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Soaring strategy investigation of cinereous vulture (*Aegypius monachus*) by sailplane

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ABSTRACT

Soaring has great importance to large and heavy terrestrial birds because they can gain altitude without using power in this way. The cinereous vultures were near threatened species in the world, so it was hard to observe them while circling in thermals or slope soaring. Although there were enough works on conservation and breeding biology of those birds, there was not any study on the soaring technique. In this work, cinereous vulture observed and tracked in thermal columns using a glider to figure out whether the turn performance of the cinereous vulture matched well with other vulture species. Finding the pros and cons of tracking and observation of the cinereous vulture's turn performance in a thermal by a glider was another objective of the study. The results indicated that the cinereous vulture can complete the thermal circling with a narrower radius which provides advantages to stay in the strongest part of the thermal.

Keywords: *Aegypius monachus*, Avian flight, Cinereous vulture, Flight behaviour, Thermal soaring

Thermals came about by the heat differences between the land and air. These differences then create the rising air columns which are extremely important for birds and gliders because both use these warm air streams to fly into the air in a cheaper way (Reddy 2016). There were two main objectives in this study. The first one was figuring out whether the thermal performance of the cinereous vulture matched well with other vulture species and comparing its thermal performance to the other birds observed in the literature. The second objective was understanding whether tracking and observation of the cinereous vulture's turn performance in a thermal with glider were convenient and figuring out the pros and cons of this approach. There was a study that involved observing vulture from motorglider (Pennycuick 1971). That work explained vulture's better performance in thermal even though it performed a low glide performance compared to motorglider. Differences between the soaring techniques of human-made aerial vehicles and birds were also studied (Akos *et al.* 2008). Flight performance equations of turning radius in thermal were created from experimental studies (Gillies 2011). In that work, the different soaring techniques for peregrine falcon, stork, paraglider, and hang glider were discussed and also the turning performances were calculated and compared. The soaring ability and flight performance of vultures also attracted researchers' attention owing to long-broad wings which were excellent for soaring. On the other hand, there was enough work on conversation biology of cinereous vultures in Turkey (Yamaç and Bilgin 2012). Energy consumption of the soaring for raptors was discussed according to a heart rate of vultures (Duriez *et al*. 2014). Thermals directly linked to daily weather condition, so thermal energies at different periods in a day determines the birds' flight time, also these conditions varied seasonally especially important for immigrants (Van Loon 2011, Duerr *et al*. 2015). Wind effect on the soaring flight as well as gliding speed and performance are of great importance. The effects of wind can be measured from the soaring data of birds because the birds generally follow the thermal's movements until the top (Weinzierl *et al*. 2016). No bird can use a single thermal until the end of the day; therefore, it must change thermals and fly next one. For this reason, they must optimize their speed to provide a lower sink rate until the next one (Taylor 2016, Singh *et al*. 2018). Decision making also plays an important role to select take-off time for soaring (Harel *et al*. 2016). Wing size also affects the soaring performance by creating contact area with thermal and lower wing loading always provides a lower turning radius and stall speed (Grilli 2017). In addition, the cinereous vultures were near-threatened bird species and it was a great chance to identify them near an airfield (BirdLife International 2017). Furthermore, the soaring ability can be changed with the bank angle (Williams 2018). However, the vultures' broad wings (that have a low AR) increase the induced drag. So, the vultures solved that problem by creating natural winglets with their thumb feathers at wingtips. The effect of these structures and the drag were measured by experimental data from the

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wind tunnel, soaring performance was also observed (Pennycuick 1983, Williams 2018). Humans tried to develop new skills to use thermals better by understanding the soaring flight of birds. However, birds use these upstream air movements more complex. Sometimes, they make S turns in thermals or passes thermals without any manoeuvre with level flight. Some birds fly with a flock like storks generally turn different directions. However, raptors generally turn into a fixed direction like glider pilots. For these reasons, comparison of different bird species or human strategies and connection of flight performance to soaring strategy are important. However, there hasn't been any study on cinereous vulture's soaring technique. In this study, theoretical calculations were proved by tracking and observation with camera records and GPS data of glider. Also, the results compared with other soaring birds studied in the literature.

MATERIALS AND METHODS

It was the first time, a biologist, as a trained pilot, flew in a glider to observe and track the soaring behavior of cinereous vulture in Turkey. The observations described in this paper were based on a three hours flight using an SZD-50 Puchacz glider which has camera on the left wing and could turn in thermals at lower speeds. Altitude in the airfield was 2,765 feet at sea level. Despite the low temperature, the flight path of the glider and cinereous vulture was covered by altocumulus clouds which created temporary thermals. The first flight took 2 hours and the second one lasted for an hour. Flying altitudes were minimum 300 m and maximum 600 m AGL after released from the cable of the winch. Weather conditions were ideal for slope soaring due to a strong wind from the north. In addition, other observations made on top of the hill which was located near the nest of a cinereous vulture and circling movement is recorded by video camera. From these recordings, circling time is calculated correctly. Moreover, the weight of the vulture and wing area were measured in order to find wing loading which is the key point of the turning performance. Calculating the thermal turning radius (r) of cinereous vulture was extremely important for this study. There are many different variants in thermals. The first one was the wing loading (W/S) which was the ratio of body weight to wing area. Wing loading determines the airspeed of the bird during the non-flapping flight. Another important factor on turning radius was the bank angle (θ). Thermals have different power in different areas. Some areas would be more powerful or less and therefore, it was important for the soaring birds to stay in powerful areas. If the bird can turn sharper (low turning radius), it would stay in powerful areas easily. However, that sharp turn decreases the contact area between the bird and thermal hence an optimum bank angle must be kept. Although other factors were important too, the air density was limited by environment and the lift coefficient (C_L) were limited by bird and glider's aerodynamics.

The turn radius of a flyer can be calculated in two ways. In Eq. 1, it was calculated with the aid of wing loading and bank angle. In Eq. 2 the turn radius calculated with the aid of velocity (V) and load factor (n).

$$r=\frac{2W}{CLpgS\sin\theta} \quad \text{... (1)}$$

$$r=\frac{V^2}{g\sqrt{n^2-1}} \quad \text{... (2)}$$

The load factor (n) was the ratio of the lift of the flyer to its weight.

$$n=\frac{L}{W}=\frac{1}{\cos\theta} \quad \text{... (3)}$$

Rewriting the Eq. (2) by leaving the load factor alone we get a load factor(n_{check}) for checking the load factor found from Eq. (3).

$$n_{check}=\sqrt{\left(\frac{V^4}{g^2r^2}+1\right)} \quad \text{... (4)}$$

In literature, the airspeed of vulture in thermal was expected at about 13 m/s. It was compatible with velocity estimation comes from bird size in Eq. 5. which was derived by Alerstam *et al.* (2007).

$$V=4.3\left(\frac{W}{S}\right)^{0.31} \quad \text{... (5)}$$

Still, there were two unknown parameters lift coefficient and bank angle (C_L and) for vulture so, by validating the loading factor (n) value from Eq. (3) and Eq. (4), the bank angle θ took an average value (25–35) for the vultures studied before (William *et al*. 2018). The lift coefficient validated from the bank angle and load factor relations, i.e. Eq. (3) and Eq. (4). Therefore, the lift coefficients can be estimated when the n values overlapped. Interestingly, the lift coefficients calculated experimentally were about 0.5–0.75 times of the theoretical lift coefficients presented in the literature.

RESULTS AND DISCUSSION

The first eye contact with the cinereous vulture was at 400 metres while it was circling in thermal. Then, approaching the bird from behind at about the same height as the glider was possible. Later, the bird and the glider were able to turn in the same thermal until the 500 metres. As soon as it passed 500 metres, the bird left the thermal and flew directly to the west side of the airfield for seeking prey. During the thermal circling, we had to use a spoiler that functioned as an airbrake to descend to the bird's level. Later, the vulture came back to slope soaring path to gain altitude. The flight with the vulture lasted for 1:30 h until it landed on its nest. During the flight, it wasn't easy to fly at the same altitude as the vulture due to differences between the birds' and the glider's turning performance. This difference can be seen in Fig. 1.

Fig. 1. Contact with the cinereous vulture and sharing thermal. Turning direction of the vulture was counter-clockwise. We entered the thermal by right turning then changed it to counter clockwise to follow the vulture.

As it was expected, the vulture used lower bank angles during seeking phase for the thermal. When it felt it was in the centre of the thermal, the vulture increased the bank angle to stay in the centre of the thermal column. The wind was the main effect that determined the shape of the turning radius. The prevailing wind came from the north, so when the bird-headed into the north it levelled its wings to reduce drag which pushed it back and covers distance before turning again. When the bird-headed into the south, it increased bank angle and started a steep turn. In that way, it avoided the wind effect on circling in the thermal. In the sink rate and turn radius graph were given for different bank angles.

It can be clearly seen that the cinereous vulture used different techniques between soaring flights and cross-country flights. It spread its wings while soaring to increase wing area. Wider wing area means lower sink speed and more effective area for rising air. On the other hand, thumb feathers were opened to reduce drag like a winglet and alula was used as a slot. Both properties were used for more performance at a lower speed which was of great importance for narrow circling. It also uses its variable wings in closed form when

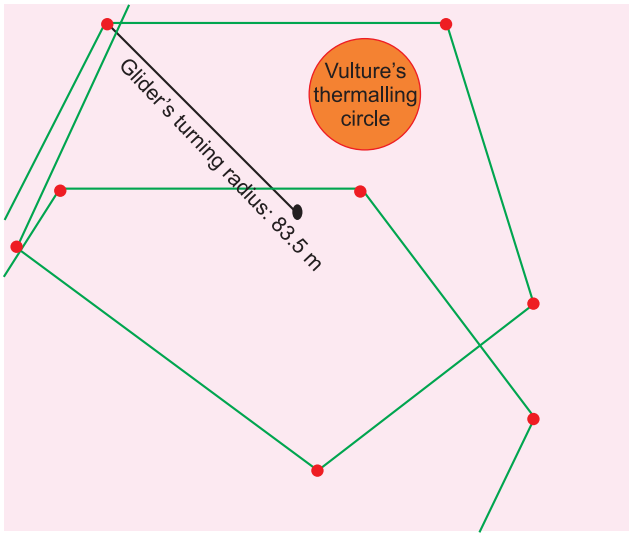

Fig. 2. Garmin flight data recorder could record the altitude, vertical acceleration, speed, and global position of the glider. All data were examined in TaskNAV, which is an Analysis System for Glider Pilots.

Table 1. Turning performance data of the sailplane and the cinereous vulture

Parameter	Sailplane	Cinereous vulture
Wing loading, W/S (N/m^2)	285.00	65.00
Lift coefficient, C_L	0.95	0.75
Turn Angle, θ (degree)	37.00	30.00
Turn Radius, r (m)	83.50	30.00
Velocity, V (m/s)	25.00	13.00
n from Eq. (3)	1.25	1.15
n_{check} from Eq. (4)	1.25	1.15

flying long distances to gain more speed during the cross-country flight. In the thermal, the vulture can circle narrower than glider during centring in the thermal thus avoiding a weaker lift area in the thermal. Moreover, the predicted higher bank angle decreases thermal performance by decreasing contact area with thermal. This fact illustrated in Fig. 2.

Turning performance comparison for the bird and the sailplane was given in Table 1. The table gave us an idea about understanding the observability of cinereous vulture with a glider. There was a gap between the circling velocities, it meant that the stalling velocity of glider limited the pursuit. Despite vulture completed one tour in 14 seconds at a lower speed, the glider completed one tour in 21 seconds. Also, the vulture's wing loading provided for a narrower circling radius in the centre of the thermal. Cinereous vulture had a low turning radius which brought the turn sharper and staying easily in powerful areas of the thermal column.

According to Akos *et al*. turning radius of the stork was 23 metres and falcon's radius was 22 metres. So, the 30 metres radius of cinereous vulture significantly higher with 30 degrees bank angle. Besides, turning radius of a Himalayan griffon vulture (*Gyps himalayensis*) and griffon vulture (*Gyps fulvus*) almost the same size and determined as 32 metres by Williams *et al*. The result of the study and the comparison with other studies can be seen in Fig. 3. These differences probably come from the difference in birds' size. The wingspan and wing area of the stork and falcon are lower than cinereous vulture but their weight is

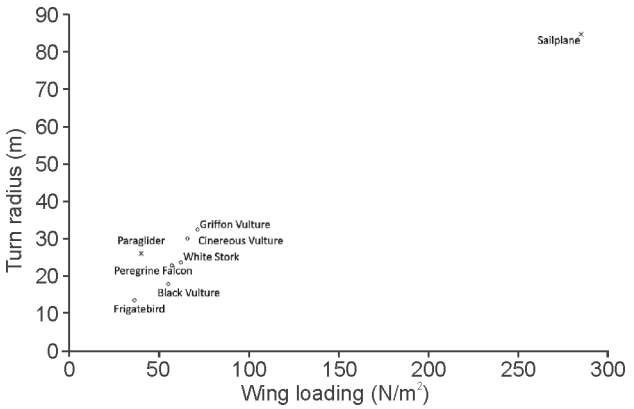

Fig. 3. The turn radius vs wing loading of sailplane, paraglider and soaring birds.

also lower which provides a lower wing loading and has a great effect on turning radius. The slight differences between a cinereous vulture and other vultures can be explained by slight differences in body masses and wing shapes.

These birds need strong thermals due to its high wing loading. For this reason, most of the individuals can be observed in the centre-west of Anatolia where is arid and has strong thermals. Of course, there is a possibility to see them out of Anatolia because cinereous vultures can use slope soaring effectively. However, existing records showed that the cinereous vultures were seen in the west of Anatolia, especially in breeding season during foraging.

Vultures can adjust their speed and bank angle to minimize their sink rates by protecting a position close to the thermal column core. Observing vulture from glider may be inconvenient due to the high performance of glider. During the thermal circling, while we completed one tour, it almost completed 1.5 tours and it used a stronger area of thermal. Therefore, it was impossible to keep the same level as the vulture. On the other hand, the speed of vulture lower than that of the glider and we couldn't observe it properly in slope soaring path. In addition, glider's sink speed was also low too and the flight would be more dangerous because of that speed extremely close to stall speed of glider especially during the rolling. Hence, using a paraglider or a hang glider would be more efficient when inside and outside the thermal as their parameters are much closer to that of the vulture. Due to data limitation in using telemetry GPS which includes an accelerometer, variometer, and altimeter, it's better to fly by manned or unmanned aircrafts for observing soaring behaviour of these birds.

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