A NEW METHOD TO CALCULATE PALAEOGRAVITY USING FOSSIL FEATHERS

Stephen W. HURRELL
11 Farmers Heath, Great Sutton, Ellesmere Port, CH66 2GX, UK
papers@dinox.org

Abstract: A recent paper on the ancient birds *Archaeopteryx* and *Confuciusornis* has shown that their feathers would not be able to support the weight of the birds in flight. The authors therefore suggested that the birds could not fly. This suggestion remains debatable since other authors have highlighted various features that indicate these birds did fly. In this paper, values for gravity which would enable these birds to fly with weaker feathers are calculated based on the controversial theory that palaeogravity was less. These values are then compared with earlier estimates of palaeogravity derived from a range of other life forms from approximately the same time period.

Keywords: *palaeogravity, Archaeopteryx, Confuciusornis, fossil feathers, feather evolution*

Introduction

Ancient birds had feathers that look a lot like those of living birds. Since most birds use feathers for flight it has been widely suggested that they must have flown: Norberg (1985), Olson (1979), Rietschel (1985), Wellnhofer (2004), and Yalden (1971). But many ancient birds seem too heavy to fly in today's gravity and it has also been argued that they didn't fly: Ostrom (1974), Senter (2006), Speakman and Thomson (1994), and Vazquez (1992). The whole issue remains controversial with some studies indicating that they would be incapable of flying while others conclude the opposite.

One bird that has been widely studied for many years is *Archaeopteryx* (see **Figure 1**). The recent fossil finds of the *Confuciusornis* bird have not been studied as intensively but this will probably change in the future since there are now hundreds of fossils. One interesting recent study of the flying ability of the ancient birds *Archaeopteryx* and *Confuciusornis*, by Robert L. Nudds and Gareth J. Dyke (2010a), analysed the strength of the fossil feathers of the birds to determine if the feathers could support the weight of the bird during flight. Based on the strength of the feathers they concluded that both birds 'were not capable of flight'.

The main strength in a primary flight feather is provided by a central shaft known as the rachis. All the barbs of the feather are attached to this central shaft so it must be strong enough to withstand the lift generated on the wing without buckling. During flight the feathers must be able to support a lift force that is at least equal to the weight of the bird (*mass* x *gravity*) so the authors calculated this buckling limit to infer the flight capabilities of the ancient birds. As modern-day birds change direction they generate forces greater than the weight of the bird, so modern-day birds have additional factors of safety to allow for this increased loading. Nudds and Dyke found that even if they assumed a small factor of safety and completely solid feathers the ancient feather was weaker than expected for a similar sized modern-day bird. The calculations revealed that the feathers of both birds were so weak that they would buckle if the birds attempted to fly.

The conclusion the authors reached was that both *Archaeopteryx* and *Confuciusornis* would not be able to flap their wings without buckling the feathers. Nudds and Dyke suggested that both birds may only have been capable of gliding down with their wings held outstretched to reduce the forces on the feathers of the wing. They would need to climb up a tree again to be able to repeat this technique. Flapping flight was not possible. Even this concept of a gliding bird produced very low safety factors which were well below those of modern birds.



Figure 1. Fossil *Archaeopteryx* showing feather impressions

The gliding technique suggested by Nudds and Dyke conforms to the well-known "top down" flight evolution model where flight developed as birds used their wings to glide down to the ground. Another widely known and debated evolution model is the "bottom up" version where flight evolved first on the ground as agile birds used their developing wings to help them run faster. An interesting alternative theory that is not as well known was suggested by Klaus Ebel (1996) almost 20 years ago. He presented evidence that originally flight did not occur above land at all but was the by-product of hunting under water. Thus, the first step to conquering the air was to learn "flying" under water. The long bony tail of *Archaeopteryx* is actually the part of its skeleton that would have helped it to fly under water. Real airborne flight only evolved later, as primitive birds began to glide over the surface of water and then developed powered flight. During this evolution towards true flight they lost their long bony tails and became more like *Confuciusornis.* A similar evolution, better backed up by fossil evidence, was also suggested for pterosaurs. However, while it can be suggested for various reasons that *Archaeopteryx* may not have fully developed the ability to fly in the Upper Jurassic, it seems that many palaeontologists believe *Confuciusornis* must have evolved to be a competent flier by the time it lived in the Lower Cretaceous, tens of millions of years later.

Both *Archaeopteryx* and *Confuciusornis* have feathered wings that appear to be capable of generating aerodynamic lift, so the conclusion that the feathers would be incapable of supporting the weight of the birds, as proposed by Nudds and Dyke, generated intense debate. Gregory S. Paul (2010) replied that the 'total biology of the birds indicates that they could achieve flapping flight' and suggested there might be errors in either the mass estimates of the birds or the shaft diameters of the feathers. Xiaoting Zheng et al. (2010) recognised that the innovative analysis offered important new insights into bird evolution. However, they believed that some recently collected data for *Confuciusornis* indicating thicker main shaft diameters, about twice those used in the original calculations, would mean that their conclusions would need to be further evaluated. But despite this they noted that 'even our measurements are considerably smaller than the predicted rachis diameter of primary feathers with similar feather length in similarly sized extant birds'. Nudds and Dyke (2010b) responded to these two comments by agreeing that their model is of course dependent on the data fed into it, but calculating the maximum lift forces sustainable by a bird still provides a novel way of estimating the flight capabilities of ancient birds. Using the other values suggested still

indicated the birds were not capable of flapping flight and the feather's strength was barely enough for gliding.

Description

One alternative hypothesis that would enable a bird to fly with weak feathers is the notion that the weight of the bird was less because gravity was less. The hypothesis that ancient life has been significantly affected by a weaker palaeogravity is a controversial proposal that has only been seriously discussed by a small number of authors: Carey (2000), Davidson (1994), Erickson (2001), Hurrell (1994, 2011 and 2012), Kort (1949), Ciechanowicz and Koziar (1994), Koziar (2011), Mardfar (2000 and 2012), Maxlow (2005 and 2014), Scalera (2002, 2003a, 2003b and 2004), and Strutinski (2012 and 2013). However, the strength of fossil feathers has never been used to estimate the strength of ancient gravity so this would introduce an interesting new alternative method of calculation.

Nudds and Dyke calculated the body mass of *Archaeopteryx* and *Confuciusornis* respectively as 0.276 kg and 0.5 kg based on their size in relation to modern birds. They also estimated the downward force required so the feathers were 'strong enough to sustain a force equal to their body weight' as equivalent to a mass of 0.188 kg and 0.215 kg respectively in today's gravity. The authors calculated their weight assuming the prevalent concept that ancient gravity was equal to the present. They then rejected the possibility of flight because they thought 'their body masses are unlikely to be this low'. However, if gravity was less on the ancient Earth then the weight of the birds would also be less. This allows us to calculate palaeogravity relatively easily by assuming that the ancient birds were able to fly with weaker feathers by today's standards. In a reduced gravity the weight (*mass* x *gravity*) would be reduced to the appropriate level required for flight. So ancient gravity (g_a) can be calculated from:

$$g_a = F_a / M_p$$

where F_a is taken as the maximum ancient force produced by the birds' wings, and M_p is the mass of the bird.

For *Archaeopteryx*:

$$g_a = F_a / M_p$$
$$= 0.188 / 0.276$$
$$= 0.68g$$

As at about 145 million years ago relative ancient gravity is calculated as 68% of present gravity.

For *Confuciusornis*:

$$g_a = F_a / M_p$$
$$= 0.215 / 0.5$$
$$= 0.43g$$

As at about 120 million years ago relative ancient gravity is calculated as 43% of present gravity.

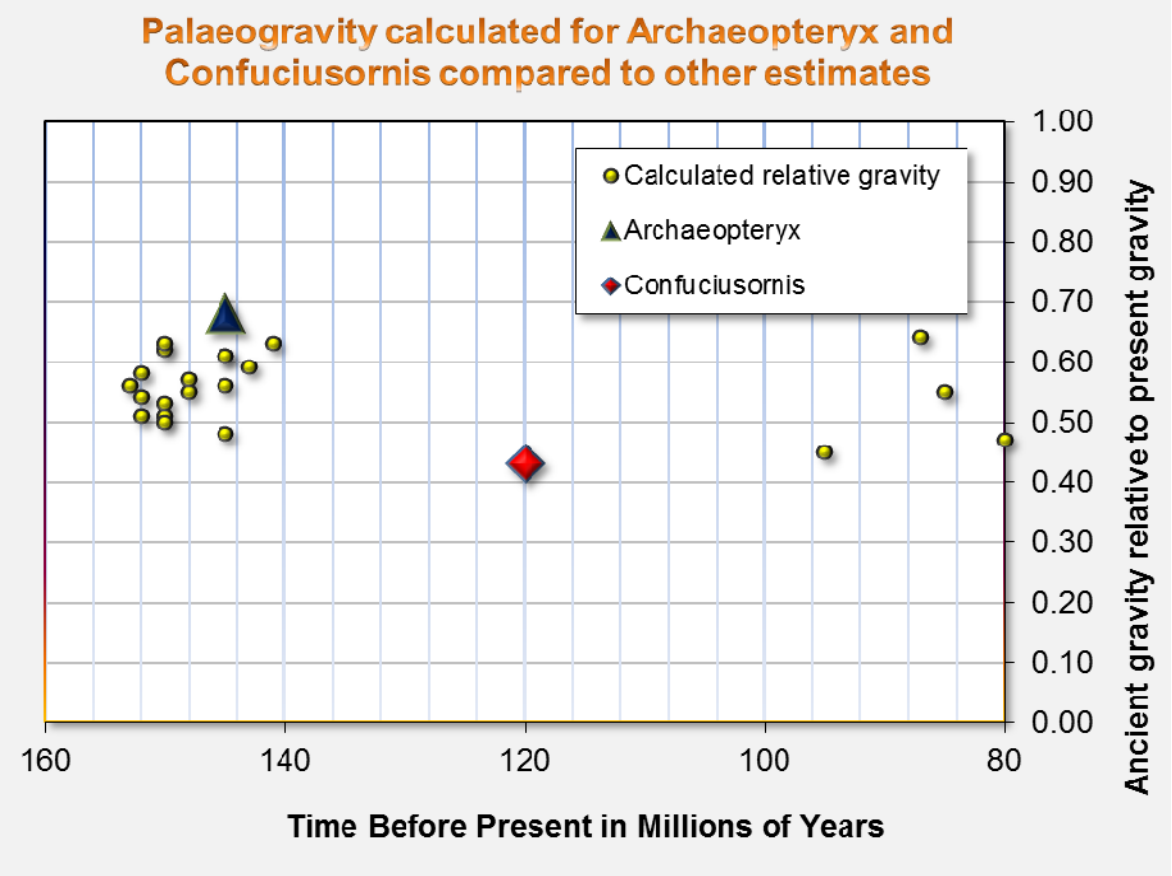


Figure 2. Palaeogravity estimates obtained from primary feather strengths of *Archaeopteryx* and *Confuciusornis* compared with a range of other estimates.

It should also be mentioned that Zheng et al (2010) queried the measurements of *Confuciusornis* and noted 'the rachises of primary feathers of confuciusornithids measure 2.1 mm to 2.3 mm in diameter on four Tianyu specimens, about twice as large as the measurements reported by Nudds and Dyke'. However, even these measurements are still less than modern birds of a similar size. For example, *C. palumbus* has a body mass of 0.49 kg with a rachis feather diameter of 2.97 mm, and the smaller *L. ridibundus* with a body mass of 0.284 kg has a feather rachis diameter of 2.6 mm. It is clear that even if the measurements need to be adjusted they are still considerably lower than modern birds require when flying.

Conclusion

Previous estimates of ancient gravity have been derived from a range of other life forms from approximately the same time period by Hurrell (2012). These previous estimates for palaeogravity can usefully be compared with the calculations obtained in this paper for birds. The leg bone strengths of *Diplodocus*, *Allosaurus* and *Giraffatitan* have given approximate values of palaeogravity as 0.51g, 0.5 g and 0.56 g relative to today's gravity. The neck ligament strength of *Diplodocus* has been calculated to indicate an approximate palaeogravity of 0.53 g. The blood pressure of *Giraffatitan* indicates an approximate palaeogravity of 0.48 g. The dynamic similarity of *Giraffatitan* compared with present-day life indicates a palaeogravity of 0.61 g. Previously unpublished additional estimates are also in a similar range for palaeogravity. Thus it appears that the estimates of ancient gravity from fossil bird feathers are in broad agreement with bone and ligament strength, blood pressure and dynamic-similarity calculations on a range of other life from that time. The values for palaeogravity obtained from *Archaeopteryx* and *Confuciusornis* are shown on a graph in **Figure 2** with the other estimates of palaeogravity mentioned above shown for comparison. The data used in **Figure 2** is shown in **table 2.**

Table 2. A table of palaeogravity estimates obtained from the primary feather strengths of *Archaeopteryx* and *Confuciusornis* compared with a range of other life using differing methods. These data are shown in graph form in Figure 2.

Animal type	Scientific Name	Time (Ma)	Calculated relative gravity	Estimation Method
Sauropod dinosaur	Supersaurus vivianae	153	0.56	Dynamic Similarity
Sauropod dinosaur	Apatosaurus ajax	152	0.58	Leg Bone Strength
Sauropod dinosaur	Apatosaurus louisai	152	0.51	Leg Bone Strength
Sauropod dinosaur	Apatosaurus (unknown)	152	0.54	Dynamic Similarity
Sauropod dinosaur	Diplodocus carnegiei	150	0.51	Leg Bone Strength
Theropod	Allosaurus fragilis	150	0.50	Leg Bone Strength
Sauropod dinosaur	Diplodocus carnegiei	150	0.53	Neck ligament
Sauropod dinosaur	Apatosaurus louisae	150	0.62	Dynamic Similarity
Sauropod dinosaur	Diplodocus longus	150	0.63	Dynamic Similarity
True Dragonfly	Isophlebia aspasia	148	0.55	Dynamic Similarity
True Dragonfly	Aeschnogomphus kuempeli	148	0.57	Dynamic Similarity
Bird	**Archaeopteryx**	**145**	**0.68**	**Feather Strength**
Sauropod dinosaur	Giraffatitan brancai	145	0.48	Blood Pressure
Sauropod dinosaur	Giraffatitan brancai	145	0.56	Leg Bone Strength
Sauropod dinosaur	Giraffatitan brancai	145	0.61	Dynamic Similarity
Sauropod dinosaur	Brachiosaurus altithorax	145	0.61	Dynamic Similarity
True Dragonfly	Prohoyaeshna milleri	143	0.59	Dynamic Similarity
True Dragonfly	Aktassia pritykinae	141	0.63	Dynamic Similarity
Bird	**Confuciusornis**	**120**	**0.43**	**Feather Strength**
Sauropod dinosaur	Argentinosaurus huinculensis	95	0.45	Dynamic Similarity
Sauropod dinosaur	Futalognkosaurus dukei	87	0.64	Dynamic Similarity
Pterosaur	Pteranodon longiceps	85	0.55	Dynamic Similarity
Sauropod dinosaur	Puertasaurus reuili	80	0.47	Dynamic Similarity

Nudds and Dyke found that the feather lengths of the two birds *Archaeopteryx* and *Confuciusornis* were very similar to present-day birds of a similar size but the rachises were narrower. They checked their calculations against a range of present-day birds and found they could predict the rachis size accurately for modern-day birds based on the feather length. Further work by Wang et al. (2012) seems to confirm this view. This is interesting for calculations of ancient gravity since it may be possible to use any fossil primary feather to calculate ancient gravity so long as the length of the feather and the diameter of the main shaft can be accurately determined. This indicates a useful area for future research.

Acknowledgements: The author would like to thank W.C. Erickson, J. Maxlow, C. Strutinski and an anonymous reader for their helpful comments.

References

Carey, S.W., 2000. Earth, universe, cosmos. University of Tasmania. 2nd edition. ISBN 085901715.

Ciechanowicz, S. and Koziar, J., 1994. Possible relation between Earth expansion and dark matter. In: F. Selleri, M. Barone (eds.), Proceedings of the International Conference "Frontiers of Fundamental Physics" (Olympia, Greece, 27–30 September, 1993). Plenum Press, New York and London, p. 321–326.

Davidson, J.K., 1994. Earth expansion requires increase in mass. *Frontiers of Fundamental Physics*, p. 295-300.

Ebel, K., 1996. On the origin of flight in Archaeopteryx and in pterosaurs. *Neues Jahrbuch Fur Geologie Und Palaontologie Abhandlungen*, v. 202, p. 269-285.

Erickson, W.C., 2001. On the Origin of dinosaurs and mammals. USA. (Available for download from http://www.frontier-knowledge.com/earth/papers/Origin of Dinosaurs and Mammals.pdf)

Hurrell, S.W., 1994. Dinosaurs and the Expanding Earth. (1st edition). Oneoff Publishing. ISBN 0 952 2603 01.

Hurrell, S.W., 2011. Dinosaurs and the Expanding Earth (3rd edition). Oneoff Publishing.com. ISBN 0 952 2603 70.

Hurrell, S., 2012. Ancient Life's Gravity and its Implications for the Expanding Earth. In, *The Earth Expansion Evidence – A Challenge for Geology, Geophysics and Astronomy-Selected Contributions to the Interdisciplinary Workshop of the 37th International School of Geophysics*. Aracne Editrice, Roma.

Kort, K., 1949. Das Wachen der Erde und die Wanderung der Kontinente. Hannover.

Koziar, J., 2011. Expanding Earth and space geodesy (extended abstract) In: S. Cwojdziński, G. Scalera (eds.), *Pre-Conference Extended Abstracts Book of the 37th Course of the International School of Geophysics. Interdisciplinary Workshop on "The Earth Expansion Evidence: A challenge for Geology, Geophysics and Astronomy" (Ettore Majorana Foundation and Centre for Scientific Culture, Erice, Sicily, 4-9 October,*

2011). Istituto Nazionale di Geofisica e Vulcanologia, Rome, p. 47-53.
Mardfar, R., 2000. The relationship between Earth gravity and Evolution. Iran.
Mardfar, R., 2012. The relationship between gravity and evolution of animals and plants – The Theory of the increasing gravity. In: *The Earth Expansion Evidence – A Challenge for Geology, Geophysics and Astronomy-Selected Contributions to the Interdisciplinary Workshop of the 37th International School of Geophysics*. Aracne Editrice, Roma.
Maxlow, J., 2005. Terra Non Firma Earth. Oneoff Publishing. ISBN 09522603.
Maxlow, J., 2014. On the Origin of Continents and Oceans: A Paradigm Shift in Understanding. ISBN 9780992565206
Norberg, R.A., 1985. The beginnings of birds. Proceedings of the International Archaeopteryx Conference, Eichstätt 1984. Hecht, M.K., Ostrom, J.H., Viohl, G. and Wellnhofer, P., eds., Freunde des Jura-Museums, Eichstätt, Germany, 1985, p. 303–318.
Nudds, R.L. and Dyke, G.J., 2010a. Narrow primary feather rachises in *Confuciusornis* and *Archaeopteryx* suggest poor flight ability. *Science*, v. 328, no. 5980, p. 887-889.
Nudds, R.L. and Dyke, G.J., 2010b. Response to comments on "Narrow Primary Feather Rachises in *Confuciusornis* and *Archaeopteryx* suggest poor flight ability". *Science*, v. 330, no. 6002, p. 320-320.
Olson, S.L. and Feduccia, A., 1979. Flight capability and the pectoral girdle of Archaeopteryx. *Nature*, v. 278, p. 247-248.
Ostrom, J.H., 1974. *Archaeopteryx* and the origin of flight. *Quarterly Review of Biology*, v. 49, no. 1, p. 27-47.
Paul, G.S., 2010. Comment on "Narrow Primary Feather Rachises in *Confuciusornis* and *Archaeopteryx* suggest poor flight ability". *Science*, v. 330, no. 6002, p. 320-320.
Rietschel, S., 1985. Feathers and wings of *Archaeopteryx*, and the question of her flight ability. The beginnings of birds, p. 251-260.
Scalera, G., 2002. Gravity and Expanding Earth. Proceedings of the 21st National Meeting. GNGTS, published on CD-rom, Roma, p. 11.
Scalera, G., 2003a. Gravity and expanding Earth. Atti del 21 Convegno Nazionale GNGTS.
Scalera, G., 2003b. The expanding Earth: a sound idea for the new millennium. In: *Why expanding Earth? A book in honour of OC Hilgenberg*.
Scalera, G., 2004. Gravity and expanding Earth. In: Romanovsky, N.P., ed., Regularities of the structure and evolution of Geospheres. Proceedings of the VI Interdisciplinary International Sci. Symposium held in Khabarovsk, 23-26 Sept. 2003, p. 303-311.
Senter, P., 2006. Scapular orientation in theropods and basal birds, and the origin of flapping flight. *Acta Palaeontologica Polonica*, v. 51, no. 2, p. 305.
Speakman, J.R. and Thomson, S.C., 1994. Flight capabilities of Archaeopteryx. *Nature*, v. 370, no. 6490, p. 514-514.
Strutinski, C., 2012. Contradictory aspects in the evolution of life. In: *The Earth Expansion Evidence – A Challenge for Geology, Geophysics and Astronomy-Selected Contributions to the Interdisciplinary Workshop of the 37th International School of Geophysics*. Aracne Editrice, Roma.
Strutinski, C., 2013. Increasing gravity – the driving force of evolution? (In German. Prepublication copy supplied by author – email: cstrutinski@yahoo.com).
Vazquez, R.J., 1992. Functional osteology of the avian wrist and the evolution of flapping flight. *Journal of Morphology*, v. 211, no. 3, p. 259-268.
Wang, X., Nudds, R.L., Palmer, C. and Dyke, G.J., 2012. Size scaling and stiffness of avian primary feathers: implications for the flight of Mesozoic birds. *Journal of evolutionary biology*, v. 25, no. 3, p. 547-555.
Wellnhofer, P., 2004. The plumage of Archaeopteryx: feathers of a dinosaur. Feathered dragons: studies on the transition from dinosaurs to birds. Bloomington: Indiana University Press. p. 282-300.
Yalden, D.W., 1971. The flying ability of Archaeopteryx. *Ibis*, v. 113, no. 3, p. 349-356.
Zheng, X., Xu, X., Zhou, Z., Miao, D. and Zhang, F., 2010. Comment on "Narrow primary feather rachises in *Confuciusornis* and *Archaeopteryx* suggest poor fight ability". *Science*, 15 October 2010, v. 330, no. 6002, p. 320.