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Effects of wing loading on take-off and turning performance which is a decisive factor in the selection of resting location of the Great Bustard (*Otis tarda*)

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Abstract

Great Bustard is one of the heaviest birds in the Western Palearctic, so aerodynamic effects are critically important for their distribution and conversation. To understand why do they need to find open areas during the resting and feeding time, aerodynamic features were discussed in this study. Mass of the Great Bustard and having proportionally small wings cause weak flight performance. In this work, those disadvantages were identified by aerodynamic approach and observation. Great Bustard tries to use the relative wind during the take-off to close these disadvantages. Also, turning performance which is affected by the same specifications with take-off performance can determine their behavior. As a result, aerodynamic factors may also play important role in their current status.

Key words: otis tarda, great bustard, conservation, bird flight, bird flight performance, Turkey

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Toy kuşunun (Otis tarda) dinlenme alanı seçiminde etkili olan kalkış ve dönüş performansına kanat yüklemesinin etkis

Özet

Batı Palearktik bölgede ki en ağır kuşlardan biri olan Toy kuşları için aerodinamik etkiler dağılımlarında ve korunmalarında oldukça önemlidir. Bu çalışmada, dinlenme ve beslenme zamanlarında neden açık alanları seçtikleri aerodinamik özellikleri bakımından tartışılmıştır. Ağırlığına göre küçük kanatlara sahip olan Toy kuşları çok daha zayıf bir uçuş performansına sahiptirler. Bu çalışmada bu dezavantajlar aerodinamik yaklaşım ve gözlemlerle açıklanmıştır. Bu dezavantajları kapatmak için Toy kuşları kalkış esnasında bağıl rüzgârları kullanmışlardır. Ayrıca kalkış performansına etki eden aynı aerodinamik özellikler kuşun davranışına etki eden dönüş performansını da etkilemektedir. Sonuç olarak türün duyarlı statüde olmasındaki en önemli etkenlerden biride aerodinamik özellikleridir.

Anahtar kelimeler: otis tarda, toy kuşu, koruma biyolojisi, kuş uçuşu, kuşların uçuş performansı, Türkiye

1. Introduction

Due to high wing loading, which means body weight divide to wing area is extremely important for flight performance that can determine flight style and behavior, Great Bustard prefers open areas and hills to take-off easily and also observe the environment. Therefore, they cannot land and take-off on a tree branch, electric pole or other narrow areas. Their long take-off distance carries many disadvantages. For example, the predators, especially foxes can find time to catch the Great Bustards during the take-off roll. Its effects are on much different flight performance. Wings beat frequency also has been attracting the researchers' attention for a long time [1,2,3]. Take-off performance is extremely important for avian flight but there is a limited number of works on that flight phase [1,2,4,5,6,7,8]. In gliding flight, wing loading determines glide speed. For high aspect ratio wings, gliding is the most effective for cheaper flights [9, 10].

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The broad wings and relatively short wingspan avoid the Great Bustard from gliding due to high induced drag. Their wing is similar to a vulture or an eagle wing morphologically. Nevertheless, these birds' wing loading is lower and they take advantage of it. Vultures and eagles are usually observed while using thermals since their lower wing loading provides lower stall speed and narrow turning radius in the thermal [11, 12]. However, Great Bustard's higher wing loading causes higher stall speed and a wide turning radius that keep them away from the well thermal performance. Therefore, they have to flap their wings for extra thrust force in order to gain speed for enough lift force [13, 14, 15]. Moreover, these reasons cause extended take-off distance because they need more lift force to overcome their weights. To ensure that force, take-off roll must be longer. Besides, the Great Bustard usually prefers sand, grass, plowed fields or steep lands hence the acceleration to static state in these areas can be more difficult. On the other hand, the relative wind may help to reduce take-off distance if the bird runs into a headwind [16]. Thus, they cannot prevent potential dangers like hitting power lines [17].

2. Materials and methods

The study area is located in the Sivrihisar, Eskişehir, Turkey. Our observations lasted for 2 months. Although, 25 individuals were identified in 2 lek areas, only 10 different take-off footprints were determined and measured. These take-offs were monitored by Canon 7D camera and 500 mm lenses before measuring take-off roll. To ensure true results, almost the same size birds were designated and others were eliminated from videos and photos. To measured wind speed and direction, anemometer and windsock were used while taking-off. Effect of the crosswind eliminated until the full crosswind. Take-off distance was measured from heel to heel of birds' footprint by tape measure.

Thrust (T) can be used for acceleration and there is a counter force called drag (D), however; we have to make an allowance for the average aerodynamic resistance during the take-off run. Therefore, we estimate the net thrust to be 20 percent of the take-off weight. An avian need a minimum velocity to take-off and need acceleration to reach that velocity. Net thrust is needed for acceleration [16].

$$F_{\text{net}}\text{=T-D=0.2W} \quad (1)$$

Well known W (Weight) is the mass times the acceleration of gravity.

$$\text{W = mg} \quad (2)$$

Kinetic energy is proportional to the mass and to the square of its velocity.

$$E_k = \frac{1}{2}mV^2 = \frac{1}{2}\left(\frac{W}{g}\right)V^2 \quad (3)$$

The energy supplied equals to the supplied work (W=F.L) so the net force (F_net) times the takeoff length (Ltakeoff). Multiplying the Eq. 1. With L and make the equality of the supplied energy and work.

$$\frac{1}{2}\left(\frac{W}{g}\right)V^2 = 0.2WL \quad (4)$$

So simply a minimum velocity needed for take-off is related with acceleration of gravity and the takeoff length (L_{takeoff})

$$V^2{}_{\text{takeoff}} = 0.4gL_{\text{takeoff}} \quad (5)$$

Another important effect on the conversation of the Great Bustard is turning radius. The turn radius can be calculated in two ways. In Eq. 6, it was calculated with the aid of wing loading and bank angle. In Eq. 7 the turn radius was calculated with aid of velocity (V) and loading factor (n).

$$r = \frac{2W}{C_L * \rho * g * S * sin\theta} \quad (6)$$

$$r = \frac{V^2}{g\sqrt{n^2-1}} \quad (7)$$

Rewriting the Eq. (7) by leaving the loading factor (n) alone, we get the Eq. 8.

$$n = \sqrt{(\frac{v^4}{g^2r^2} + 1)} \quad (8)$$

Yet another way to find the loading factor is given in. Eq. (9) and in such formula the n is related only with the bank angle (θ). Therefore, it is entitled as n_check.

$$n_{check} = \frac{L}{W} = \frac{1}{cos\theta} \quad (9)$$

However, the key point of these formulas is velocity. In our work, the estimation method comes from bird size was used [18]. Later, to prove our findings, laser speed measurement binocular was used. In literature, the airspeed of Great Bustard is expected about 17 m/s it was compatible with velocity estimation comes from bird size in Eq. 3. which was derived by Alerstam et al. [18].

$$V = 4{,}3.\left(\frac{W}{S}\right)^{0{,}31} \qquad (10)$$

Still, there were two unknown parameters (Lift coefficient (CL) and θ) for Great Bustard so, by validating the loading factor (n) value from Eq. (8) and Eq. (9). The bank angle (θ) was taken an average value (30). The lift coefficient is validated from bank angle and load factor relations i.e.Eq. (9) and Eq. (10). The lift coefficients estimated when the n values overlapped.
To find angular velocity of bird,

$$\Omega = \frac{V}{R} = g.\frac{tan\theta}{V} \quad (11)$$

3. Results

For our study area, an average 3 m/s fast wind is a significant factor. In contrast, it was seen that the bird did not try to turn into a headwind in a dangerous situation during the quick take-off. Other factors affecting take-off performance are the air density and temperature. Altitude which affects to air pressure in the study area ranges from 700 m to 800 m at the sea level and the average temperature was 20 °C which are improper conditions for better flight performance. For all of these reasons, they choose to open areas for easy take-off also they can watch the hazards easily in these places. Higher wing loading also affects the turning radius. In risky situations, the birds must change their flight direction rapidly. However, it's hard for birds which have high wing loading that provides higher flight speed.

According to our observations, the shortest take-off run is 1.57m and the longest is 5 m. Of course, it's impossible to determine the same size birds which are important for take-off performance from photos and videos.

Table 1. Total number of investigated foot prints. Relative wind speed shows the total take-off speed of Great Bustard. Short distance take-offs are supported by strong wind

A number of investigated footprints.	Takeoff Roll (m)	V_{Wind} (m/s)	$V_{Bustard}$ (m/s)	Relative wind (m/s)
1	1,57	+3	2,48	5,48
2	3,77	+1,92	3,84	5,76
3	1,94	+2,1	2,75	4,85
4	4,00	+1,5	3,96	5,46
5	4,22	+1,8	4,06	5,86
6	2,78	+2,42	3,3	5,72
7	3,21	+2	3,54	5,54
8	5,00	-1,3	4,42	3,12
9	3,20	+1,1	3,54	4,64
10	4,80	-1	4,33	3,33

Nevertheless, If the wind was eliminated, an average take-off roll would increase from 3m to 4.73m (except 8 and 10 because they took off with a tailwind). To calculate the bird's speed from equation 8, these parameters were assessed (Table 2).

Table 2: An average Aerodynamic features and performance of the Great Bustard.

Parameters	
Aspect Ratio (AR)	6.6
Wingspan (b)	220 cm
Wing Area (S)	0,73 m^2
Weight (W)	11 kg (107.91 N)
Wing Loading, W/S (N/m^2)	147.8 N/m^2
Lift Coefficient, C_L	0.99
Turn Angle θ (Degree)	30
Turn Radius (r)	50 m
Estimated Velocity (Vest)	20 m/s
Measured Velocity (V)	17 m/s
n from Eq. (8)	1.15
n_{check} by Eq. (9)	1.15

To find out turning radius, bank angle of the birds was determined from photos and videos. As a result, 30° was selected as an optimum bank angle.

Figure 1. An optimum bank angle of the Great Bustard. Sharper bank angles cause higher sink rate so that energy consumption increases to keep level flight.

In addition, Great Bustard usually takes-off into the wind as it can be seen at table 1 except dangerous situations. In contrast, tailwind generally adversely affects take-off distances and it also affects individuals in this study. However, more frequently flapping style reduces the tailwind effects and decay proportion between the headwind and tailwind.

Another effect of wing loading is the turning radius. They need 100 m to change their direction 180° which means length of the football pitch. If we compared with the almost the same weight birds, Cinereous Vulture's turning radius would be 30m with 30° bank angle. Also, almost the same wing area of Golden Eagle's turning radius would be 32 m. For these reason, higher turning radius causes lower soaring ability. So, it's impossible to use thermals for these birds Moreover, we know that their bank angle is sharper. Besides, low angular velocity doesn't provide high manoeuvrability. For this reason, they can't change their flight direction quickly so they hit power lines suddenly or can't addle the predators and hunters..

4. Conclusions and discussion

That results also may explain why Great Bustard population is lower in Turkey [19] than Europe because their ability to fly is already limited with these aerodynamic specification, higher altitude of mainland of the Turkey [20] make this flight ability lower with lower air density. Moreover, most of the population is seen in center of Anatolia and east of Turkey. Cultivated lands of these regions long and wide which provide longer and enough take-off area. As can be seen in results, most of the taking-offs made into headwind to ensure shorter take-off distances. Therefore, their habitat distribution is limited in Turkey. Besides, we often interacted with these birds in the morning when the weather was cold which also means higher air density that increases flight performance.

9 kg of Cinerous Vulture can take-off from tree and other small places without take-off roll. Although mass of the vulture near Great Bustard, Great Bustards' wing area significantly lower than the vultures. These differences in wing loading decrease flight performance and increase energy consumption. For these reasons, permanent hunts are effective on these birds because they cannot astonish hunters with quick turns, so they are easy target for hunters to follow them. Due to high energy consumption they become tired later. Hence, they would be easy target for permanent hunters.

According to Akos et al. [21] turning radius of stork is 20 m. If we look at eating habits of that birds, their food selection looks the same. However, with 20 m of turning radius stork can use thermals and reach other regions easily while the flying long distance is hard for Great Bustard. For this reason, threaten level between stork and Great Bustard may come from that aerodynamic differences.

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The effect of high wing loading is the Great Bustard must flap their wings continuously which needs more energy. In that case, they fly short distances at low altitude that means they take advantages of ground effect which provides low energy consumption at low altitudes. Of course, the bigger size of that bird is measured and also known. In our work, 11 kg male was studied. However, they can reach up to 15 kg. For that size, the effects of wing loading are felted much more might be fatal.

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