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巨型翼龙中的飞行效率和长距离旅行

Soaring Efficiency and Long Distance Travel in Giant Pterosaurs

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Azhdarchid pterosaurs include the largest known flying animals, with the largest species reaching a potential mass of over 250 kg. Prior work suggests that several features of azhdarchid anatomy could be associated with a soaring-dominated lifestyle, including large size, burst-flapping adapted pectoral girdle and proximal forelimb, moderate to high wing aspect ratio, and exceptional pneumaticity. However, long-range flight ability of azhdarchid pterosaurs has not been quantified in the literature. Furthermore, while the flight of giant pterosaurs has been modeled for a range of large species (Hankin and Watson 1914; Bramwell and Whitfield 1974; Brower 1983; Chatterjee and Templin 2004) and researchers have invariably concluded that they were capable of flight, some recent studies have called into the question the flight abilities of pterosaurs at large body masses (Chatterjee and Templin, 2004; Sato et al. 2009), especially the relatively 'heavy' masses in the recent literature (Paul 1991, 2002; Witton 2008). Here we present the results from a quantitative analysis of long-distance travel efficiency in azhdarchid pterosaurs, demonstrating that the largest pterosaurs should not only have been effective flyers, but had the potential to be the furthest-traveling animals known to science.

Power analysis indicates that the largest pterosaurs needed to reach external sources of lift, following launch, before they exhausted anaerobic muscle endurance. Following climb out, even large azhdarchids should have been capable of staying aloft by using external sources of lift. A quantitative framework already exists for estimating maximum migration range in soaring birds using thermal lift. We have extended this framework to pterosaurs by altering existing models to accommodate the membrane wings of pterosaurs and uncertainty in potential muscle physiologies. Maximum fuel capacity (stored as fat and additional muscle) was estimated by taking the difference between body masses scaled from skeletal strength (maximum) versus mass for maximum wing efficiency (maximizing lift coefficient according to reconstructed aspect ratio). This new migration model indicates that the largest azhdarchid pterosaurs had the capacity for non-stop flights exceeding more than 16000 km.

The ability of large pterosaurs, especially azhdarchids, to effectively reach external sources of lift was great augmented by 1) adaptations for a powerful launch (Habib, 2008) that would allow them to exceed stall speed without utilizing excessive amounts of valuable anaerobic capacity, and 2) adaptations for rapid generation of full circulation on the wing, which would have substantially reduced the time and energy expenditure of climb out. Approximately 2.5 chord lengths are usually required before a wing develops full steady state circulation, known in the literature as the "Wagner Effect" (Wagner, 1925). Analysis of the tensile support in azdarchid wings suggests a potential for rapid translation and twisting of the outboard wing, which would be promoted by the T-shaped cross section of the wing phalanges. Such rapid translation can develop full circulation up to five times faster than otherwise possible and greatly reduce the flapping cycles needed to reach maximum circulation during climb out, an observation previously made by at least one other pterosaur worker (Cunningham, pers comm.) but previously unmentioned in the formal pterosaur literature. These improvements to the efficiency of the initial climb out from launch would have extended the required proximity to external lift sources, and broadened the potential habitat range of giant pterosaurs.

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