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# LEG THRUST IMPORTANT IN FLIGHT TAKE-OFF IN THE PIGEON

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SUMMARY

Measurements of the force generated by the legs of rock doves *Columba livia* during vertical and near-vertical take-off showed that the birds were able to develop an upward directed force of from 1·3 to 2·3 times their body weight. This force resulted in an instantaneous acceleration of 15·63 m $s^{-2}$ at maximum thrust. Motion pictures taken during the take-off showed that as the birds' feet left the experimental perch, their wings were in the overhead clap position. We suggest that the vertical take-off in birds is accomplished in three stages; leg thrust, clap-and-fling and steady-state flight.

## INTRODUCTION

Level, flapping flight in birds can be generally explained in terms of classical, steady-state lift generation mechanisms (Prandtl, 1952). Pennycuick (1975) developed a theoretical aerodynamic model for the power requirements of level flight based in part on the experimental results obtained by Tucker (1973). Hovering flight presents problems not easily explained by steady-state aerodynamics (Norbert, 1975). Birds which take off vertically, like some pigeons, shorebirds and ducks, must somehow generate even more lift than that required for hovering flight.

In a vertical take-off in still air, the only way a winged craft can produce a relative wind over its airfoils is by moving its wings. This method of lift generation is inherently less energy-efficient than accelerating a fixed-wing craft or animal along a horizontal surface until it rises to the desired altitude. A bird has the capacity to move its wings, but is less efficient than a helicopter, because the wings must move in reciprocating, rather than rotary fashion.

Weis-Fogh (1973) proposed an alternative method of lift generation that might be used by hovering insects or small birds flying at airspeeds too low to sustain themselves in the air by conventional means. His proposed mechanism, called 'clap-and-fling' requires that the animal slap its wings together over its back and then bring them smartly down, after having first separated them at the leading edges.

Key words: Bird flight, aerodynamics, take-off.

Nachtigall & Rothe (1982) filmed pigeons flying in a wind tunnel in horizontal flight, and observed that the birds' wings did move in a way consonant with the 'clap-and-fling' hypothesis. Simpson (1983) filmed pigeons taking off vertically, and also observed an apparent 'clap-and-fling' wing movement.

Even if a pigeon were to use 'clap-and-fling' to gain additional lift during the energetically demanding vertical take-off, it would be advantageous to propel itself off the ground or perch by means of a strong leg thrust. A jump would increase the circulation of air over the wings, provide additional lift at the low air speeds encountered just after leaving the ground, and provide ground clearance for the wings.

We report here measurements of the strength of the force provided by the legs of the common pigeon in vertical and near-vertical take-offs.

## METHODS

Four pigeons were maintained indoors in individual cages for a week before the experiment in the spring of 1983. Their body masses ranged from 0·240 to 0·400 kg ($\bar{X} = 0{\cdot}309 \pm 0{\cdot}055$ s.d.).

The thrust-measuring apparatus was constructed using two Grass FTO3C force-displacement transducers mounted at right angles to each other in a rigid 18 mm thick aluminium frame. The self-resonance frequency of the transducers was 330 Hz. A 1-cm diameter wooden perch was mounted to the horizontal transducer in such a way that the perch was free to move both up-and-down and back-and-forth. A bird sitting on the perch would compress the horizontal transducer in proportion to its weight. If the bird took off vertically, the transducer would be compressed further by an amount corresponding to the leg thrust. If the bird took off at an angle, the resultant vector force would be resolved by the vertical and horizontal transducers.

The transducers were connected to a Grass H25-60 polygraph. The polygraph record moved horizontally over the bed of the machine, and a mirror was mounted at a 45° angle over the chart paper, so that the movement of the pens could be recorded in the field of a 16 mm ciné camera, operated at 32 frames $s^{-1}$, which was set up to film the birds as they took off.

During an experimental trial, a bird's wings and body were securely held until both feet secured a firm purchase on the perch, then it was released. The response of the birds varied. Only trials in which the bird took off deliberately, having initially gained balance were included in the analysis.

After a trial, the bird was captured, then allowed to rest for 15 min before the next trial. Transducers were calibrated with static weights before and after each run.

## RESULTS

Sixteen trials yielded usable results, usable being defined as 'bird in balance, both feet on the perch before take-off'. Of these, eight represented vertical departures. Fig. 1 shows a representative force curve for a vertical take-off. When the bird

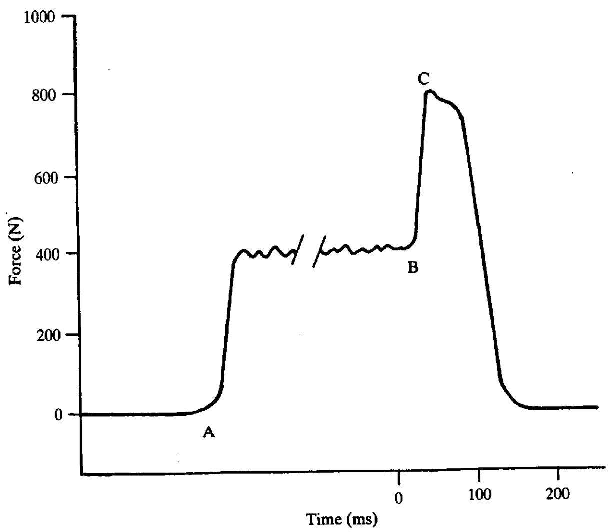


Fig. 1. Representative force curve for take-off. A is where the bird is placed on the perch, B is the start of take-off, and C is the start of the plateau phase.

begins its take-off, there is an immediate downward force on the perch. As the force reaches its maximum, there is a plateau in the curve. Each of the vertical take-off trials showed this plateau, but we were not able to identify a characteristic behaviour associated with the plateau from the film.

After the plateau phase, there is a rapid decrease in the force on the perch as the bird departs. The initial phase lasted 33·7 ± 13·0 ms s.d., the plateau 50·0 ± 14·1 ms s.d. and the decreasing phase 32·5 ± 12·8 ms s.d. The entire take-off manœuvre lasted 116·2 ± 25·0 ms s.d.

The downward force on the perch in vertical take-offs ranged from 3·92 to 5·88 N ($\bar{X}$ = 4·83 ± 0·93 s.d.). Expressed as a multiple of body weight, the birds demonstrated a downward force of 1·65 ± 0·41 s.d. times their own weight.

Downward force on the perch provides a reactive upward acceleration. Using the mean weight and downward forces in the vertical trials, the upward acceleration at the time of maximum downward force is 15·63 m $s^{-2}$. This acceleration would propel the bird to a height of approximately 3 cm above the perch.

Examination of the film frames showed that the birds' wings were clapped together within ±0·03 s of the time when the feet left the perch, and that at the completion of the first downward stroke, the wing tips were no closer than 3 cm to the level of the perch.

## DISCUSSION

The values reported here for leg thrust should be interpreted as minimum values. If the wings are contributing lift, either by 'clap-and-fling' or steady-state aerodynamics, the recorded values would tend to be lower. Thus, the legs alone can provide an acceleration in excess of $1\,g_n$, and in some cases, slightly over $2\,g_n$.

These strong leg forces may be relevant to a consideration of the hypothesis that bird flight originated by saltation (Caple, Balda & Willis, 1983) rather than gliding.

We suggest that the vertical take-off in birds like the pigeon is accomplished in three stages. In the first, the bird moves its wings upward toward the 'clap' position, while contracting the appropriate leg muscles for the push off ground or perch. Some of our films suggested a slight squat before upward movement, but this was not seen in all the trials. During the leg push, it is probable that there is little, if any aerodynamic lift from the wings.

At the moment when the feet leave the ground, the wings are in the 'clap' position, ready to start generating lift. The upward movement of the bird provided by the legs would increase the airflow over the lifting surfaces, permitting 'clap-and-fling' to generate enough lift for positive vertical flight. The additional height provided by the jump allows the wings to make a complete stroke without touching ground.

After the bird is well clear of the ground, it can shift toward level flight and the steady-state aerodynamics mode, which would be more economical from an energetic standpoint.

One might expect that the legs of birds which regularly practice vertical take-offs would have more muscular development than closely related forms which do not practice vertical flight, and it would be interesting to test whether or not a vertical take-off is possible if the bird were temporarily denied the use of its legs.

We thank Tom Chrostek for obtaining the birds and assisting during trials.

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