The flying ability of *Quetzalcoatlus northropi* in a reduced gravity

The envisaged flying ability of the gigantic *Quetzalcoatlus northropi* pterosaur has produced ongoing debate since its first discovery, mainly because aeronautical calculations show it is too large to produce continuous powered flight in our gravity. This problem has encouraged a number of authors to suggest that continuous powered flight might be possible in a reduced gravity. This study quantifies the flying ability of a *Quetzalcoatlus northropi* in a reduced gravity of 0.62g (6.08 m/s^2). The results show that *Quetzalcoatlus northropi* was capable of producing continuous powered flight in this reduced gravity, allowing its flying ability to be comparable with the largest flying animals of today.

THE PROBLEM

In the early 1970s Douglas Lawson and his colleagues discovered the remains of several large pterosaurs in the Maastrichtian sediments of the Late Cretaceous of North America, placing their age at approximately 68 million years old. One of these fossils was the humerus bone of a gigantic wing that far surpassed the size of any pterosaur wing found previously. Lawson (1975) named the pterosaur *Quetzalcoatlus northropi*. Most recent studies estimate that its wing span was in the 10 to 11 metres range, while it stood as tall as giraffe, as illustrated in Figure 1.

The flying abilities of the largest pterosaurs have been constantly debated since their first discovery. Many seemed too large to fly. The problem is one of scale. We can predict how a particular quantity will vary if the size of an animal changes. Birds encounter the same problem. If we image a series of "geometrically similar" birds of various sizes, both the mass and volume should vary with the cube of the length. However, the power available scales less than the power required to fly as the mass increases. The trend has readily visible consequences so that small birds have power to spare. Large birds often struggle to even take off. It is difficult to establish what the heaviest living bird is but the upper limit seems to be between 12 to 16 kg with a wing span in the 3 metre range. All these observations about flight have profound implications for pterosaurs that were obviously much larger and heavier than current physical limits seem to allow.

When Lawson (1975) first announced the discovery of *Quetzalcoatlus northropi*, with an estimated wing span of between 11 to 21 metres, engineers pointed out that it was impossible for such a large animal to fly in our gravity, so the palaeontologists must be wrong. The palaeontologists responded that it must be the engineers who were wrong since the animal obviously existed. The debate about its flying ability continued when Langston (1981) published an article about the discovery of *Quetzalcoatlus northropi* in the journal *Science*, estimating the wing span at a conservative 11.2 metres. Most palaeontologists were adamant that *Quetzalcoatlus northropi* could fly even if aeronautical calculations predicted this was impossible. Bakker (1986, p290) perhaps summed up the feelings of most palaeontologists when he reflected that the "…aerial leviathan was stupefyingly large. Mechanical engineers go often astray when analysing the strength of skeletons." The debate has continued to this day.

A REDUCED GRAVITY SOLUTION

A number of authors, including Pennycuick (2008a, 2015), Sato *et al* (2009) and others have suggested that a reduced gravity would allow pterosaurs to achieve fully powered flight.

Colin Pennycuick is well known for researching the mechanics of animals' flight. He produced a computer program, *Flight*, which can calculate flying performance without enquiring if the numbers came from a bird, a bat or a pterosaur. He performed many measurements on birds to show that the predictions of the *Flight* program were confirmed by reality. These studies have highlighted the difficulties that large animals such as pterosaurs would have in finding enough power to fly. In his latest 2015 book, *Birds never get lost*, he repeated the judgement he voiced for many years,

> "Among living species, the big birds that can flap well get up to masses of 12 kg, or occasionally to 16 kg, with obvious difficulties in finding enough power to fly. That raises problems, because through the second half of the Cretaceous, there was a wide range of pterosaurs that had wing spans of 5 m and up, against 3 m for modern birds." … "These end-Cretaceous giants were far bigger than giant swans, and there is no way in which they could have flown by flapping flight, under today's strength of gravity. Is it possible that the Earth surface gravity might have been progressively reduced, through the last few million years of the Cretaceous?" [Pennycuick, C., & Pennycuick, S. (2015) p 53]

Sato *et al* (2009) also suggested that gravitational conditions might be different to those in modern times after concluding that the largest pterosaurs would be unable to fly, based on their studies of the modern day ocean going albatross and petrel.

Calculations of the flying ability of *Quetzalcoatlus northropi* in a reduced gravity are complex. Fortunately, the use of Pennycuick's *Flight* program simplifies this task. We only need to input the variables: mass, flight muscle mass, gravity, wing span and wing area. The rest of the variables can be set to standard values and the program calculates how well this animal could fly.

Mass

Mass estimates for *Quetzalcoatlus northropi* have varied widely. Chatterjee & Templin (2004) estimated *Quetzalcoatlus northropi* had a mass of 70 kg but this low estimate seems mainly to have been suggested to allow it to glide. Paul (2002, p146) estimated a mass of between 200-250 kg and this seems to have been uninfluenced by any worries about its aerodynamic capability. Henderson (2010) estimated a mass of 544 kg but Witton and Habib (2010) reduced the mass estimate for the Henderson *Quetzalcoatlus northropi* model to about 240 kg, estimating that the most reliable upper estimate was in the 200-250 kg range. The mass used for *Quetzalcoatlus northropi* in this study is 250 kg.

Flight muscle mass

The fight muscle mass is set at 17%. Since the proportion of flight muscle mass to body mass is similar to levels observed in large birds (Goose - 17%, Bustard – 17%, Vulture – 15 to 17%) we know these flight muscles can be continuously powered by the heart-lung system of the pterosaur.

Gravity

The palaeogravity at the time of *Quetzalcoatlus northropi* has been previously calculated using the weight–mass method [see Hurrell (2020a) for an overview of this method and the results obtained]. These calculations indicate that it is likely that a reduced palaeogravity of 0.62g (6.08 m/s^2) existed at the time *Quetzalcoatlus northropi* flew, about 68 million years ago. This reduced palaeogravity can be input directly into the *Flight* program.

Wing span

Chatterjee & Templin (2004) estimated *Quetzalcoatlus northropi* had a wing span of 10.4 metres. Paul (2002, p146) estimated a wing span of between 10 to 11 metres. Witton and Habib (2010) used a wing span of 9.64 metres in their flight calculation. The wing span used in this study is 10 metres.

Wing area

The key parameter that affects the lift-to-drag ratio of a wing is the aspect ratio of the wing. This can be defined in terms of the "plan view" of the wing most simply as the ratio of the overall length of the wings to their average width, or chord. From aeronautical considerations it would seem that an optimum wing shape would be 10 metres wide with an area of 7 square metres. This is an aspect ratio of 14.3:1 producing an effective lift-to-drag ratio of 24.8:1 at the minimum power speed of 20.7 m/s.

Athletic Flying Ability of *Quetzalcoatlus northropi*

The athletic ability of today's flying animals is related to their size. Small birds can easily take off and land but larger birds clearly struggle. One way of quantifying their athletic ability is to calculate their rate-of-climb. A comparison of wing span to the maximum rate of climb shows how this variable is a good indication of a bird's athletic ability. The Pennycuick *Flight* program indicates that the maximum rate of climb for *Quetzalcoatlus northropi* in a reduced gravity of 0.62g would be 0.425 m/s, indicating that its athletic ability would be comparable with the largest flying animals of today.

Take-off

Trying to reconstruct large pterosaurs capable of flight in 1g has led many palaeontologists to infer that take-off could not occur without assistance from slopes, constant headwinds or cliff edges. A pterosaur adapted to living in a reduced palaeogravity would encounter none of these hindrances. The 17% flight muscle mass of *Quetzalcoatlus northropi* in a 0.62g palaeogravity would enable it to generate enough lift to take off without any further assistance.

Pterosaurs were quadrupedal while on the ground so Habib (2008) has described how it would seem reasonable to image that they launched into the air directly from that position. Their strong arms are particularly well-developed around the shoulders. Far from being weak flyers, pterosaurs could employ their powerful flight muscles to almost explode into the air. This would all happen in a very rapid motion so that even the largest pterosaurs would be clear of the ground in a second or so. Small pterosaurs would be able to spring into the air vertically but the climb angle would decrease with size. The calculated climb rate for *Quetzalcoatlus northropi* in a 0.62g palaeogravity is 0.425 m/s so it would require a relatively open environment to take off, free of any trees for example.

In the air

In a 0.62g palaeogravity environment the flight muscles of *Quetzalcoatlus northropi* can be reduced to only 17% of the total body mass. This low flight muscle mass means the heart and lung system would be able to always supply these muscles so they can operate aerobically. It can continuously flap its wings from the moment it takes off to the time when it lands.

Landing

A recently discovered trackway of a pterosaur landing indicates this was relatively easy. Mazin *et al* (2009) describe how the footprints of a pterosaur landing indicate that it appears to have lost most of its flight speed before landing to drop onto both feet simultaneously. The entire body must have pitched up so the legs could swing into a landing position. After gently lowering itself onto the floor the animal dropped forward onto its hands in one fluid motion as the wings were folded away.

On the ground

All known pterosaur trackways indicate that they habitually walked on all four limbs. Trackways from giant pterosaurs with an estimated shoulder height of 2.5 metres have been described by Hwang *et al* (2002). The pterosaur foot prints are consistently found in front of their hand prints, indicating that their hands had to be clear of the ground before the foot was placed on the ground.

Various feeding strategies have been suggested for the large pterosaurs. One suggestion was that the largest pterosaurs dined on a range of smaller animals and various eggs. A modern day comparison might be a heron that regularly feeds on small ducklings – a search on YouTube will show the often brutal way this is accomplished. An interesting comparison is that a human-sized animal of about 70 kg mass would seem to make a convenient size snack for *Quetzalcoatlus northropi*. The CollectA *Quetzalcoatlus* model includes a baby sauropod dinosaur that is just about to be eaten. Could it still fly with that added mass? Entering the appropriate figures into the *Flight* program (as a payload mass) indicates that its rate of climb would only be reduced from 0.425 m/s to 0.121 m/s. Our *Quetzalcoatlus northropi* could easily include a 70 kg mass animal in its diet. Time travelling humans would need to watch the skies!

Figure 1. *Quetzalcoatlus northropi* and a giraffe to the same scale. The *Quetzalcoatlus* is a CollectA model that is just about to eat a baby *Alamosaurus*, while the giraffe is a PNSO model. The watermark background is a photograph of a *Quetzalcoatlus* Wild Safari model in full flight.

Migrating

All animals need energy to migrate and this energy is in the form of fat. The distance our *Quetzalcoatlus northropi* can fly (its range) depends on the fat fraction (with a typical value of 20% of body mass) and this can be calculated using the migrate function of the *Flight* program.

The *Flight* program can calculate a power curve and the rate at which fat is consumed. It calculates that *Quetzalcoatlus northropi* runs out of fat having flown 11,945 km continuously for 117.8 hours. It is clear that our *Quetzalcoatlus northropi* could very easily migrate from what is now the USA to Central Europe, crossing the developing Atlantic Ocean in the process.

Conclusions

Aeronautical calculations show that in a palaeogravity of 0.62g a gigantic *Quetzalcoatlus northropi* pterosaur, with a wing span of 10 metres and a mass of 250 kg, would have a similar athletic ability to the largest birds of today. The main attributes of a gigantic *Quetzalcoatlus northropi* in a 0.62g environment would be:

- The flight muscle mass would enable it to generate enough lift to take off without any further assistance, negating any requirements for wind or slope assistance.
- The maximum rate of climb would be 0.425 m/s, indicating that its athletic ability would be comparable with the largest flying animals of today.
- Flight muscles could be continuously powered by the heart-lung system of the pterosaur, negating any requirement to be a glider.
- It could fly 11,945 km continuously with 20% fat reserves, so could very easily migrate from what is now the USA to Central Europe, crossing the developing Atlantic Ocean in the process.
- It could easily include a 70 kg mass animal in its diet without limiting its flying ability substantially.

References

Alexander, R.M. (1998). *All-time giants: the largest animals and their problems.* Palaeontology 41:1231–1245

Bakker, R. (1986). *The Dinosaur Heresies: New Theories Unlocking the Mystery of the Dinosaurs and Their Extinction.*

Buffetaut, E., Clarke, J. B., & Le Loeuff, J. (1996). *A terminal Cretaceous pterosaur from the Corbières (southern France) and the problem of pterosaur extinction.* Bulletin de la Société géologique de France, 167(6), 753-759.

Chatterjee, S., & Templin, R. J. (2004). *Posture, locomotion, and paleoecology of pterosaurs* (Vol. 376). Geological Society of America.

Godfrey, S.J., Currie, P.J. (2005). *Pterosaurs.* In Dinosaur Provincial Park: A spectacular ancient ecosystem. Edited by Currie and Koppelhus. Indiana University Press.

Habib (2008). *Comparative evidence for quadrupedal launch.* In Pterosaurs. Zitteliana.

Henderson, D. M., Peterson, J. (2006). *An azhdarchid pterosaur cervical vertebra from the Hell Creek Formation (Maastrichtian) of southeastern Montana.* Journal of Vertebrate Paleontology.

Henderson, D. M. (2010). *Pterosaur body mass estimates from three-dimensional mathematical slicing.* Journal of Vertebrate Paleontology, 30(3), 768-785.

Hurrell, S.W., (2020a). *Can we calculate palaeogravity?* http://dinox.org/hurrell2020c

Hurrell, S.W., (2020b). *The flying ability of the pterosaur Quetzalcoatlus northropi in a reduced gravity.* http://dinox.org/hurrell2020d

Hwang, K. G., Huh, M. I. N., Lockley, M. G., Unwin, D. M., & Wright, J. L. (2002). *New pterosaur tracks (Pteraichnidae) from the Late Cretaceous Uhangri Formation, southwestern Korea.* Geological Magazine, 139(4), 421-435.

Langston, W. (1981). *Pterosaurs.* Scientific American, 244(2), 122-137.

Lawson, D. A. (1975). *Pterosaur from the latest Cretaceous of West Texas: discovery of the largest flying creature.* Science 187:947–948.

MacCready, P. (1985). *The great pterodactyl project.* Engineering & Science, California Institute of Technology 49(2):18–24.

Mazin, J. M., Billon-Bruyat, J. P., & Padian, K. (2009). *First record of a pterosaur landing trackway.* Proceedings of the Royal Society B: Biological Sciences, 276(1674), 3881-3886.

Medbo, J. I., Mohn, A. C., Tabata, I., Bahr, R., Vaage, O., & Sejersted, O. M. (1988). *Anaerobic capacity determined by maximal accumulated O2 deficit.* Journal of applied physiology, 64(1), 50-60.

Padian, K., Smith, S. (1992). *New light on Late Cretaceous pterosaur material from Montana.* Journal of Vertebrate Paleontology.

Paul, G. S. (2002). *Dinosaurs of the air: the evolution and loss of flight in dinosaurs and birds.* JHU Press. ISBN: 978-0801867637.

Pennycuick, C.J. (2008a). *Modelling the Flying Bird.* Published by Elsevier Inc. ISBN: 9780123742995.

Pennycuick, C.J. (2008b). *Flight 1.25 Installation package.* https://booksite.elsevier.com/9780123742995/

Pennycuick, C., & Pennycuick, S. (2015). *Birds Never Get Lost.* Troubador Publishing. ISBN: 9781785890482.

Sato, K., Sakamoto, K. Q., Watanuki, Y., Takahashi, A., Katsumata, N., Bost, C. A., & Weimerskirch, H. (2009). *Scaling of soaring seabirds and implications for flight abilities of giant pterosaurs.* PLoS One, 4(4), e5400.

Witton, M.P. (2013). *Pterosaurs.* Princeton University Press. ISBN: 978-0691150611

Witton, M. P., & Habib, M. B. (2010). *On the size and flight diversity of giant pterosaurs, the use of birds as pterosaur analogues and comments on pterosaur flightlessness.* PloS one, 5(11), e13982.

NOTES

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