

Exposing a Suboptimal Exposure Mode in Observer-Directed Aerial Photography

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In observer-directed archaeological aerial photography, the shutter-priority exposure mode may seem the obvious choice because it allows the photographer to guarantee a short exposure time. This paper argues that aperture-priority mode with Auto ISO and a maximum exposure-time limit offers a more controlled compromise: it keeps the aperture near the optical optimum, prevents the exposure time from becoming too long within the selected ISO range, and leaves ISO as the flexible exposure variable. Various scenario-based calculations show how the maximum acceptable exposure time varies with ground speed, flying height, focal length, photosite pitch, and the acceptable level of motion blur.

The exposure duo and the practical exposure triad

Among many parameters, photographic image formation is primarily governed by aperture, exposure time, and ISO. The close relationship among aperture, exposure time, and ISO is commonly described by the so-called ‘exposure triangle’, because all three influence how light or dark the final image appears. Strictly speaking, however, this terminology is incorrect: of this triad of variables, only aperture and exposure time determine exposure in the physical sense. Exposure refers to the amount of electromagnetic radiation received by the image sensor per unit area during image capture (in this text, exposure primarily concerns the visible part of the electromagnetic spectrum, commonly called light). Aperture controls the effective opening of the photographic objective and thus the irradiance reaching the image sensor, i.e. the electromagnetic radiant power arriving per unit area. Exposure time controls the duration over which that irradiance is collected. A larger aperture or longer exposure time increases exposure; a smaller aperture or shorter exposure time decreases it. ISO, by contrast, does not change the amount of electromagnetic radiation captured by the digital image sensor, but mainly controls how strongly the recorded signal is amplified; in analogue photography, changing ISO meant using a film with a different sensitivity. That is why ISO belongs to the practical control system of photography, even though it is not an exposure parameter in the strict radiometric sense. Aperture, exposure time, and ISO are nevertheless normally considered together because they jointly determine the appearance and usability of the final photograph. Changing one of them often requires compensation by one or both of the others.

Each of the three camera parameters also controls a specific trade-off in image quality. ISO mainly affects the visibility of image noise: higher ISO values (e.g. ISO 6400) usually make noise more visible, although modern image sensors and RAW-processing workflows can handle moderate to high ISO values

Glossary of Terminology

Circle of confusion. Even when perfectly focused, a lens images an object point as a small blur spot, because of diffraction and optical aberrations. For points nearer or farther than the focusing distance, defocus adds blur and can become the dominant contribution, depending on aperture and other variables. The total blur spot, typically approximated as a circle, is called the blur circle or circle of confusion. Most depth-of-field calculators, however, consider only the defocus blur and judge sharpness against a chosen maximum diameter: the **circle-of-confusion threshold**.

ISO setting. ISO is the internationally used short name for the International Organization for Standardization, which publishes standards across many fields, including photography. In film photography, ISO ratings describe the film's sensitivity to light. In digital photography, the ISO setting relates the exposure at the sensor to the camera's output image signal levels. Although often called ‘sensor sensitivity’, ISO itself changes neither the amount of light captured nor how efficiently the sensor converts it into electrical charge. Raising ISO generally amplifies the image signal, including the noise already present.

Optical aberrations. Departures from ideal image formation by a lens. Some enlarge or alter the shape of the blur spot formed by an object point (see circle of confusion); others distort image geometry. Real photographic lenses exhibit several aberrations to varying degrees, including spherical aberration, coma, astigmatism, chromatic aberration, distortion, and field curvature. Lens designers reduce and balance them, but some always remain (**residual aberrations**). Those that enlarge the blur spot generally diminish at smaller apertures.

Photosite. An individual light-sensitive element on an image sensor that converts incoming light into an electrical signal. Photosites are often misleadingly called pixels: a pixel (picture element) is the smallest element of the digital image, computed from photosite signals. A conventional 20-megapixel camera has about 20 million photosites contributing to the image. Photosites outside the image area may support colour interpolation at the edges or, shielded from light, provide black-level reference signals. The centre-to-centre distance between neighbouring photosites is the **photosite pitch**, usually expressed in micrometres (µm; thousandths of a millimetre). Projecting this spacing onto the photographed ground surface gives the local **ground sampling distance (GSD)**.

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very well. Image sensor size and sensor technology also matter, because smaller sensors generally show more visible noise at the same ISO setting when framing, exposure settings, and output size are comparable.

The camera setting conventionally called shutter speed controls motion blur by determining exposure time. A short exposure time (e.g. 1/4000 s) can freeze motion, whereas a longer exposure time, such as 1 s, can smear moving detail across the image sensor. In aerial photography, this motion can come from the subject, such as vegetation moving in the wind. More often, however, it comes from the camera platform itself: the aircraft moves forward, vibrates, and changes attitude during exposure. The exposure time must be short enough to limit motion blur, expressed as image smear, caused by both the platform and the scene.

Aperture controls depth of field, diffraction, and the visibility of residual optical aberrations. Depth of field increases as the aperture is stopped down (e.g. from $f/4$ to $f/8$), meaning that more of the scene appears acceptably sharp. At wide apertures, the photographic objective uses a larger cone of light rays, including more marginal rays that pass through the outer parts of the optical system. Residual aberrations such as spherical aberration, coma, and astigmatism can then become more visible. Stopping down reduces the contribution of these marginal light rays and often improves image sharpness, but this benefit does not continue indefinitely. Once aperture-dependent aberrations have been sufficiently suppressed, further stopping down no longer improves the optical image; it increasingly replaces residual aberration blur with diffraction blur. Diffraction is the spreading of electromagnetic radiation caused by the finite aperture of the optical system. Even a perfect photographic lens cannot focus light to an infinitely small point, and the diffraction pattern grows larger as the aperture narrows. This creates a practical aperture balance: a wider aperture yields shallower depth of field and may make optical aberrations more visible, whereas a smaller aperture yields greater depth of field, less visible aberrations, but more diffraction softening. Between these extremes, many photographic objectives achieve their best overall performance roughly 1 to 3 stops down from maximum aperture. For example, a professional $f/2.8$ zoom may be close to its optical optimum around $f/4$ to $f/5.6$, where residual aberrations are already reduced but diffraction is still limited. Where available, online lens-test data (from websites such as [DXOMARK](#), [ePHOTOzine](#), [LensTip](#), [OpticalLimits/Photozone](#), and [The Digital Picture](#)) can be used to identify the optimum aperture more specifically. If such information is unavailable, stopping down by about 2 stops from maximum aperture is often a reasonable practice.

In aerial photography, this aperture balance differs from many forms of terrestrial photography. When photographing from several hundred metres above the surface, the focusing distance is very large. The depth of field, which depends not only on aperture but also on focusing distance, focal length, and the accepted blur criterion, is often already extensive, especially with moderate focal lengths. Stopping down to $f/8$ or $f/11$ may then add little useful depth of field, while it can visibly reduce image sharpness through diffraction. The aperture choice is then less about maximising depth of field than about keeping the objective within its best-performing aperture range, where residual aberrations and diffraction softening are both limited. That is why archaeological aerial photographers should choose

an exposure time that minimises image smear and an aperture that avoids unnecessary softening of image detail. At the same time, the focal length must be chosen to provide the required spatial detail without causing excessive image motion at the aircraft speed and flying height.

Reflected-light metering and exposure modes

When a camera is pointed at a scene, its exposure system responds to the light reflected or emitted by that scene. The camera then records the radiation incident on the image sensor, according to the sensor's spectral sensitivities. However, it does not know what caused that sensor response: it cannot distinguish whether a particular response results from a highly reflective surface under moderate illumination or from a less reflective surface under stronger illumination. That is why reflected-light metering must apply a standard calibration assumption (International Organization for Standardization, 1974), commonly described photographically as rendering the metered scene near middle grey.

This assumption works as long as the frame is not dominated by a highly reflective object, such as snow, pale sand, or a white wall. In such cases, the camera underexposes the object, rendering it too dark and making the white object appear greyish. Conversely, if a low-reflectance object dominates the frame, the camera may increase exposure, rendering the image too bright and making that object appear greyish. The meter is not technically malfunctioning; it is solving an ambiguous radiometric problem by applying a standard photographic assumption.

In archaeological aerial photography, this problem is generally less critical because the photographed landscape usually contains a mixture of soil, vegetation, roads, buildings, and other surfaces. Modern multi-segment metering systems are also considerably more sophisticated than a simple average meter. As a result, the camera's exposure recommendation can often be trusted, and small exposure deviations can later be compensated for during RAW development.

All of this implies that if illumination remained constant, as it often does in studio work, one could use fixed manual exposure settings. In practical aerial photography, however, the scene may remain largely unchanged while the radiation reaching the image sensor changes substantially. These changes may result from haze, changing solar elevation, passing clouds, or the anisotropic reflectance behaviour of surfaces. For this reason, archaeological aerial photography is usually not conducted using a single fixed manual exposure setting throughout an entire flight. The exposure system should be allowed to respond to real changes in scene radiance, but it should not be allowed to choose settings that compromise geometric image sharpness.

Cameras address this trade-off through exposure modes, which determine which parameters the photographer sets and which the camera adjusts automatically. Manual mode represents the limiting case already mentioned: aperture, shutter speed, and, optionally, ISO are fixed, giving maximum control. However, it can be too rigid when illumination changes quickly during a flight. In aperture-priority mode, the photographer sets the aperture, while the camera adjusts the shutter speed and, optionally, ISO to achieve the metered exposure. In shutter-priority mode, the photographer sets the shutter speed, while the camera adjusts the aperture and, optionally, ISO. In program or fully automatic modes, the camera has broader control over

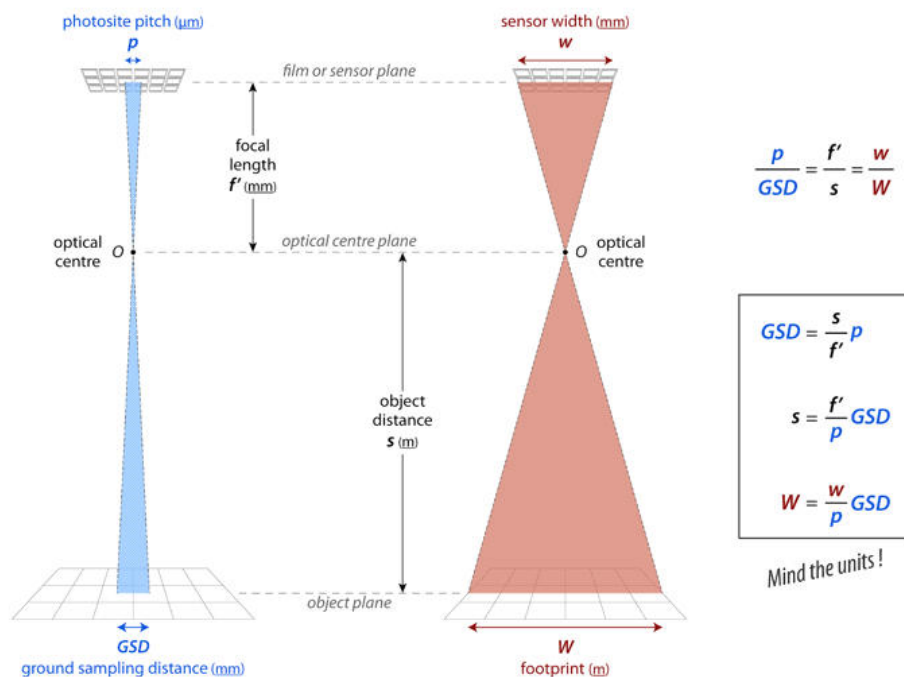


Figure 1. Relationship between photosite pitch p , ground sampling distance (GSD), focal length f' , object distance s , image sensor width w , and footprint W for the simplified near-nadir case over approximately flat terrain.

exposure parameters, which can be convenient but is less suitable when aperture or exposure time must be constrained to maintain geometric sharpness. Program mode is less restrictive than fully automatic mode because the photographer can still control settings such as ISO and exposure compensation. Using program shift, the photographer can also select a different camera-proposed combination of aperture and exposure time that produces an equivalent exposure. However, the available combinations are still determined by the camera. Fully automatic mode is the least appropriate option for archaeological aerial photography, as it gives the photographer no direct control over aperture, exposure time, or ISO. It should be avoided when consistent image sharpness and predictable geometric quality are required.

Because an aircraft is moving, many aerial photographers understandably choose shutter-priority mode. They reason that a short exposure time is the most obvious defence against motion blur. This is not wrong, but it is incomplete. Shutter-priority mode has two separate weaknesses in aerial photography. First, it protects exposure time by giving up control over aperture. Second, it is often used with exposure times that seem short in ordinary photography but are still too long for aerial acquisition with modern, high-photosite-count (i.e. multi-megapixel) image sensors.

The first problem is one of control. In very sunny conditions, shutter-priority mode may stop the photographic objective down to $f/8$, $f/11$, or even $f/16$ at ISO 100 or ISO 200. For aerial photographs acquired several hundred metres above the surface, this is usually unnecessary. At such distances, the far depth-of-field limit of a 50 mm objective on a high-photosite-count full-frame camera is typically already at infinity near $f/1$, provided focus is set appropriately and a circle-of-confusion threshold of twice the image sensor's photosite pitch is adopted. Here, photosite pitch p indicates the centre-to-centre distance between neighbouring photosites on the image sensor (see Figure 1). A

photosite pitch p of roughly $4\text{ }\mu\text{m}$, typical of many high-photosite-count full-frame image sensors, thus yields a circle-of-confusion threshold of about $8\text{ }\mu\text{m}$. This threshold specifies the maximum diameter of the image of an object point still considered acceptably sharp in depth-of-field calculations. This $2p$ criterion is more stringent than the traditional sensor-diagonal/1500 criterion, which equals about $30\text{ }\mu\text{m}$ for a full-frame image sensor and is used in most depth-of-field calculators (Nasse, 2010). The $f/1$ value merely demonstrates that depth of field does not require substantial stopping down. Since such a wide aperture is unavailable on most photographic lenses and many professional objectives perform best around $f/5.6$, the latter is a more realistic working aperture. At $f/5.6$, depth of field is already more than sufficient for virtually all observer-directed aerial reconnaissance, and stopping down further provides no useful gain when imaging terrain. Smaller apertures mainly increase diffraction softening. On high-photosite-count full-frame image sensors, diffraction becomes increasingly relevant from about $f/8$ and is clearly undesirable by $f/11$ when maximum sharpness is required. Conversely, if a very short exposure time is selected in low-light conditions, shutter-priority mode may keep the objective at its widest aperture, where residual aberrations can be more pronounced. In both cases, the problem is that the aperture is no longer controlled directly.

Before discussing the better alternative, it is useful to quantify the second problem: how short does the exposure time actually need to be?

How short must the exposure time be?

In ordinary photography, exposure times such as $1/500\text{ s}$ or $1/1000\text{ s}$ seem short. In aerial photography from a moving aircraft, they may still be too long. At a ground speed of 150 km/h , an aircraft travels approximately 41.7 m/s , so the camera moves about 8.3 cm during a $1/500\text{ s}$ exposure and about 4.2 cm

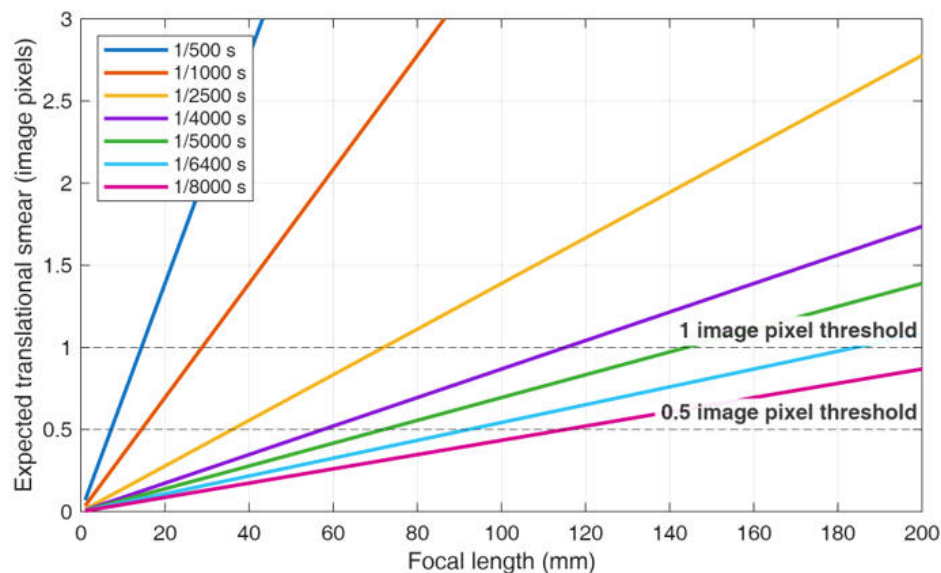


Figure 2. Expected translational image smear at common exposure times as a function of focal length, assuming a flying height of 300 m, a ground speed of 150 km/h, and a photosite pitch of 4.0 μm (as a representative round value for modern high-photosite-count full-frame image sensors).

during a 1/1000 s exposure. Whether this movement produces visible image smear depends mainly on the ground sampling distance (GSD), that is, the image sensor's photosite pitch projected onto the terrain. For a given photosite pitch, this projection depends mainly on the focal length f of the photographic objective and the object distance s , which in the simplified near-nadir case corresponds approximately to the flying height above the terrain (see Figure 1). For a near-nadir photograph over approximately flat terrain, the ratio f/s defines the image scale. In oblique photographs, image scale, and thus also GSD, varies across the frame. For the simplified near-nadir case, the expected translational smear in image pixels is motion during exposure divided by the GSD.

Using a 50 mm objective at a flying height of 300 m and a photosite pitch of 4.0 μm yields a GSD of approximately 2.4 cm. At 150 km/h, the 8.3 cm travelled during 1/500 s corresponds to about 3.5 image pixels of smear (8.3 cm / 2.4 cm), while the 4.2 cm travelled during 1/1000 s still corresponds to about 1.7 image pixels (4.2 cm / 2.4 cm; see Figure 2).

This simplified mathematical model only describes translational platform motion during exposure. Other effects, such as vibration, angular motion, turbulence, focus error, atmospheric effects, and object motion, can further degrade image sharpness. Image stabilisation, also called vibration reduction or vibration compensation, does not eliminate the need for short exposure times. In-lens, sensor-shift, and combined stabilisation systems primarily compensate for small angular motions and, in some cases, limited translational shake of the camera. They are not designed to compensate for the systematic image displacement caused by the aircraft's forward motion relative to the terrain and should not be used to justify longer exposure times. Moreover, image stabilisation must be deactivated when acquiring images for photogrammetric processing because it changes the camera's interior orientation between exposures (Nocerino *et al.*, 2022).

For the translational component considered here, image smear should be evaluated against an explicit threshold. Zero smear is impossible in practice, but it can be kept small enough

to be negligible for visual interpretation and photogrammetric processing (Sieberth *et al.*, 2014). A smear of one image pixel is a useful upper warning limit, but it should not be treated as an ideal value. For high-quality photogrammetric work, a stricter threshold of about 0.5 image pixels is more defensible (Grenzdörffer, 2008; see Figure 2), whereas 0.3 image pixels is the author's own demanding target for situations requiring maximum image sharpness. The examples in Table 1 use a 24–120 mm zoom lens fitted to a Nikon Z 7II-class full-frame camera featuring a 4.33 μm photosite pitch. The ground speed is assumed to be 150 km/h, which represents a typical observer-directed acquisition speed during circling or slower survey flights.

These values show why exposure times such as 1/500 s or 1/1000 s are often too long. At a flying height of 300 m with a 50 mm focal length, keeping smear below 1 image pixel at 150 km/h requires an exposure time of about 1/1600 s or shorter. Keeping smear within half a pixel requires roughly 1/3200 s or shorter. The higher the ground speed, the lower the flying height, the longer the focal length, or the smaller the photosite pitch, the shorter the exposure time needs to be. Figure 3 shows the combined effect of flying height and focal length for a Nikon Z 7II-class image sensor with a 4.33 μm photosite pitch, while Figure 4 illustrates how the required exposure-time limit varies with photosite pitch at a fixed flying height of 300 m. Both figures assume a ground speed of 150 km/h and a maximum translational smear of 1 image pixel. Because translational displacement during exposure is directly proportional to ground speed, the maximum acceptable exposure time decreases in inverse proportion to ground speed (see Figure 5).

Figures 3 and 4 make it clear that, even at a 400 m flying height and a ground speed of 150 km/h, the upper end of a commonly used 24–120 mm photographic zoom requires approximately 1/2900 s for a smear of one image pixel and nearly 1/5800 s for a smear of half an image pixel. Since many cameras cannot use exposure times shorter than 1/4000 s, focal lengths around 120 mm are often outside the comfortable range for this type of acquisition when applying the stricter half-pixel threshold. Even a focal length of 105 mm, as found at the upper

Flying height	Focal length	GSD	Approx. exposure-time limit for 1 px smear	Approx. exposure-time limit for 0.5 px smear
200 m	24 mm	3.61 cm/px	1/1200 s	1/2300 s
200 m	50 mm	1.73 cm/px	1/2400 s	1/4800 s
200 m	60 mm	1.44 cm/px	1/2900 s	1/5800 s
200 m	120 mm	0.72 cm/px	1/5800 s	1/11500 s
300 m	24 mm	5.41 cm/px	1/800 s	1/1500 s
300 m	50 mm	2.60 cm/px	1/1600 s	1/3200 s
300 m	60 mm	2.17 cm/px	1/1900 s	1/3800 s
300 m	120 mm	1.08 cm/px	1/3800 s	1/7700 s
400 m	24 mm	7.22 cm/px	1/600 s	1/1200 s
400 m	50 mm	3.46 cm/px	1/1200 s	1/2400 s
400 m	60 mm	2.89 cm/px	1/1400 s	1/2900 s
400 m	120 mm	1.44 cm/px	1/2900 s	1/5800 s
500 m	24 mm	9.02 cm/px	1/500 s	1/900 s
500 m	50 mm	4.33 cm/px	1/1000 s	1/1900 s
500 m	60 mm	3.61 cm/px	1/1200 s	1/2300 s
500 m	120 mm	1.80 cm/px	1/2300 s	1/4600 s

Table 1. Approximate exposure-time limits required to limit image-space motion smear to 1 px and 0.5 px for different flying heights and focal lengths, assuming a 4.33 μm photosite pitch and a ground speed of 150 km/h.

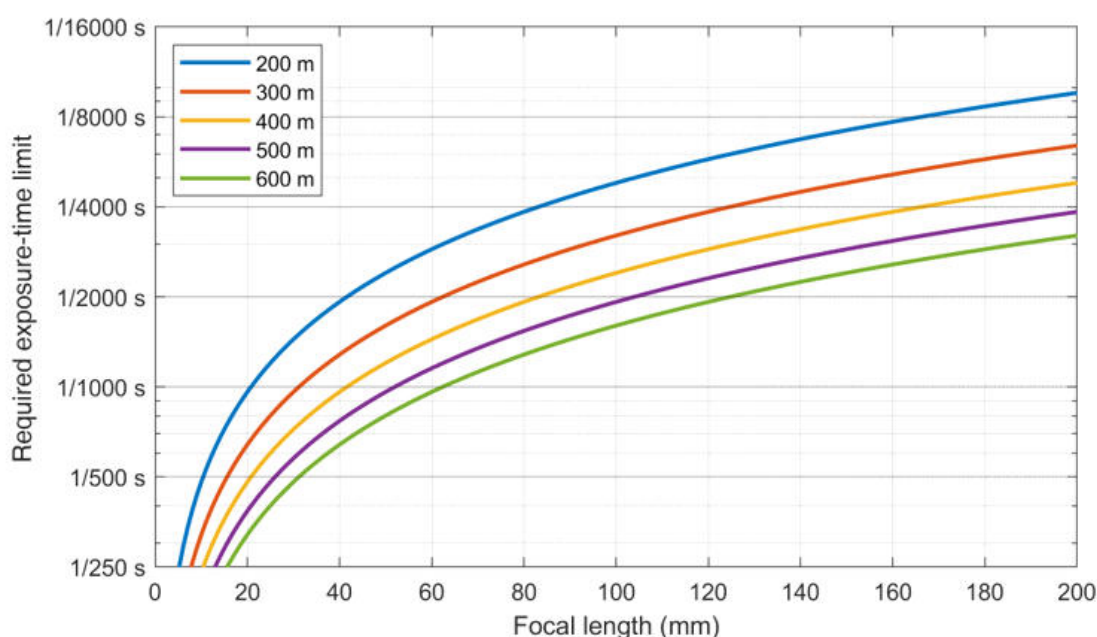


Figure 3. Required exposure-time limit as a function of focal length and flying height to keep translational image smear at or below 1 image pixel, assuming a Nikon Z 7II with a photosite pitch of 4.33 μm and a ground speed of 150 km/h.

end of 24–105 mm zooms, can become problematic when flying lower or at higher ground speeds (see Figure 5).

For side-looking oblique photographs, the situation is slightly different because GSD varies across the frame. In an oblique image taken with the camera pointed sideways from the aircraft and downward towards the ground, the GSD near the image centre is coarser than in a nadir image (because the object distance s is longer). As a simple centre-frame approximation, the along-track GSD relevant to forward-motion smear can be corrected by dividing the nadir GSD by the cosine of the off-nadir angle θ . At $\theta = 45^\circ$, this gives a coarsening factor of $1/\cos(45^\circ) \approx 1.4$ (see Figure 6). The same ground displacement consequently spans fewer image pixels, so the shutter-speed denominator required to meet a given image-space smear threshold decreases by a factor of $\cos(45^\circ) \approx 0.7$ (see Figure 6). In the 300 m and 50 mm example, the one-pixel threshold is relaxed from about 1/1600 s in nadir geometry to $1/(1600 \times$

$\cos(45^\circ)$), or roughly 1/1100 s, near the centre of the 45° oblique image. The half-pixel threshold changes similarly, from about 1/3200 s to approximately 1/2300 s. However, the longer permissible exposure time does not result from reduced aircraft motion, but merely reflects the coarser, spatially variable sampling of terrain in oblique imagery.

When flying in a circle, the same principle applies. As ground speed decreases, translational smear decreases in direct proportion, allowing slightly longer exposure times. Circling an object can also help, as it keeps the camera pointed at the same target. This may reduce smear near the centre of the image. However, other parts of the frame can still move during the exposure, especially if they are closer than the target. While circling can thus reduce motion smear in some cases, it should not be used as a general justification for long exposure times.

The practical conclusion is straightforward. Shutter-priority mode solves the motion-smear problem only if the selected

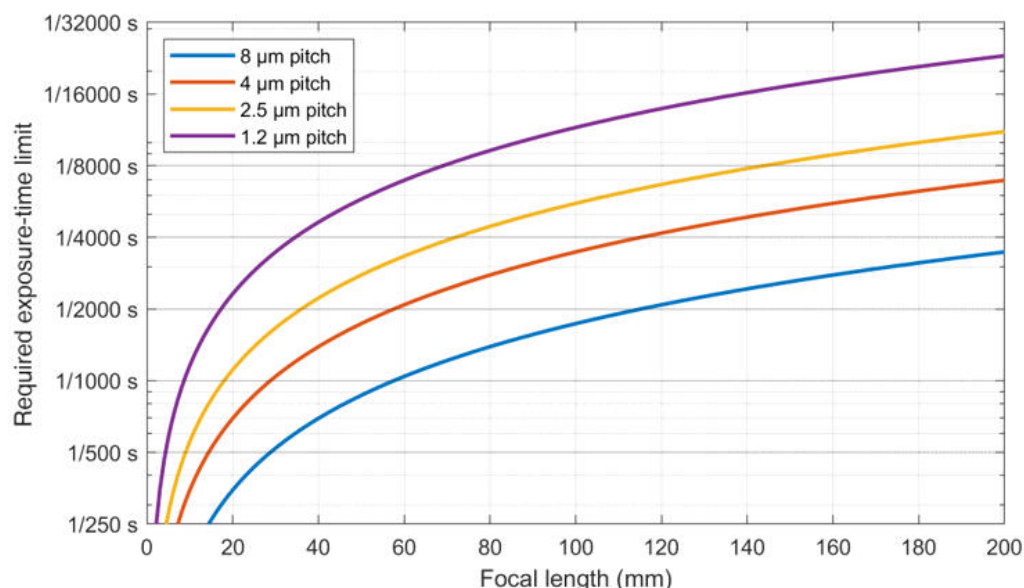


Figure 4. Required exposure-time limit as a function of focal length for different photosite pitches to keep translational image smear at or below 1 image pixel, assuming a flying height of 300 m and a ground speed of 150 km/h. The selected photosite pitches are representative values: 8 μm for large-pitch or lower-photosite-count image sensors, including some older full-frame cameras and medium-format digital backs; 4 μm for modern high-photosite-count full-frame cameras; 2.5 μm for 1-inch-type compact-camera sensors; and 1.2 μm for small high-photosite-count action-camera or smartphone image sensors.

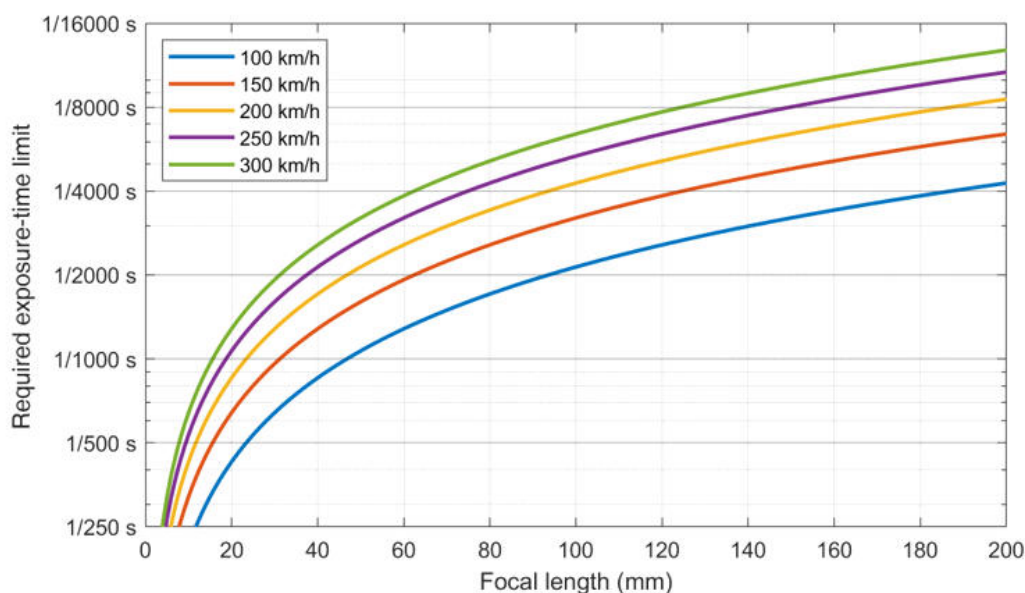


Figure 5. Required exposure-time limit as a function of focal length for different ground speeds, assuming a flying height of 300 m, a photosite pitch of 4.33 μm , and a maximum translational smear of 1 image pixel.

exposure time is sufficiently short. That value must be justified by ground speed, flying height, focal length, photosite pitch, viewing geometry, and the acceptable pixel-smear threshold. For modern high-photosite-count cameras used on fast light aircraft, exposure times such as 1/500 s should generally be considered too long, while 1/1000 s is often still borderline unless the aircraft is flying slowly, the focal length is short, the flying height is relatively high, and a one-pixel smear threshold is acceptable. At around 50 mm and flying heights of 300 m to 400 m, exposure times of about 1/2500 s to 1/4000 s are much more defensible for typical observer-directed flight around 150

km/h. Shorter exposure times, such as 1/5000 s, 1/6400 s, or 1/8000 s, remain preferable when ground speed increases, longer focal lengths are used, or a stricter half-pixel smear threshold is required. At 120 mm, even 1/8000 s may be necessary or insufficient, depending on flying height and ground speed.

For older cameras limited to 1/4000 s, the practical advice is not to abandon acquisition with short exposure times, but to respect the limit: use the shortest available exposure time, restrict the focal length more carefully, and avoid combining a low flying height with a long focal length. When comparing like

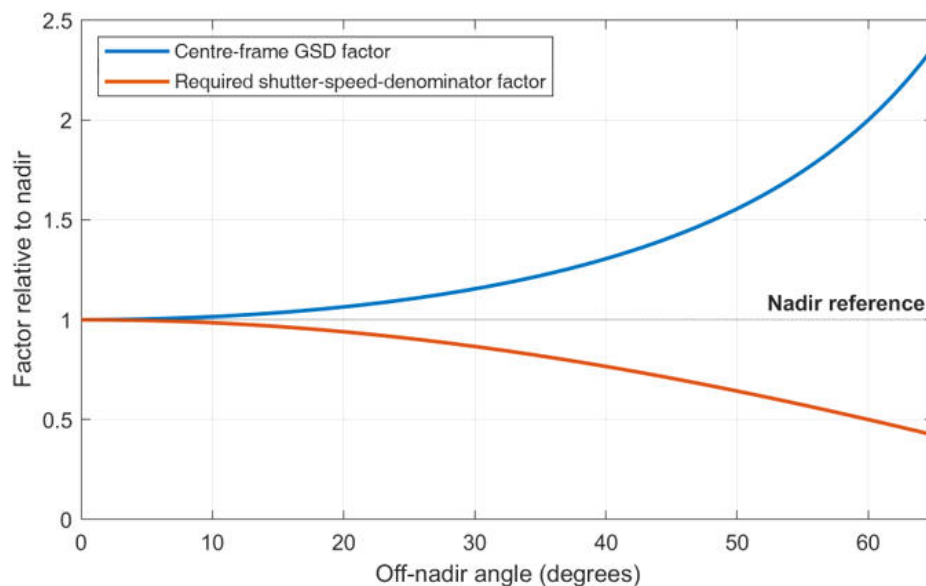


Figure 6. Centre-frame oblique correction for side-looking aerial imagery, showing how the along-track GSD factor increases as $1/\cos\theta$ while the required shutter-speed denominator decreases as $\cos\theta$.

with like (full-frame with full-frame, APS-C with APS-C), older models often have a lower photosite count and thus a larger photosite pitch. As a result, $1/4000$ s may be more acceptable in terms of pixel smear on such a camera than on a modern high-photosite-count model. Even then, longer focal lengths remain risky unless flying height, ground speed, viewing geometry, and smear tolerance have been checked explicitly.

This brings the argument back to aperture control. Shutter-priority mode can be useful only if the selected exposure time is short enough, but it achieves this exposure-time control by giving the camera freedom over aperture. Depending on light levels, this can place the photographic objective outside its best-performing aperture range: too wide, where residual aberrations may be more visible, or too narrow, where diffraction softening becomes stronger. A better strategy is to reverse the priority: keep the aperture near the photographic objective's optical optimum, enable automatic ISO, and set a maximum exposure-time limit. This is the role of aperture priority combined with automatic ISO.

Auto ISO and aperture priority

Automatic ISO (Auto ISO) is a camera function that allows the camera to adjust the ISO value as part of its exposure calculation. Instead of fixing ISO at a single value, the photographer defines an allowed ISO range, for example from ISO 100 to ISO 3200. Within this range, the camera can adjust ISO when the selected aperture and/or exposure time would otherwise lead to under- or overexposure.

For aerial photography, Auto ISO is useful only if it is configured to keep the exposure time short enough to limit motion-induced pixel smear. This can be achieved by combining Auto ISO with a maximum exposure-time limit. In camera menus, this limit usually appears as a minimum-shutter-speed setting (i.e. the longest exposure time the camera may choose before raising ISO). For example, the camera may be set to start at ISO 100, increase ISO up to ISO 1600 when needed, and avoid exposure times longer than $1/4000$ s. If the available

light is insufficient to maintain $1/4000$ s at ISO 100, the camera may raise ISO up to, but not beyond, the selected ceiling. In this configuration, ISO acts as a safety valve: it allows the camera to respond to changing illumination while helping to prevent exposure times that would cause unacceptable pixel smear.

This setup is especially relevant in aperture-priority mode. In this mode, the photographer sets the aperture to a value at which the photographic objective performs well optically (e.g. $f/4$, $f/5.6$, or $f/6.3$), while the camera determines the exposure time. If Auto ISO and a minimum-shutter-speed setting are enabled, the camera initially maintains the metered exposure using the selected aperture and an appropriate exposure time. When this would require an exposure time longer than the chosen limit, the ISO is raised instead, up to the permitted upper limit. Under strong illumination, the camera can use shorter exposure times. This provides the desired hierarchy for aerial photography: the photographer controls the aperture, the exposure time is kept from becoming too long, and ISO serves as the flexible compromise. This approach is practical because modern full-frame and APS-C cameras can often produce images with acceptable noise levels at ISO 1600, and because reducing noise is generally much easier than correcting motion-induced pixel smear. This configuration also retains quick exposure compensation: when the reflected-light meter is misled by, for example, snow-covered or predominantly dark terrain, the photographer can bias the metered exposure directly, and the camera applies the correction through the exposure time (within the configured limit) and ISO, while the aperture remains unchanged.

The same logic does not transfer cleanly to shutter-priority mode. In shutter-priority mode, the photographer has already set the shutter speed (e.g. $1/4000$ s), and the camera adjusts the aperture to obtain the required exposure. Shutter priority can thus guarantee a short exposure time, but it gives up aperture control. Under strong illumination, the camera may stop down the photographic objective to $f/8$, $f/11$, or even smaller apertures, thereby increasing diffraction softening without adding useful depth of field for distant terrain. Under low-

illumination conditions, the camera may fully open the photographic objective, resulting in softening due to aperture-dependent aberrations. Although Auto ISO may still be available, the minimum-shutter-speed logic cannot serve as the primary control mechanism, since the photographer has already set the exposure time. The camera may still raise ISO if the maximum aperture is insufficient to obtain the required exposure, or it may reach the lowest ISO limit and the smallest available aperture (i.e. the largest available f -number) if the illumination is too strong. In either case, ISO is only a secondary compensation mechanism; it cannot preserve the desired aerial-photography hierarchy in which aperture is controlled, exposure time is limited, and ISO is used as the flexible compromise. A closely related alternative is manual mode combined with Auto ISO: the photographer fixes both the aperture and the exposure time, ISO remains the flexible variable, and exposure compensation can act through ISO where supported. This configuration realises the same hierarchy and can work equally well. Nevertheless, aperture-priority mode is recommended here because, under strong illumination, it automatically selects exposure times even shorter than the configured limit, further reducing motion smear, whereas a manually fixed exposure time leaves that reserve unused.

However, there is one caveat to be aware of. Even in aperture-priority mode with Auto ISO, the selected minimum-shutter-speed setting does not guarantee a sufficiently short exposure time. If the camera reaches the selected maximum ISO and still cannot obtain the metered exposure, many cameras will allow the exposure time to become longer than the selected limit. Because exactly this should be avoided in aerial photography, the ISO ceiling must be set high enough for the expected lighting conditions, and the photographer should check during the flight that the camera actually maintains the intended exposure-time limit. Under such conditions, an upper limit as high as ISO 6400 may be preferable to the alternative of motion-induced pixel smear. Although such ISO values increase image noise, current denoising methods can often reduce it substantially. In addition, residual noise is usually preferable to pixel smear in photogrammetric processing, georeferencing, and interpretative mapping, because noise primarily affects local image texture, whereas smear displaces and blends image detail.

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Conclusion

Aperture-priority mode with Auto ISO and a maximum exposure-time limit is the preferred practical compromise for producing sharp aerial images during observer-directed archaeological aerial photography. It provides the camera with the appropriate hierarchy for aerial image sharpness: the aperture remains near the optical optimum of the photographic objective, the exposure time is kept from becoming too long within the predefined ISO range, and ISO serves as the flexible exposure variable. In summary, the recommended default exposure strategy is to select aperture-priority mode with an aperture near the optical optimum, set Auto ISO to an ISO ceiling appropriate for the intended output, and set the longest exposure time to the value required by the acquisition geometry (or, if the camera cannot reach that value, to the shortest exposure time it offers while restricting focal length accordingly). For many high-photosite-count cameras operated from fast light aircraft, this means treating 1/2500 s to 1/4000 s as a practical working range for moderate focal lengths during observer-directed surveys, while preferring 1/5000 s, 1/6400 s, or 1/8000 s for faster flight, longer focal lengths, lower flying heights, or stricter pixel-smear thresholds.

Interactive companion tool

The calculations underlying this paper, including those used to produce Figures 2 to 6, can be explored interactively with AirSharp, an aerial image sharpness calculator freely available at: <https://beyondconventionalboundaries.github.io/airsharp>. Readers can enter their own camera, lens, flight, and sharpness parameters and immediately see the resulting ground sampling distance, expected motion smear, and required exposure-time limit, along with interactive versions of Figures 2 to 6. The tool also computes depth-of-field and diffraction values (topics beyond the scope of this paper) and complements the discussion of Auto ISO by estimating the ISO value implied by the scene illumination, chosen aperture, and exposure time. Every setting is encoded in the page address, allowing specific configurations to be bookmarked or shared. The tool runs entirely in the browser, and all underlying formulas and version history are documented on the page.

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