# BALLOONISTS' REPORTS OF SOUNDS AUDIBLE TO MIGRATING BIRDS

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Recent radar observations have shown many birds migrating on overcast nights. Often they appear to be well-oriented even under circumstances where visual cues must be very limited or absent altogether (reviewed by Eastwood, 1967; Griffin, 1969). For example Drury and Nisbet (1964) observed well-oriented migrants over the ocean on nights with widespread total overcast at altitudes well above those where most migrants fly. The radar employed would not detect birds flying below about 200 m, so that the birds tracked must have been high enough to have great difficulty seeing details on the ocean surface. Bellrose (1967) reported almost equally accurate migratory orientation at altitudes above, below, and within cloud layers. Eastwood and Rider (1965) also described cases where the altitudinal distribution of birds was continuous through layers of stratus clouds several hundred feet thick. In some cases these clouds were much thicker than the pulse volume of the radar employed, so that if the birds had avoided flying inside the overcast a gap in their altitudinal distribution would have been expected. Still more recent radar observations with more closely correlated meteorological data have provided additional evidence of at least roughly oriented migration in or between layers of cloud (Griffin, 1972; Williams et al., 1972). Biologists are understandably reluctant to believe that birds maintain accurate orientation unless they can see either stars, moon, or features on the surface such as lights. But the circumstantial evidence for nonvisual orientation is sufficient to warrant consideration of alternate sources of directional information for birds migrating on overcast nights.

One such possibility is sound. At first thought it may seem unlikely that reliable sounds would be available to birds several hundred meters above the ground or ocean. We would like to call attention to some fragmentary evidence, not ordinarily available in the contemporary literature, about the occurrence of sounds originating from the ground and audible at altitudes where birds commonly migrate. In addition to its possible role in orientation, sound may be worthy of consideration as an environmental factor of importance to birds for other reasons—such as identifying the general type of terrain they are flying over (forest, swamp, ocean, city, etc.). The calls of other birds may also be of great importance for maintaining the integrity of flocks and even perhaps for orientation as discussed elsewhere (Griffin, 1969). But the purpose of this speculative paper is to encourage future observations and experiments in an area that has been almost wholly neglected.

Our impressions about the presence of sound at considerable altitudes are based on very limited evidence. Airplanes, helicopters, and gliders are quite noisy, and while mountain climbers often notice sounds from the surrounding valleys, we ordinarily feel sounds to be important only at short range. Most of our acoustic experience involves both a source and a listener at the surface of the earth, but these are not the optimal conditions for transmission of sound over long distances. Not only are many obstacles likely to intervene, but reflections from the ground, or refraction at low altitudes all tend to bend and scatter sound waves (Humphreys, 1929). In contrast sounds originating at the ground and traveling upward encounter much less deflection and distortion. The physical absorption of sound in traveling through air becomes a serious factor only at frequencies approaching the upper limit of auditory sensitivity in men or birds (Griffin, 1971).

Schwartzkopff (1968) and Konishi (1969) have measured the auditory thresholds of several species of birds and found that while hearing could be demonstrated in various species from about 40 Hz to 29 kHz, the audiograms (graphs of auditory threshold as a function of frequency) were roughly similar for men and birds—with maximum sensitivity around 1 to 4 kHz. The sounds generated by a bird's motion and wingbeats must have some masking effect, but this is very difficult to estimate, as are other differences between the conditions during migration and those of laboratory experiments on auditory sensitivity. Lacking more directly relevant data, a reasonable working hypothesis is that a migrating bird can hear any sounds audible to an alert man. Thus the best available evidence about sounds that may be audible to migrants comes from observers carried aloft by free balloons.

Modern balloonists generally use hot-air balloons that are rather noisy, either from heater sounds or the crackling of the plastic gas envelopes. Furthermore free ballooning is now rarely practiced at night during the seasons of migration, and still less often in or near clouds. We have not been able to locate any pertinent data from contemporary balloonists, although specially planned balloon flights might be informative. The early balloonists were far less inhibited in their ascents than their modern counterparts, primarily because before 1900 balloons and kites were the only available devices to carry human observers aloft. The early balloonists were exploring a new medium, and some of them were careful observers keenly interested in measuring all aspects of the atmosphere at all hours and seasons. Such scientific balloon flights almost always carried mercury or aneroid barometers to determine altitude, and in the following discussion approximate altitudes are quoted in meters above the ground surface. In most cases the terrain was not at any great altitude above sea level, however, so that corrections for ground altitude and also for local barometric pressure would not have been important for the data discussed here. Gas-filled (rather than hot-air) balloons were used in the flights discussed below.

*Sources*.—The early editions of the Encyclopaedia Britannica list some of the better known balloonists and their writing; Rolt (1966) includes a detailed bibliography; and Milbank (1943) lists what was written in the United States. The libraries of the following institutions were searched thoroughly: The New York Public Library, Columbia University, the Massachusetts Institute of Technology, and the Air and Space Museum of the Smithsonian Institution. Papers by James Glaisher in the Annual Reports of the British Association for the Advancement of Science (1862-66) pay substantial attention to sounds and are an excellent source of precise information about time, position, altitude, and weather conditions for each report. Glaisher, et al. (1873) is a more popular account of ballooning; but the section by Flammarion is valuable for reports of echo experiments, sounds heard over water, and night flying. Bacon (1901) discussed echoes and the propagation of sound through the air under various weather conditions. He was keenly interested in sound and performed many experiments, including firing a cannon suspended beneath the gondola in order to observe the quality of the sound both from the ground and from the balloon itself. Flying over the English Channel was a popular aeronautical occupation that yielded most of the reports of sounds heard over the water (Burnaby, 1882; Butler, 1907; Hollond and Mason, 1836).

## Types of Sound Audible at Various Altitudes

Bacon (1903) vividly summarized his experiences, which seem to have been representative: "Anon each time as we descended from higher levels the familiar sounds of earth would return in a definite and striking sequence. There were voices of many kinds, the shriller pipes always leading,—the crow of cocks unseen, and indeed invisible from distance, the bark of a dog, next the cries of human beings, but the shouts of children always first. Again, the absence of all echo from sounds below contrasted strangely with the full return of one's own voice off the earth, as we came down to short range." Our literature search yielded 165 balloonists' reports of sounds heard aloft, and these can be conveniently divided into the categories shown in Table 1 with reference to their origin and the conditions under which they were heard. This sample is biased by what the balloonists considered of sufficient interest to report. Thus presum-

TABLE 1
ALTITUDES FROM WHICH BALLOONISTS HEARD VARIOUS TYPES OF SOUND[1]

| Type of sound | Below 1,000 m | 1,000 to 2,000 m | Above 2,000 m | Total |
|---|---|---|---|---|
| City sounds | 10 | 5 | 1 | 16 |
| Country sounds | 9 | 7 | 4 | 20 |
| Sounds from water | 4 | 10 | 5 | 19 |
| Human voices | 26 | 12 | 1 | 39 |
| Musical instruments | 7 | 7 | 3 | 17 |
| Guns | 6 | 7 | 9 | 22 |
| Trains | 4 | 5 | 11 | 20 |
| Total | 70 | 59 | 36 | 165 |
| Ground echoes of sounds from balloon | 6 | 5 | 0 | 11 |
| Sounds heard at night | 18 | 11 | 1 | 30 |
| Sounds heard from inside clouds | 28 | 27 | 10 | 65 |

[1] As not all reports include time of day or cloud conditions, the last two groups include a smaller total number of cases.

ably all categories were also heard at lower altitudes than those mentioned. Much of the time balloonists marveled at the silence of the medium they were exploring for the first time, and it is difficult to judge how often sounds from the surface were audible at all at various altitudes.

City sounds were noted from 330 to 2,245 m, the highest being the "roar of London" (Glaisher, 1862). Country sounds included the song of a lark, barnyard fowl, barking dogs, and the wind rushing through woods. The highest was the lowing of cattle and the rattling of a carriage on a country road at 4,500 m (Roberts, 1802). Sounds from water included waves crashing on a beach and sounds from rivers and lakes. The highest was the roar of Niagara Falls heard at 4,500 m by Wise (1873). Shouts or cheering from people who saw a balloon passing overhead included "a powerful and sonorous voice inviting the aeronauts to dinner at the caller's chateau" heard from 120 m (Glaisher, 1862). Glaisher (1863) reported that the shouting of several thousand people could *not* be heard at 1,600 m. The general opinion of the aeronauts was that it is more difficult to make oneself heard calling down to the earth than to hear people shouting up at the balloon, presumably because of quieter listening conditions aloft.

The aeronauts often heard a band or an individual instrument playing beneath them. The highest was the roll of a drum heard at 3,900 m (Amick, 1875). There were many reports of church bells and clocks striking, the highest being a peal of bells from a village belfry at 2,725 m (Dumont, 1905). The highest of all reports (7,150 m) was "the sound of thunder below" which later turned out to be artillery practice (Flammarion, 1873). The sounds of rattling cars or whistles of locomotives were heard at altitudes up to 6,650 m (Glaisher, 1863). Artificial sound sources or moving sources such as trains may seem alien to the behavior of migrants, but even these could convey limited information about the terrain below. Sounds from human activities have undoubtedly increased in extent and intensity during the past century, and they may be of increasing importance to birds.

Night sounds are especially interesting because most bird migration takes place at night. The highest report was of a barking dog at 2,145 m (Wise, 1873). Tissandier states (in Glaisher et al., 1873) "in the stillness of the night the course of a river, or even that of a small stream produces at this elevation (about 1000 meters) almost the effect of a high waterfall. At the height of 3000 feet (900 meters) the croaking of frogs in a morass is heard in all its intensity, and even the sharp note of the mole cricket is distinguished easily at an altitude of 2500 feet (750 meters)." Flammarion reports the croaking of thousands of frogs, and dogs barking (Glaiser et al., 1873); and Butler (1907) reports various birds and a dog.

*Sound in cloud.*—This category encompasses reports when the balloon was either in cloud, directly beneath cloud, or in fog, and is of special interest because these are conditions under which birds could not see the stars or perhaps not even the ground. The highest report was "when in clouds at 4 miles high (6400 meters) heard railway train" (Glaisher et al., 1873). Many of the aeronauts seemed to take special notice of sound when they were in cloud or fog. Donaldson (quoted by Amick, 1875) felt that fog conveys sound better than dry air, and that a cloud conveyed sound better than fog. The following report by Flammarion (Glaisher et al., 1873) is one of the more complete accounts of sound transmission in cloud and an aeronaut's conjectures about it.

"Suddenly whilst we are thus suspended in the misty air, we hear an admirable concert of instrumental music, which seems to come from the cloud itself and from a distance of a few yards only from us. Our eyes endeavor to penetrate the depths of white, homogeneous nebulous matter which surrounds us in every direction. We listen with no little astonishment to the sounds of the mysterious orchestra; then . . . I find that the humidity of the air decreases as we rise in the cloud and has sunk gradually to 87, and the thermometer has risen to 62.7 F.

"A fog is much more sonorous than dry air, and collects sound with such intensity that whenever, in passing through a cloud, we have heard a band playing in a town beneath us, the music always seemed close at hand. At the limit at which sound can be perceived through pure air, the interposition of a cloud, though it hides an entire town from sight, is far from weakening sounds; in fact, it may happen that such a cloud enables the aeronaut to detect slight noises which without it he would not have perceived.

"We were serenaded by some excellent orchestral music whilst sailing over Antony and over Boulainvilliers; we were then entirely enveloped in clouds and about 3280 feet (1000 meters) above each of those towns."

These observations may be related to thermal discontinuities in the atmosphere such as the temperature inversion noted at about 700 m.

*Echoes*.—Several balloonists experimented with echoes by calling down to the ground, blowing loud horns, or by firing a small cannon to determine the quality of the returning sound. These reports are especially interesting in connection with the suggestion that migrating birds might use flight calls for echolocation when no other cues are available to them (Graber and Cochran, 1960; Griffin, 1969; Swan, 1970). Wise (1873) recorded the highest echo: "While viewing this scene from over a mile high (1600 m.) my attention was suddenly drawn to a conversation between two individuals. At first I thought it was a delusion, but upon close observation it proved to be a fact, for I could distinctly hear words, such as 'I don't know, Did you see him?' I tried the experiment upon my voice and found it to echo distinctly, which also brought shouts, probably from those whose conversation I heard. This happened over a little stream, at a clear point entirely surrounded by woods, and just at sunset."

Beaufoy (1811) reports that at 1,775 m he shouted as loudly as possible and got no echo. Bacon (1901), who experimented often with echoes, states that they are usually "lost" at 300 m, but on some days they are lost at 275 m, and on others echoes can be heard up to about 760 m. Bacon also reports that during a night flight at 600 m he blew a hunting horn and go no echo back; at double the altitude (1,200 m) "the echoes came back after a protracted interval with far greater clearness." When, 25 minutes later, the balloon had dropped to 60 m the echoes had faded somewhat and then again when the balloon rose to 600 m the echoes had vanished entirely. "Though I might challenge the earth again and again it would vouchsafe no answer."

While no direct evidence supports the use of echolocation by nocturnal migrants, a comparable artificial device was perfected about 40 years ago as a sonic altimeter for aircraft (Delsasso, 1931; Florisson, 1932; Rice, 1936). The apparatus Rice developed consisted of a powerful whistle that emitted short blasts at about 3000 Hz with an emitted sound level of roughly 135 dB above the standard reference level of 0.0002 dyne/cm$^2$. (People living close to airports should be duly grateful that radio guidance devices rendered sonic altimeters obsolete long before air traffic increased to its present level!) Despite the noise of 225- and 450-horsepower airplanes, ground echoes could be heard up to about 800 feet (240 m) with full engine power, and to about 1500 feet (460 m) in a glide with the engine idling. Furthermore Rice reports that an experienced pilot could still discern the echo down to altitudes of a few feet, so that "blind" landings were considered possible. Of course no bird emits nearly so loud a sound, but birds would have the considerable advantage of being able to listen for echoes without the masking of noise from an airplane engine.

## Sounds as Possible Directional Cues

Granting that migrating birds can hear various sounds from the surface, it remains an open question whether this would assist them in any way to maintain their orientation. The simplest cases would be sounds associated with some type of topographical feature that extends far enough to provide directional guidance. The sounds of breaking waves along a coastline may well be loud enough to be recognized at considerable altitudes. Rivers are probably less clearly and characteristically audible, but sounds from amphibians or artificial sounds may be characteristic of major streams.

A more difficult but nevertheless intriguing question is whether the directional distribution of sounds from the surface of the earth could convey any helpful information to birds. Consider for example the sound from breaking waves in the open ocean or large lakes, as contrasted to breakers at the shore. Is the acoustic spectrum of a breaking wave different when heard from various directions relative to the wave movement? No answers to this question are to be found in the early balloonists' literature, and a direct study of the matter might be of interest. The same question might be asked about the sound of wind in vegetation; do leaves of trees moved by the wind generate sounds that differ in quality when heard from different directions relative to the wind direction? A breaking wave or gust may be heard as a discrete sound source. There is every reason to believe that birds have good capability for directional localization of sound sources (Schwartzkopff, 1968; Konishi, 1969). Under conditions where discrete sounds reach birds from different sources on the surface a crude form of orientation may be possible even when all else fails. Just as birds might orient visually by heading first for one and then another visible landmark, so conceivably they might orient toward successive sound sources, first a certain town, then the chorus of amphibians from a given swamp, next the sound of a particular running stream, and so forth. One could hardly expect this type of orientation to be as accurate as sun- or star-compass orientation, but under conditions of restricted visibility it might suffice to prevent serious disorientation.

Many migrants clearly seem to maintain accurate orientation over the ocean, far from land, at night and under widespread overcast (Drury and

Nisbet, 1964). Under these circumstances the sounds of breaking waves might be helpful in orientation even though they do not provide the simple equivalent of a compass. For example wind direction is a possible guiding cue, but under conditions of limited visibility it is dfficult for a flying bird or airplane pilot to determine wind drift. Could sounds reaching birds from the ocean surface provide enough indication of wind drift to allow orientation on this basis? Two possibilities, among others, deserve consideration and possibly direct investigation in the future. One assumes that bird flight speeds are sufficiently greater than the speeds of wave movement that a breaking wave could be considered a stationary source of sound. In this case the bird might note how its progress toward or away from the source compared to its heading. If, for example, it was heading directly toward a given sound source but found itself drifting to one side, this would provide information concerning the existence of a crosswind. Such use of sounds to judge wind drift would also provide information about the wind direction itself. Many small birds fly downwind surprisingly often (Gauthreaux, 1971). Perhaps when they cannot see the surface of the earth they adjust their headings to maximize their rate of passing over whatever sound sources may be audible.

A second theoretical possibility would be for birds to note the direction in which the noise generating event itself moves. Granting that the net motion of a water particle is zero, the upper, noise-generating portion of a breaking wave does move in the direction of the wave itself, with the return motion of the water occurring below the surface. If this motion could be detected by a bird flying above the wave, it would convey some information about the direction of wave movement. Gusts of wind moving vegetation could also reveal wind direction in the same manner.

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## Summary

The 19th century balloonists often noted that commonly occurring sounds are audible, at least under some conditions, up to altitudes of 3,000 m or more. The cackling of geese, the singing of frogs and insects, the sound of wind blowing through woods, and the barking of dogs were commonly heard up to roughly 1,000 m. Musical instruments, bells, guns, and trains were heard to considerably higher altitudes. A diffuse hum or roar characterized large cities such as Paris or London. Breaking waves and the sounds of running streams were frequently noted. Thus

migrating birds may well be able to hear characteristic sounds from the ground or water beneath them.

A bird might be able to detect and correct for its wind drift, even without visual cues from the surface of the earth, by localizing sound sources and comparing its actual progress with its heading. Downwind flight, for instance, could be achieved by turning so that each successive sound source first heard straight ahead remains in the saggital plane as the bird passes rapidly over it. Even when flying in or between layers of cloud birds could in this way determine wind direction.

Early balloonists studied ground echoes of shouts and other loud sounds generated in the balloon, and they sometimes noted much louder and clearer echoes from lakes or streams than from fields or woods. A sonic altimeter was later developed for use from airplanes. This suggests the possibility that nocturnal migrants could employ a crude form of echolocation, provided that their flight calls are loud enough to generate audible echoes from the surface.

An important question, concerning which virtually no data are yet available, is the degree to which sounds originating at the surface (or echoes from the surface) differ in acoustic spectrum depending upon the direction from which they are heard. If breaking waves or other sounds generated by the wind sound different according to their direction, this could theoretically provide directional information to a migrating bird.

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