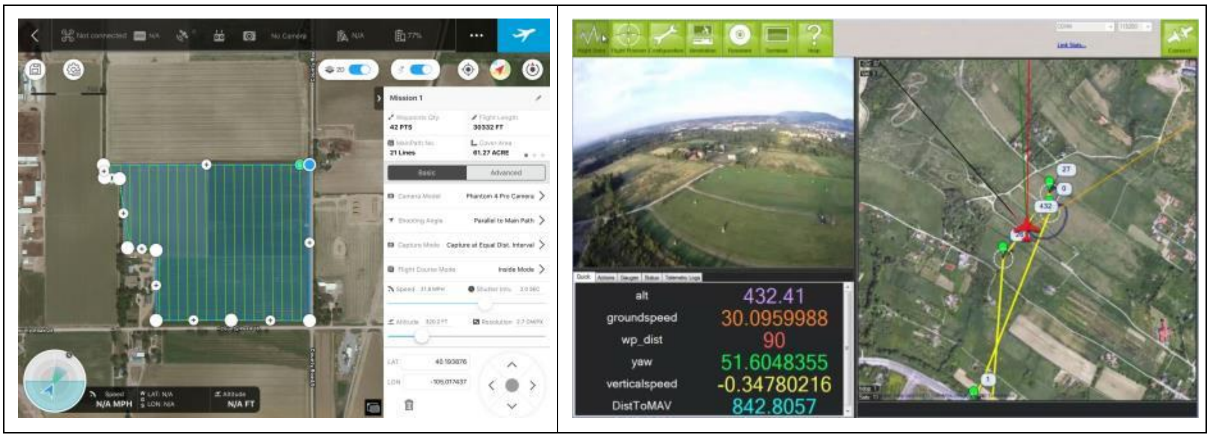

Image 3. DJI Groundstation PRO flight planning tool (*left*); Mission Planner's flight UAV telemetric- and video stream (*right*).

When flying in areas with changing relief, we have to consider the fact that the UAV as well as flight planning software calculate flight altitude by default by the place the UAV was switched on. Flying on a similar altitude to the starting point is a suitable option if the relief is more or less even. Commonly, the differences between the relative heights of the mapped area can be three to four times smaller than flight altitude. If differences between heights are greater, both ground resolution as well as overlap percentages of photos in different parts of the mapping area will start changing in a considerable manner, since both of these factors are directly connected to the distance between camera and the object (Nesbit *et al*., 2022).

In order to maintain a constant altitude in regards to the terrain, we generally have to switch on a corresponding function *terrain following* in the flight planning software. It is therefore important for the flight planner to know where to get a terrain model, how old and how precise it is and whether the situation has changed in the meantime. For example, in case a tall building has been erected recently that is not reflected in the older terrain model, and the UAV should, according to the flight plan, pass right through it. Sometimes it is necessary to create an altitude model that is up to date, and only then develop the final flight plan. Best results, especially in ortho photography, can be acquired when in addition to monitoring the terrain, we also turn the camera's optical axes perpendicular to the object surface (Trajkovski *et al*., 2020).

With even more complicated objects, it is possible to use the so-called reversed photogrammetry, in which case with the help of an existing terrain model an optimal 3D flight plan (E.g. Agisoft Metashape) is compiled from essential camera positions and -angles.

The flight plan is then uploaded to the drone control panel. The last phase will be execution of the flight plan, the UAV flying autonomously according to the plan. The pilot is able to monitor and control the drone, and in case of a sensor, also the work of the sensor during the flight in real time and, if necessary, also stop the flight.

As battery voltage starts dropping very fast when a certain threshold is reached, then when planning a flight, it is recommended to keep a reserve of *ca* 20% of the battery capacity. Sub-zero temperatures can drastically decrease the amount of energy emitted, and a reserve of 30–40% is advisable. With temperatures around zero and high humidity (E.g. fog), we need to take into consideration the possibility of propeller and/or wing icing. Icing will very quickly decrease their effectiveness and in the worst-case result in an UAV crash.

As to the weather, usually wind and rain/snow cause biggest problems for the flight. Even if some UAVs are rainproof, cameras and LIDARs are not operable during rain/snow falls. Wind resistance of a specific drone is usually indicated in its technical documentation. Assessing wind force is dependent on the height: 4 m/s on the ground may mean 8–10 m/s at the altitude of 100 metres. By default, weather forecast uses a measurement height of 10 m for wind. What is especially dangerous, are the gusts of wind (E.g. in case of thunderclouds). In addition, the so-called wind corridors with considerably stronger wind can form between tall objects (high-rise buildings), and adjacent to such objects also vertical airflows can occur.

Flying with windy weather, moving vegetation, especially trees, can be a problem for mapping flights. Unfortunately, a precondition of the efficient application of photogrammetry for the development of 3D models and ortho photos is the immobility of the object during the session. Certain movement in vegetation is inevitable, but in case the wind gets stronger, the results will worsen very quickly, especially if we are dealing with tall trees.

Another constant problem is the uneven and changing light caused by clouds that in its turn changes the photos. Homogeneous illumination conditions are especially important for the collection of spectral information, but also when creating 3D images, since uneven and sharp shadows decrease the accuracy of the model. In changing light conditions laser scanning has an advantage over photogrammetry, for scanning method is not affected by shadows (Wallace et al., 2016).

For photography-based mapping, windless (< 3 m/s) weather with overcast would suit the best. The second-best option would be windless weather with clear sky, and the flight should be planned to take place as close to noon as possible for the shadows to be shortest possible. In the case of longer flights, it is inevitable that sunny weather causes shadows that move noticeably and that are visible in photogrammetry output.

3.5. Flying

Preparations for a specific flight start at home or in an office. It would be irritating to drive back from the planned surveillance spot just for the reason that you forgot a small thing such as a cable. To avoid the situation described above, we provide an example of a well-organized fieldwork preparation for mapping vegetation with a multirotor.

Before you start out you need to:

- Apply and get **permissions** to use the airspace (NOTAM-notice check <24 h before the planned flight);
- Check the existence of the UAV operator's registration number;
- Pay attention to the **weather forecast**, especially wind direction and velocity (at flight height!), precipitation and the nature of cloud coverage. Weather forecasts can be considered precise *ca* 2–3 days prior to the planned flight. A reasonably precise forecast is offered by uavforecast.com., for example.
- Check the **disturbances in the earth's magnetic field**, since these can have a substantial effect on GNSS and compass accuracy. Disturbances are usually caused by solar activity. Disturbances in the magnetic field that are dangerous for UAVs are indicated by the Kp-index > 4 – 5. This index has to be checked on the same day of the flight, since disturbances in the magnetic field cannot be predicted (uavforecast.com shows the Kp-index). Sometimes, the GNSS system accuracy is disturbed consciously for military purposes;
- When planning the **logistics,** suitable access points (by car) need to be found (E.g. we need a permission to access areas under protection, or private land, etc.), and best possible control panel locations regarding communication range and visibility need to be established. It is advisable to consider involving other people – viewers who support the drone pilot, control the sensors, monitor safety and air space, etc. are always of help.
- Identify the relief and the location of potentially **dangerous objects** (E.g. television masts, power lines, chimneys, cranes, etc.). For the location of such background information, the geo-portal's aerial photos, relief models and maps of the Estonian Land Board are suitable. NB! Keep in mind that the mapping situation and the reality might not coincide.
- Compile a preliminary drone flight plan;

- Plan the locations of **reference points** and **-data** on the ground and arrange an optimal access to them;
- Check, whether you have the **sensors**, **memory cards**, **connection cables**, **spare parts**, etc. and whether they are compatible and working;
- **Check the batteries and charge them** (both UAV's and other appliances);
- If necessary, take along insect repellent, sun shade/screen, camping chair, and other gear contributing to a comfortable stay for the pilot.

For a successful fieldwork on the surveillance area, you need to:

- check the flight area visually and mark down reference points, especially in urban areas, where cranes, masts, and similar dangerous objects may emerge, objects that are not (yet) reflected in the Land Board's data;
- monitor the weather (thunder clouds, etc.);
- check the UAV, its control panel and the communication between them;
- check the UAV defence mechanism *fail-safe* configurations. One of the most critical ones is return-to-launch (RTL) altitude. What is more, it is necessary to think through and plan with a companion the pilot's conduct in case of malfunctions or disturbances. Plan safe landing spots for crash landing;
- check the prepared autonomous flight plan and adjust it to match the local conditions, if necessary;
- check the sensors and configure them to match the local conditions;
- instruct anyone nearby on safety measures;
- check the air space visually;
- check safety in the proximity of the UAV, switch on the flight mode (*arm*);
- wait for the IMU and gimbal calibration to be completed and GNSS location to be locked. At the moment of locking, home point gets fixated where the UAV would automatically fly to in case of malfunctions;
- before mapping, take photos of the calibration panels, if necessary;
- pilot the UAV a couple of metres above the ground;
- test the UAV manually piloting it to all the directions and turning it around its axes;
- pilot the UAV along the vertical axes into obstacle free flying area, i.e. to the altitude higher than any objects in the flight area;
- apply the prepared autonomous flight plan that is downloaded into UAV memory;

NB! If the movement of the UAV seems unusual, bring the drone back to the ground immediately. In case of more serious malfunctions we may need to crash the UAV, but try to do that in the area chosen previously where the danger to humans is minimal. If the UAV cannot resist the strong wind we need to reduce its height (may cause communication malfunction or loss!) and try to pilot the UAV back as close to the ground as possible, or at least land it at a recognizable and safe spot. There is no need to tread the latter, but the safe spots must be chosen prior to the flight, since in case of malfunctions we might not think as quickly and clearly as necessary. Before crash landing, it is helpful to take a photo straight down in order to identify the location visually, and this way we can also make use of the coordinates that come along with UAV images. Air traffic controller needs to be informed in case the communication fails in the work area of drone planes.

After UAV landing you need to:

- Check the engines, feeling them with your bare hand. Engines in good mechanical order should have approximately similar (warm) temperature. If the engine is very hot, a problem might lay in the coil, or the like. Such an engine needs to be exchanged or at least tested in controlled and safe conditions before the next flight.
- Check the quality of the collected data;

- Collect the reference point markers, calibration panels and other equipment;

After the flight you need to:

- Download the data and logs from the sensors and controllers, systematize and archive the data. If many flights are performed in short time period, it is wise to download the data from the UAVs data carrier and back it up immediately by an external hard drive, for example;
- Discharge the batteries to storage voltage if there is more than a week to the next mission.

Post-flight analysis

After the UAV has completed the mission, you need to analyse and evaluate the data acquired during the flight with an aim to assess the success of the fieldwork and note down details to improve next time.

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