Difficulty of observing flying birds

Alistair Fraser (text and pictures) draft: June 8, 2017

Observing difficulties

I enjoy viewing and photographing local wildlife. Many of my images are of stationary birds: perched in trees, floating on water, standing on ground. Only rarely do I get a detailed picture of a bird in flight, and when I do, the bird is almost always large. This struck me as odd in that small birds don't fly as quickly. Shouldn't they be easier to photograph in flight?

Most birds I photograph, such as this nesting loon, are stationary.

Further, if one culls through a wide variety of pictures taken by other bird photographers, it is apparent that only a small proportion of them are close views of birds in steady horizontal flight (neither accelerating nor decelerating), and the flying birds shown are generally large. This, in spite of such flight being the basic behaviour of birds and small birds being plentiful. Why is the defining characteristic of class Aves infrequently recorded? The short answer is: Taking such pictures is difficult. This note will explore why it is so.

The study will confine itself to the difficulty of observing or photographing a bird flying across one's field of view at its normal cruising speed. Many other situations that are easier to photograph are not treated:

Usually, when a bird has dangling legs, it is either landing or taking off and so is flying at less than cruising speed.

birds landing or lifting off (often signalled by dangling legs); some smaller birds, such as hummingbirds (capable of hovering); ones rendered nearly stationary by flying into a strong wind; those slope soaring or riding thermals, those flying directly towards or away from the observer. These easier situations are excluded.


Not every flying bird with dangling legs is landing or taking off.

The problem

In what way does the difficulty of making detailed observations (binoculars), or taking pictures (camera) of the steady flight of birds vary with the size of the bird? (Actually, this issue extends well beyond birds to aircraft and insects.)

Aerodynamics teaches us, and observations confirm, that a flyer has a characteristic cruising speed and that this speed depends primarily on the wing loading. Because wing loading generally increases with flyer size, cruising speed does also. Therefore aircraft cruise faster than swans, which cruise faster than song birds, which cruise faster than insects. Yet, despite flying slowly, the smallest fliers are the most difficult to observe in flight.


Excluded from consideration is the easy case of a bird rendered stationary by flying into a strong wind.

Why is this? Is it possible to work out how observing or photographing difficulty changes with the size of the bird?

Viewing comparable detail

First, we have to decide how to

compare observations of birds of different sizes. We assume that to observe comparable detail when using binoculars or camera that each bird should occupy the same fraction of the binocular view or camera frame, possibly all or merely a quarter of it. The actual fraction doesn't matter, it is merely necessary to assume that it is the same for a bird of each size. It is easy to specify this condition by saying that we want each bird observed to have the same angular size, $\beta = L/D$, where L is some characteristic dimension of the bird and D is the distance from observer to bird. Clearly, to see comparable detail, this distance must be less when L is small.


Also not considered are hovering birds or ones flying toward or away.

Difficulty of tracking

Second, we need a measure of the difficulty of making such a detailed observation. A good choice for observational difficulty is the rapidity with which a bird rotates across one's field of view. This is the bird's angular velocity about the observer, $\omega = U/D$, where U is the cruising speed of the bird. The higher the angular velocity, the more difficult it is to track, and consequently to obtain a detailed view.

Cruising speed

To link viewing and tracking difficulties, we need to relate the bird's speed to its size. There isn't a unique relationship encompassing all birds owing to the variability of the configuration of birds in various phylogenetic groups, but there is a general trend that will prove insightful.

Flying is different than surface transport such as running. When something runs, the faster it goes the more power it takes. When something flies, there is an optimal speed, above or below of which power requirements increase. This is the bird's cruising speed.

From a bird's (or aircraft's, or insect's) point of view, economical flight involves choosing the speed that requires the least power. Should the bird fly slower, the power needed to stay aloft dominates. Should it fly faster, the power needed to overcoming wind resistance dominates. The cruising speed is a compromise that takes the least power and so is the most comfortable speed for the bird to use. A bird can fly a bit slower or faster than the cruising speed, but generally does not choose to do so because deviating from this optimal speed becomes increasingly difficult. (This compromise is not required of a runner, where a surface provides support.)

Detailed pictures of a flying bird, such as a hawk are difficult to take.

From aerodynamics we discover that the cruising speed, U, is proportional to the square root of both the wing loading, W/S, and $1/C_L$, where W is the bird's weight, S is the surface area of the wings and C_L is the lift coefficient. This can be written $U \propto (W/SC_L)^{.5}$, where $\propto$ means, is proportional to. Often C_L has been assumed to be constant. This greatly simplifies relating cruising speed to the size of the bird. Alas, C_L seems to vary somewhat with the size of the bird, particularly between different phylogenetic groups.

Fortunately, a recent paper about bird flight speeds[1] reported on the cruising speeds of 138 species, ranging in mass between 0.01–10 kg. It found an approximate relationship that assigned the variability in $1/C_L$ to the wing loading which instead of it being raised to the 0.5 power, now became raised to the 0.31 power. The resulting relationship, $U \propto (W/S)^{.31}$, is certainly good enough for my purposes for it characterizes the variability of cruising speed for a large number of bird species. (Exponents 0.27 and 0.35 bracket the 95% confidence interval.)

How difficulty depends upon bird size

We are now in a position to relate the difficulty of observing or photographing, ω, to the size of the bird, L.

We can now make some approximations: weight, $W \propto L^3$, and the surface area of the wings, $S \propto L^2$. Despite the variability of bird configurations, these should be adequate approximations. Combining these relationships, and holding β (the bird's angular size) constant, we discover that,

$$\omega \propto L^{-.69}$$

This says that the smaller the flying bird, the more difficult it is to make a detailed observation or take a good picture.

Alternative interpretation

The expression just derived used the angular velocity, ω, of the bird flying past the observer as the measure of observing difficulty.

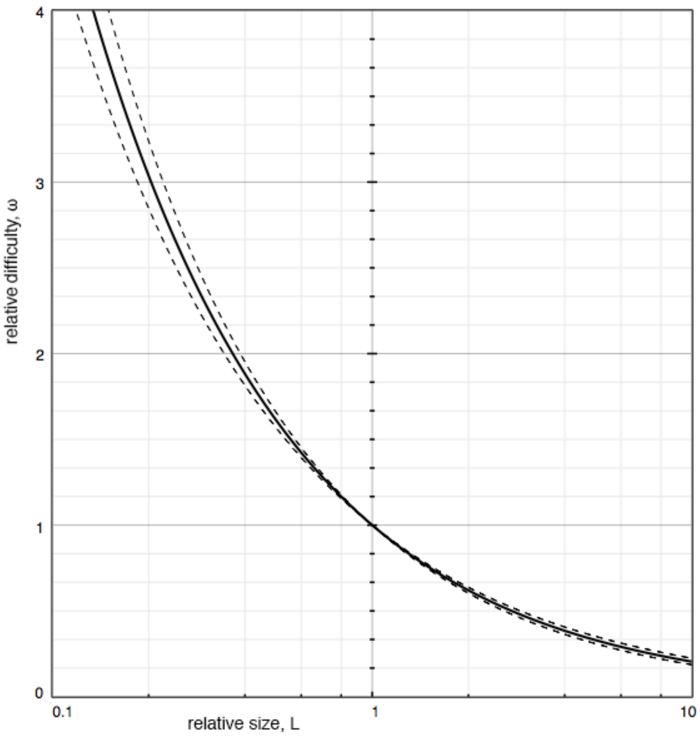
The issue might have been approached differently by calculating the bird's cruising speed as measured in terms of its own body length (rather than, say, metres). So, a measure of the difficulty of observing would be the number of body lengths the bird flies each second, it being more difficult to keep a bird occupying most of a camera frame if it is moving at many bird lengths a second. The interesting thing is that this alternative measure of observing difficulty produces exactly the same expression as did the first derivation.

So, there is an alternative interpretation of the difficulty of photographing small birds flying: While smaller birds fly slower when measured by standard units; smaller birds fly faster than large birds when the measuring stick is their own body size.

Extracting numbers

These equivalent interpretations are informative, but qualitative. Is it possible to get real numbers out of the relationship? There are two difficulties: This is merely a proportionality; It depends upon the skill and technology of the observer or photographer. Each problem vanishes if a reference bird is chosen for which the observer regularly obtains satisfactory observations or photographs of flight. It might be a Red-tailed Hawk, but any successfully observed bird will do. L becomes a ratio of the test bird to the standard. Similarly, ω becomes the resulting ratio of the difficulties and $\propto$ is replaced by =. In the resulting equation, the variables are now interpreted as relative.

$$\omega = L^{-.69}$$



Relative observing difficulty as a function of the relative flyer size, $\omega = L^{-.69}$*. The dashed lines show the 95% confidence interval.*

We now have something useful that produces real numbers based upon the skills of a particular observer.

Forging ahead

Continuing with our use of a Red-tailed Hawk as a reference, we note that a Bald Eagle's wingspan of about 203 cm is 1.6 times that of the hawk's 124 cm. So, L is 1.6 giving a relative difficulty, ω, of about 0.72. This suggests that a flying eagle is about a quarter easier to observe or photograph than the flying hawk.

Or consider a Tree Swallow with a wing span of about 32 cm. Relative L will be about 0.256 and the difficulty is now about 2.6. A detailed observation or image of this bird in flight would be about two and a half times more difficult to make as would one of our reference hawk.

Pictures of an eagle are a bit easier to take than those of a hawk.

Calibrating the system

This analysis suggests that taking this picture of a Tree Swallow was over twice as difficult as taking the one of a Red-tailed Hawk.

Something interesting has taken place here. By choosing the smallest bird for which the photographer regularly gets satisfactory observations, both photographer and equipment have been taken into account. The reference bird is unlikely to be the hawk chosen for this illustration. Whatever the choice, if the photographer becomes more decrepit, a larger bird may have to be chosen as a reference; if the camera resolution, burst shooting, focus speed, or image stabilization improves, the calibration may shift to a smaller bird. The choice is based upon skill and equipment.

Interpretation

What does it mean to be, say, twice as difficult? The calculated difficulty could be interpreted as being the odds of failure. This is something a nature photographer understands: the number of shots it takes to obtain a good image, at least by comparison to the reference. So, if a photographer required, say, ten shots to get one good image of the Red-tailed Hawk, then the Tree Swallow might require 10 times 2.6 or 26 shots. Of course, making such comparisons would have greater validity for birds within a phylogenetic group where the flight characteristics are more closely matched. However, the approach remains instructive as to the nature of the photographic problem with most birds.

But, it gets worse

In my experience, the analysis just given underestimates the difficulty of photographing small birds. The problem seems to be that small birds are also agile: they can change direction much more rapidly than can large birds. The measure of this is the bird's angular acceleration about its own centre of mass, something that equals τ/I where τ is the torque (equal to rF, where r is the turning radius and F is the force exerted). **I** is the moment of inertia (proportional to Mr^2, where M is mass). Important is the fact that the force, F, that can be exerted to make a turn, varies as the cross-sectional area of the muscles and therefore scales as L^2. Scaling $r \propto L$ and $M \propto L^3$, we discover that agility scales as L^{-2}. This result is the same as applied by Andersson and Norberg[2], 1981, to the ability of birds to make an abrupt turn and by Walter and Carrier[3], 2002, to rodents (although each expresses it as $M^{-2/3}$).

Even an intermediate sized bird, such as a magpie, is exceedingly difficult to photograph in steady horizontal flight.

The L^{-2} curve climbs even more rapidly for small birds than the curve showing the tracking difficulty, ω (angular velocity). It seems that if a small bird decides to change direction, the photographer is just out of luck.

The workaround

Small birds move too quickly and erratically to track with a handheld camera. Yet, sometimes a feeder or berry bush attracts them in large numbers and many pass through the same space. On such occasions a shotgun approach seems best: focus on a likely spot in the vicinity and take a large number of pictures in rapid succession. Sometimes a good image of a bird in flight is recorded; endless duds are deleted.

Conclusions

While it is the case that small birds fly more slowly than big birds, in order to get a comparably good view of one, the smaller bird must be closer. The resulting increase in its angular velocity dominates to make small birds much more difficult to observe or photograph in free flight. Erratic flight increases the difficulty. At such times a shotgun approach seems best: take many, many, pictures.

A detailed picture of a small bird (Mountain Bluebird) in steady flight is difficult because it has a large angular velocity about the camera.

Acknowledgement

I am indebted to both Gary Davidson and Thomas Alerstam for insightful comments on my drafts.

References

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