Original Article

Institution of MECHANICAL ENGINEERS

Journal of MECHANICAL ENGINEERING SCIENCE

Proc IMechE Part C:
J Mechanical Engineering Science
0(0) 1–18

DOI: 10.1177/0954406219861995
journals.sagepub.com/home/pic
SAGE

Design of flying robots inspired by the evolution of avian flight

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Abstract

Bionic design of flying robots based on natural models has become a hot topic in mechanical engineering. The research going on in this direction considers that there is a lot to learn from flying animals such as birds, insects, and bats, from walking on the ground to getting enough power to be airborne. To get an efficient design of flying robots, we must better understand the origin of flight. This paper focuses on the review of avian flight and its possible application in the design of flying robots. Different hypotheses have been proposed to tackle the origin and evolution of avian flight from cursorial dinosaurs to modern birds, including the famous *ground-up* and *tree-down* theories. During the past decade, discoveries of feathered and winged dinosaurs from Liaoning, China, strongly supported the theory that birds originated from theropod dinosaurs. The transition from running on the ground to maneuver in the sky involves various stages of flights and plumages, which can be now illustrated by several representative paravian dinosaurs from Liaoning. Those fossils provide good research bases for the design of flying robots. *Microraptor* is one of those important transitional stages in the evolution of flight. This paravian dinosaur is characterized by the presence of pennaceous feathers along both its arms and its legs, but how it could actually fly is still debated. It is of course difficult to evaluate the flight performances of an extinct animal, but aerodynamics of a four-wing robot can be developed to get some knowledge about its flying capacity. Fossil and living flying animals with different morphologies, stability, and control mechanism can be a source of inspiration for designing socially relevant products.

Keywords

Flying robot, bionic design, *Microraptor*, nonvolant theropod, evolution of flight, modern birds

Date received: 9 September 2018; accepted: 14 June 2019

Introduction

The origin and early evolution of birds and avian flight is one of the most discussed topics in palaeontology. Two years after Darwin's celebrated book *On the Origin of Species*, one of the major clues for understanding the origin of birds was already discovered in Upper Jurassic limestones from Bavaria in Germany.[1,2] The skeleton of *Archaeopteryx* is characterized by a mosaic of "reptilian" (teeth, claws, bony tail, unfused hand fingers) and avian (feathers, furcular, perching feet).[3] Recent discoveries of hundreds of incredibly preserved specimens of feathered dinosaurs and early birds from Middle Jurassic to Early Cretaceous deposits in north eastern China definitely proved that birds are closely related to small carnivorous dinosaurs. Dinosaurs did not completely disappear 65 million years ago, as often depicted, but some of them, known as "birds", survived and even flourished until today.

Amongst theropods dinosaurs, birds form a clade named *Paraves*, which is a broad group from the Late Jurassic period, include *dromaeosaurids*, *troodontids*, *anchiornithids*, and *scansoriopterygids*.[4] Birds are closely related to *dromaeosaurids* and *troodontids* and with the discoveries of more and new fossils, this fact is becoming more and core convincing.[4,5] Both were feathered dinosaurs and had mixed features of birds and reptiles. Over the past few years, new fossils of feathered and winged dinosaurs have been discovered. Species like *Anchiornis huxleyi* and *Xiaotingia* are earlier than *Archaeopteryx*. Scientists believed that it was a difficult task to differentiate between birds and its close ancestor (*dromaeosaurids* and *troodontids*).[6]

The origin of flight and evolution of birds can be further investigated throughout mechanical and

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aerodynamic approaches. The mechanical and robotic industries even offer novel approaches for biologists to test their hypotheses.[7] On the other hand, the industry can also take lessons from nature to produce highly efficient devices. Biomimetics is the integrative field that merges the knowledge of biology and engineering to emulate the models, elements, and compounds of living beings to meet the demands and to solve complex problems. Biomimetic approaches can be used to solve various engineering problems. The anatomy, aerodynamics, and control of birds, bats, and insect are potentially a source of inspiration for the development of bioinspired devices. Attributes such as wing size, speed of flight, and Reynolds number play an important role not only for animals, but also for the biomimetic flying robots. Ornithopter, fixed-winged flying robots, and micro aerial vehicles (MAV) get their inspiration either from birds or insect. The flapping-wing micro aerial vehicle (FWMAV) is one of the developments in biomimetic or bioinspired design, which focuses on both insect and bird flapping. The wing design is important in FWMAV, with quality design and better driving mechanism. The aerodynamic performance along with the stability of biomimetic devices can be improved. Recently, unmanned aerial vehicle (UAV) has achieved a lot of attention because of its diverse applications not only in air but also in water.

The main objective of this review is to provide an insight into the origin of flight by considering the evolutionary, biophysical, and mechanical viewpoints. This paper is divided into six sections: the upcoming section describes structure and anatomy of bird's wing, the evolution of flight apparatus including the model proposed to explain the origin of avian flight and the feather evolution along with the hypothesized stages that explain how feather might have evolved. Selected taxa presenting key innovations in the evolutionary pathway from cursorial theropods to modern birds are introduced in the next section. Subsequently, the morphology, flight capacities, and aerodynamic performances of *Microraptor*, an Early Cretaceous dromaeosaurid paravian from China, are presented with further details. Biomimetic phenomena related to flying capabilities of birds, bats, and insects that were used in the development of bioinspired devices by taking inspiration from their anatomy, aerodynamics abilities, and control are discussed in later. Finally, the article is concluded in the last section.

Bird anatomy and origin of flight

Tens and thousands of species like butterflies, beetles, bats, birds, etc. fly in the skies but millions of years ago, did flight exist? How did these species defy the laws of gravity and take the first flight? How did they learn to fly or flap their wings? The greatest achievement in evolution is the increasing power of flight. Evolution involves the change of inherited features over a period and occurs to support the survival of living beings. The main focus of this section is to give a brief overview of morphology and structure of the bird's wing along with the structure and evolution of feathers. How flight has evolved and different hypothesis to explain the origin of flight is also discussed here.

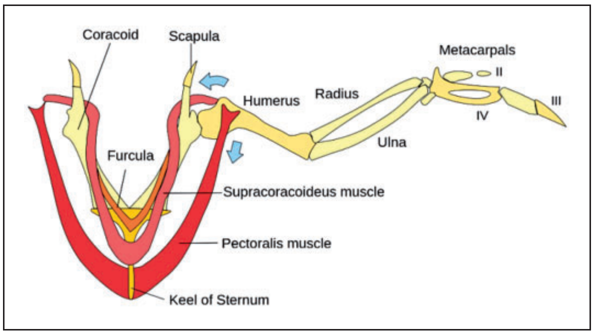

Figure 1. Bird's wing muscle and bones.[8]

Wing anatomy

Flight occurs when an animal is able to produce enough lift and thrust to move its body in the air and complex mechanism is required for getting from the ground and staying airborne. The most obvious adaptations for flight can be observed in bird's wings. In actual birds, the anatomy of the scapular girdle and of the forearm is completely modified to enable them to flap their wings and provide sufficient power for flight. Figure 1 shows a simplified and systematic pictorial version of bird's wing.[8]

In birds, the long bones are particularly light and hollow, housing a network of air sacs from the lungs that help them in storing and circulating oxygen throughout their body. To flap their wings, birds contract their large pectoral (breast) muscles, which are anchored to a keel on their particularly enlarged sternum (breastbone), to pull down the humerus for wing downstroke. The supracoracoideus muscles are used for wing upstroke and helps in twisting and flapping. The powerful skeleton of birds can tolerate all kinds of stresses during take-off, landing, flapping, and changing orientation.[9] The coracoid is elongated, allowing a variety of movements in birds. The clavicles are fused together and form furcula to stabilize the shoulder during the flight. It is the shape and arrangement of feathers that enable the birds to create lift with their wings for free flight. Flight feathers in birds form the large wing and tail feathers provide lift and maneuverability in flight. Remiges are flight feathers of the wing and are divided into primary feathers, secondary feathers and tertial feathers.[10] In modern birds, 9–10 primaries are attached to the fused bones of the hand. Secondaries are inner flight feathers attached to the ulna bone in the bird's forearm. In modern birds, their number varies from 9 to 25, depending on the species. Tertial feathers are the innermost flight feathers of the wing, attached to the humerus bone in the bird's upper arm; there are usually 3–4 tertials. Rectrices are the flight feathers of the tail. Most modern bird species have 10–12 rectrices. Coverts are contour feathers that cover the bases of the flight feathers; they help to even out the incoming air over the wings.

Feather evolution

The oldest known feathered dinosaur's fossil is of Archaeopteryx. After Archaeopteryx, several feathered dinosaurs have been discovered. Theropod dinosaurs may have transitions from scales (*Sauropoda*) to filaments (*Caudipteryx*) and then to feathers (*Archaeopteryx*).[11] These transitions have millions of years between them. In 1996, palaeologists uncovered *Sinosauropteryx*, small bipedal feathered dinosaurs, which had melanosomes in its feather.[12] Since the discovery of *Sinosauropteryx*, Late Jurassic and Early Cretaceous formations in north-eastern China have yielded numerous exquisitely preserved fossils of feathered dinosaurs that document the cumulative evolution of avian characters along the theropod lineage. After two decades of discoveries, feathers and feather-related structures are known to be widespread among dinosaurs, with more than 50 nonavialan paravian taxa, known from a series of fossils with great ranges of size, osteology, limb proportions, and integumentary covering. Although the plumage was not developed for flight initially, feathers subsequently provided aerodynamic capabilities for gliding and flapping flights. The discovery of four wings opens new directions and thoughts related to the evolution of avian flight and feathers.

Figure 2 represents the hypothetical stages in the evolution of feathers.[13] Stage I consists of a hollow cylinder that resembled the calamus of a modern feather strand that turns out from epidermal to form a cavity or filament. Stage II involves the formation of unbranched barbs and a basal calamus. Stage III is further divided into stage III (a) and III (b).[13,14] In stage III (a), secondary branches known as barbules stem from the barbs. In stage III (b), tufted barbs fuse to form a central shaft that are also known as barbules. In stage IV, barbules develop hooklets to interlock adjacent barbs and form a closed vane feather. Stage V represents the development of pennaceous feathers with asymmetric vanes.[14] Figure 3 shows a horned-owl's feather, in which the serrated edge is used to reduce the airflow noise.

During evolution, both the size and mass of carnivorous dinosaurs became smaller and smaller[13,15–17] in order to adapt the needs of agile motion in competing for cursorial running.[3,18,19] Simultaneously, the body started to cover by downy filaments, plumulaceous and pennaceous feathers either for thermoregulation, sexual selection, or display functions.[20–22] Although the feathers were not developed for flight initially,[13,23] they did evolve into flying apparatuses later.

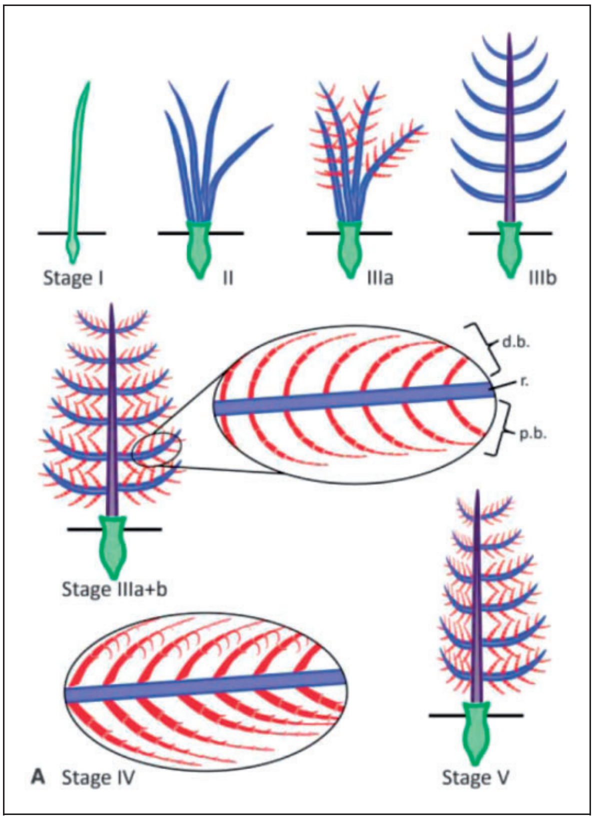

Figure 2. The evolution of feather through different hypothesized stages.[13]

Figure 3. A horned owls feather (Photo credit: David Tomzik).

Origin of avian flight

Even though the idea that bird descended from dinosaurs has now been widely accepted, there is still an intriguing question about how paravian dinosaurs learned to fly. The main arguable opinion is whether the flight began from the trees down or rising up from

Table 1. Summary of the model proposed to explain the origin of avian flight.

Model proposed to explain origin of avian flight	
Arboreal hypothesis	– Proposed by Marsh in 1880 – "Trees down" – Ancestors were tree-dweller and went through gliding stage
Cursorial hypothesis	– Proposed by Williston's in 1879 – "Ground up" – No arboreal phase, nor gliding stage
Wing-assisted incline running	– Individual can move on the incline plane by running while flapping their wings
Cursorial – arboreal transition theory	– The dinosaur ran on an elevated position before parachuting into a tree by utilizing the kinetic, potential, and upslope wind energies

the ground.[2,24] The scientists come to a consensus that the flight might evolve through the stages of ground-dwelling quadrupedal reptile, cursorial bipedal ground-dweller, arboreal life, parachuting, gliding, and actively powered flapping flight.[3,25,26] Historically, theories on the origin of avian flight have been grouped into two opposing camps: arboreal (tree down) and cursorial (ground up), after that many other philosophies and hypotheses have been suggested to explain the origin of avian flight.[27] The model proposed to discuss and explain the origin of flight are summarized in Table 1.

Arboreal theory. This theory was first proposed by Marsh in 1880.[3] The arboreal theory is widely accepted as the hypothesis interprets that the flight ability started from gliding[3,25,26,28] (as shown in Figure 4), followed by jumping from one branch to another in a tree and eventually flying down from an elevated position.[29] It is reasonable to assume that the winged ancestors of birds ought to dwell on trees so that they could have the possibility to glide down. The ancestral dinosaurs of early bird had to get on a tree and then take advantage of the gravitational potential energy to glide. Some palaeontologists investigated the claws of *Archaeopteryx* and found that it was capable of trunk-climbing,[26,29,30] but evidence of fossils in support of this are still weak.[31,32] Therefore, the question of why, how and when a nonvolant dinosaur got up the tree is still unsolved.[3,15,25] This provides a very good opportunity for the scientists in mechanical engineering to investigate the question from the viewpoint of mechanisms, kinematics, and dynamics.

Cursorial theory. This theory was said to be originally outlined by Williston in 1879, and then further explained by Nopsca (1907, 1923).[34] According to this theory, the birds' ancestor lived on the ground where they ran to attain a certain velocity followed by extension of forelimbs and magnification of scales in order to increase the surface area to produce thrust.[3] Figure 5 illustrates the use of wings by Archaeopteryx to produce lift and thrust. The theropods with cursorial skeleton adaption had feathers on their forelimbs and some even had on their hindlimbs.[35] The feathers on hind limbs may hinder their running capacity, making it difficult for them to reach a certain speed suitable for gliding and taking off although many components of the avian flight apparatus evolved originally in the terrestrial environments.[2,3,24,25,28] This is a rather good research direction for the scholars in mechanical engineering rather than those in palaeontology. The seemingly conflicts should be interpreted with the design and experiments of robotic mechanisms with such features.

Wing-assisted incline running. The wing-assisted incline running (WAIR) hypothesis is a derived version of the cursorial model prompted by observations of chukar chicks. Young birds have proportionally thinner limbs, less constrained joints, and symmetric feathers that later develop into asymmetric feathers when growing up. The WAIR model proposes that wings developed their aerodynamic functions as a result of the need to run quickly up very steep slopes, such as tree trunks, to escape from predators. The progression from wing-assisted incline running to flight can be seen in the growth of birds, from when they are hatchlings to fully grown adults.[11,37] Juvenile birds enrich the performance of their wings and legs and ultimately learn how to attain flight capability.

As discussed above, the arboreal hypothesis holds that paravian dinosaurs developed flight by descending from heights, while the major tenet of the cursorial hypothesis is that avian precursors were ground-dwelling theropods that took to the air by co-opting a previously developed wing stroke. Since both of these hypotheses had no connection with each other, and were inadequate to explain the evolution of flight in birds. Therefore, we have recently developed a transition theory,[33] which provides a connection between arboreal and cursorial hypotheses. It explained in detail how theropods might have learned to glide up to the trees or glide between the trees. The biophysical phenomena depended on the upslope and downslope wind of that era as per the meteorological conditions.

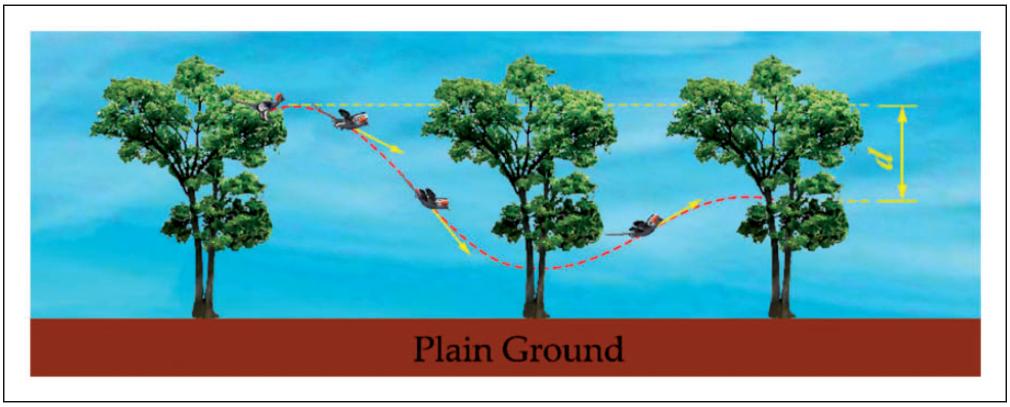

Figure 4. Anchiornis Huxleyi changing its trajectory during gliding.[33]

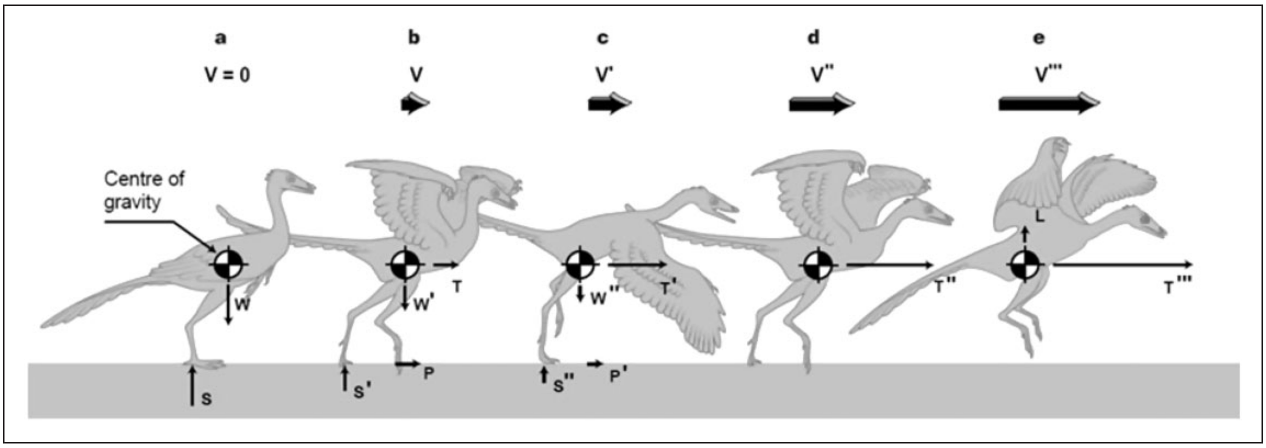

Figure 5. Pictorial model of Archaeopteryx illustrating the generating of lift and thrust.[36]

It was concluded that the dinosaur travelled a longer distance parachuting from an elevated position by utilizing the kinetic, potential and upslope wind energies. These results are considered useful for aerodynamic design and selection of control parameters of the flying robots for testing the theory and designing a kind of gliding vehicle.

In conclusion, it is important to have good knowledge and understanding of different hypotheses created to comprehend the origin and evolution of flight. Among these, *Arboreal* and *Cursorial* theories are the most significant ones because while studying about the flight and morphological aspects of winged dinosaurs these hypotheses play important roles for developing their biophysical phenomena. The evolution of feathers gives an insight of how the feathers were evolved from scales. It can be suggested that the primary purpose of the feather is not flying, but to provide thermal insulation (to trap heat) to survive against diverse weather conditions and to communicate. This opinion seems to be improbable and debatable when looking from an evolutionary point of view.[38] The anatomy structure of bird's wing plays a vital role while developing a bio-inspired or biomimetic MAV or FWMAV, which will have better aerodynamic efficiency and maneuverability. Birds are now believed to be the descendant of theropod dinosaurs due to some similarities in morphology and osteology between them. It is difficult to compare between extinct dinosaurs, extant birds, and transitional phases of them by studying fossils only because the extant organisms have shared some derived features of different extinct species. However, by joining the discovered puzzle pieces, an extensive skeleton evolution from theropod dinosaurs to birds can be studied.

Representative paravians

The discovery of feather and then winged dinosaurs opened a new discussion about the origin of birds. It is safe to say that theropods dinosaurs were the ancestors of modern birds. In this section, some paravians, representing potential intermediate steps between typical cursorial theropods and modern birds are briefly presented.

Caudipteryx

The fossil of *Caudipteryx* (shown in Figure 6) were found in 1997 at Yixian Formation Liaoning, China.[39] *Caudipteryx* was a small feathered dinosaur that belonged to *Oviraptorosauria*, a subgroup of *Maniraptora*.[40] The body of *Caudipteryx* was mostly covered with plumulaceous downy feathers, although pennaceous feathers were developed along its forelimb and at the end of its shortened bony tail. However, these pennaceous feathers were proportionally short, with a slender calamus and a symmetrical vane, so they were not aerodynamically efficient and appropriate for flight.[41] In any case, with its shortened forelimbs and its long and robust hindlimbs, *Caudipetryx* was a cursorial dinosaur not adapted at all for flying or even for climbing in the trees. Pennaceous feathers thus appeared well, before the phylogenetic divergence of paravians capable of gliding or flying.[40]

The three fossils of *Caudipteryx* (measurements are given in Table 2) seem to be mature individuals because of the presence of developed wrist and ankle bones. The feathers of the *Caudipteryx* were symmetrical and were considered as a flightless bird but from that, it cannot be concluded that they could not fly.[16] On the other hand, the size and orientation of *Caudipteryx* legs indicate that they were cursorial in nature. Its shoulder and skull were not fully developed and had a reduced third finger in the skeleton of a limb. The feathers of *Caudipteryx* distress the hypothesis that flight and feather developed together.[42]

Figure 6. Fossil of Caudipteryx zoui Senckenberg Frankfurt, Germany (Photo credit: David Tomzik).

Table 2. Hindlimb measurements of Caudipteryx in mm.[42]

Species name	Femur	Tibia	Tarsus	Total leg
Caudipteryx zoui (NGMC 97-9-A)	149	182	117	448
Caudipteryx zoui (IVVP)	146	193	113	452
Caudipteryx zoui (V 12344)	149	196	124	469

Anchiornis

Anchiornis huxleyi was a small four-wing dinosaur, believed to exist almost 155 million years ago. The first fossil of *Anchiornis huxleyi* was discovered in Yaolugou area, Liaoning, China. Its size was about that of a crow. Pennaceous feathers were developed along its forelimbs, hindlimbs, and tail. Although the feathers along its long legs (mostly its metatarsus and tibia) were proportionally shorter than those along its forelimbs, they likely hindered the cursorial capacities of *Anchiornis*.[43] The feathers of *Anchiornis huxleyi* overlapped each other and cannot be separated which made it difficult to lift-off from the ground.[44] The morphology of fossil suggested that this four-wing dinosaur might have the ability to glide from elevated position.[45] The thorough study of well-preserved fossil helped to get the minor details like the shape of the feathers and their color. Table 3 gives a hindlimb measurement of four different specimens of *Anchiornis huxleyi*, which shows the variations of femur length from 90.5 mm to 50.9 mm.

Microraptor

One of the most impressive discoveries is of a crow-size dinosaur known as *Microraptor*. The details about different features and characteristics of *Microraptor* are discussed in the next section. *Microraptor* was a crow-sized, four-winged dromaeosaurid paravian from the Early Cretaceous of Liaoning, China. Long asymmetrical pennacous feathers are developed along both its forelimbs and its hindlimbs. Since the discovery of *Archaeopteryx*, scientists from all around the world are digging deeper to have a better understanding of the feathered dinosaurs. *Microraptor* is the main focus of this review

Table 3. Hindlimb measurements of Anchiornis huxleyi in mm.[46]

Species name	Femur (left)	Femur (right)	Tibiotarsus (left)	Tibiotarsus (right)
PKUP V1068	88.5	90.5	112	117.7
BMNHC PH804	–	50.9	69.5	69.1
BMNHC PH822	–	70.5	108.6	108
BMNHC PH823	68.7	67.8	95.2	92.13

because the four-wing chapter is the transitional segment between avian and nonvolant individuals and birds in due course lost the feathers on their hindlimbs and developed more advanced and stronger forelimb feathers.[47] Before *Microraptor*, there were dinosaurs with two wings, later the four-winged dinosaurs appeared in the history of avian evolution, but soon after that the feathers on the hindlimbs started to degenerate until disappeared ultimately. This transition from two wings to four wings and then in modern birds again the two wings make this species an interesting area to research.

Archaeopteryx

Archaeopteryx is a basal bird from the Upper Jurassic of Solnhofen area, Germany. Since the discovery of the first specimen in 1861 (housed in the Natural History Museum, London; Figure 7), a dozen specimens have been unearthed in the lithographic limestone quarries from Solnhofen area; however, their systematics remains particularly confusing and it is still uncertain how many species or even genera are in fact represented in the so-called *Archaeopteryx* hypodigm. Because its skeleton is a mosaic of "reptilian" and avian characters, making *Archaeopteryx* a clear candidate for a transitional fossil between nonvolant feathered dinosaurs and modern birds, its flight abilities have been debated for more than a century, ranging from preflight to powered flapping flight. Table 4 summarized some of the potential intermediate paravians between typical cursorial theropods and modern birds. Ostrom emphasised on cursorial aptitude and suggested that *Archaeopteryx* was a flightless individual and use its wings to trap insect to feed on[3] while Feduccia, on the other hand, thought that it could fly.[32]

The flight muscles of *Archaeopteryx* was relatively weak because the muscles include only 9% of the

Table 4. Discovery area and salient features of some representative species in the evolution from dinosaurs to modern birds.

Species	Discovery region	Salient features
Caudipteryx	Yixian Formation Liaoning, China	Have forewings, feathery tail, feathers are small, symmetrical and not aerodynamically efficient
Anchiornis	Yaolugou area, Liaoning, China	Feathers on both forelimbs and hindwings, smaller forelimb feathers, longer hindwing feathers, feathery tail, may glide from an elevated area
Microraptor	Lower Cretaceous Jehol Group, Chaoyang Basin, Liaoning, China	Long feather on both forelimbs and hindlimbs, asymmetrical feathers, suitable for gliding, feathers are aerodynamically efficient
Archaeopteryx	Solnhofen limestone, Germany	Three-fingered hand, have a furcular, toothless beak, enlarge sternum, walked on two feet
Jeholornis	Liaoning, China	Bird-like features, long feathery tail, forewings, few teeth on the lower jaw, movement of the wing might not be effective as a modern bird
Confuciusornis	Yixian and Jiufotang Formations, China	Have beak, two long forewings, bony sternum, short tail

Figure 7. London specimen of Archaeopteryx (Left), Archaeopteryx siemensi in Berlin (Right).

body mass which is far less than the average 25% of the body mass found in modern birds.[48,49] Therefore, even if *Archaeopteryx* was capable of flapping flight, its musculature was likely not powerful enough for generating sufficient lift for taking off from the ground at low velocity.[50] Moreover, the wing articulations likely limited the flight performances of *Archaeopteryx*.[28] The lack of a supracoracoideus pulley, the primary elevator of the wing, would prevent *Archaeopteryx* from executing humeral rotation on the glenoid during the upstroke, a condition necessary for cursorial takeoff. The wrist of *Archaeopteryx* also lacks the interlocking system to execute rapid wing beats during ground takeoff.[28] Flight simulation models already suggested that for *Archaeopteryx*, takeoff from a perch would have been more efficient and cost effective than from the ground. *Archaeopteryx* may have made short flights between trees, utilizing phugoid gliding with this method, and they could travel from treetop to treetop without expending much muscular energy.[28]

Jeholornis

Jeholornis is a primitive bird from the Early Cretaceous of Liaoning, China. Its skeleton closely resembles that of *Archaeopteryx*; however, its teeth were reduced compared to those in *Archaeopteryx* and its bony tail was proportionally longer; both its shoulder girdle and its manual fingers were more robust, suggesting a stronger wing musculature. The most striking difference is the presence of an ossified sternum in *Jeholornis* for insertion of a powerful pectoralis muscle, responsible for wing downstroke as in modern birds.[51,52] *Jeholornis* is also characterized by the presence of two functional feathered tails: one like that of some modern birds with a fan-shaped tract of feathers over the proximal tail vertebrae and another distal frond like that of feathered dinosaurs such as *Caudipteryx* and *Microraptor*. This unique "two-tail" plumage likely served both aerodynamic (flight and balance) and ornamental functions.[53]

Confuciusornis

Figure 8. Confuciusornis's fossil in Nature Museum Senckenberg Frankfurt, Germany (Photo credit: David Tomzik).

Confuciusornis was a small-sized dinosaur, almost the size of a crow, dated back to 125 to 120 million years ago.[54] Figure 8 shows the fossil of *Confuciusornis* resides in Naturmuseum Senckenberg located in Frankfurt, Germany. It shared a lot of common features with the modern bird including a beak, a shortened bony tail, a keeled ossified sternum, its skull still resembled that of the theropods dinosaurs in the presence of a bony arch separating the eye socket from the infratemporal fenestra, causing the immobility of the beak relative to the back of the skull. The humerus is particularly large and pierced by an oval hole that reduced the weight of the bone, but also enlarged the attachment area for the flight muscles. Like in modern birds, the scapulae were fused to the coracoids and may have formed a solid base for the attachment of wing muscles. However, as in *Archaeopteryx*, the shoulder joint was oriented laterally instead of angled dorsally as in modern birds and *Confuciusornis* was unable to lift its wing high above its back. *Confuciusornis* was therefore incapable of the upstroke required for flapping flight.[55] The stomach content of *Confuciusornis* contained fish remains, suggesting that *Confuciusornis* was an omnivorous bird.[56] It had a beak, a bony sternum like *Jeholornis*, a simple skull, short tail and two long wings that are similar in shape to those of extant birds.

Flight feathers in *Confuciusornis* were asymmetrical and the primary feathers were longer than the secondary feathers as in modern birds. However, the central shafts of the primaries were too thin and weak to have remained rigid during the power stroke required for flapping flight.[15] Whether their thin and relatively weak wings were able to produce enough energy for power flight and to insure stability and control over its flight[57] remain open questions that should be answered by mechanical engineering investigations.

These still unsolved questions provide theoretical and experimental topics for mechanical design and manufacturing on the one hand, and on the other hand, their solutions should also allow to design more efficient flying robots. Interestingly, many specimens of *Confuciusornis* preserved a single pair of long, streamer-like tail feathers, similar to those present in some modern birds-of-paradise. The presence or absence of those tail feathers might reflect sexual dimorphism.[58]

Flying capabilities of *Microraptor*

General morphology of Microraptor

Microraptor was first described in 2000, as the smallest known nonvolant theropods dinosaur: adult specimens are estimated up to 77 cm with a weight up to 1 kg.[18] Numerous well-preserved specimens have been discovered in the meantime, all from the Early Cretaceous Jehol Biota of Liaoning, China. Three species have been named so far (*M. zhaoianus*, *M. gui*, and *M. hanqingi*), although some palaeontologists have suggested that all of them represent variation in a single species, *M.* zhaoianus.[59,60] Figure 9 depicts a fossil of *Microraptor gui*, found in Liaoning province (China) and cast of fossil plate resides in Seckenberg Frankfurt, Germany. *Microraptor* has a short trunk, a fused sternum and shoulder structure that is almost similar to those of modern birds.[26] Although its skeleton closely resembles that of basalmost birds including *Archaeopteryx*, *Microraptor* is classified within the nonavian theropod family Dromaeosauridae, together with iconic "raptors" such as *Velociraptor*, *Deinonychus*, and *Dromaeosaurus*.

In 2003, the discovery of *Microraptor gui* was particularly important, because it documented the first evidence that basal dromaeosaurid dinosaurs had four wings, one on each of its forelimbs and hindlimbs, somewhat resembling one possible arrangement of the quartet of flight surfaces on a tandem wing aircraft of today. Long pennaceous feathers with asymmetrical vanes were developed along the arms, legs, and tail of *Microraptor*. It had both primary and secondary flight feathers. This standard wing pattern was mirrored on the hindlimbs, with flight feathers anchored to the upper foot bones as well as the upper and lower leg[26,47] and probably could glide, representing an intermediate stage towards the active, flapping-flight stage.[26] The orientation of the shoulder joint possibly allowed the flapping of wings in downward and upward strokes[55] and the development of an ossified sternum allowed the development of a powerful brachialis muscle, suggesting that *Microraptor* potentially possessed active flight capabilities. The wings of *Microraptor* were larger than those of *Archaeopteryx* which might help it generate more lift.[61] The flight feathers in extant birds are organized in the similar fashion to that of hind wing of *Microraptor*.[26,47] The long feathers on the hindlimbs suggest that *Microraptor* was not a fast-running terrestrial dinosaur,[62] because such long feathers likely provided resistance to fast running, in contradiction to the cursorial hypothesis for the origin of flight.[63,64] As in modern birds, the flight feathers of *Microraptor* were rooted deeply in the soft tissue of the animal with their very base touching or articulating with the wing bones.[65]

Figure 9. The fossil of *Microraptor gui*, Senckenberg Frankfurt, Germany (Photo credit: David Tomzik).

The manual and pedal claws of *Microraptor* were elongated, curved and had pointed tip, resembling those in extant climbing animals (woodpeckers) and perching birds.[32,47] The small size and other structural features of *Microraptor* are also compatible with arboreal habits, but further evidence, including the construction of an accurate *Microraptor* robot, is urgently needed to test this tree down hypothesis.[18] In the next decade, there will be a lot of joint research projects between palaeontologists and scientists in mechanical engineering.

Osteology of Microraptor

Xu et al.[18] described the specimen of *Microraptor zhaoianus* (IVPP 12330) as extremely small animal, almost 47 mm in length. The fossil (IVPP 12330) has an incomplete structure i.e. fragmentary skull, hands, and hindlimbs, but besides some incomplete parts, it had complete ribs, pelvic girdle and tail. *Microraptor zhaoianus* had mix features of both troodontids (teeth and metatarsals) and paraves (ischium and sacral).[18] The well-developed femur, fused sacral vertebrae, and dentition indicates that the discovered fossil of *Microraptor zhaoianus* is of mature animal.[15,48,49]

After the discovery of fossil (IVPP 12330), new specimens of *Microraptor zhaoianus* (CAGS 20-7-004 and CAGS 20-8-001) were described by Hwang et al.[66] The animal described by them was almost 55 cm in length, had incomplete manus, pectoal girdle, ilium, and cervical vertebrae. Although both the specimens lack many important parts only CAGS-20-8-001 was well sustained. The morphology and anatomy of the skull, vertebrae, ribs, pectoral girdle, pelvic girdle, forelimbs, hindlimbs, and dentition had been described and discussed in detail for both the specimen.[66] The features of CAGS 20-7-004 and CAGS 20-8-001 were similar to different clades of theropod dinosaurs thus making *Microraptor* an important research element in relation to evolution and origin of flight.

In 2002, Xu et al.[26] uncovered a new specimen of *Microraptor* (IVPP V13352) from Chaoyang western Liaoning, China and named it *Microraptor gui*. *Microraptor gui*, identified as small dinosaurs about 77 cm in length, had feathers on both forelimbs and hindlimbs, long feathery tail, large sternum, fused scapula, and had approximately 26 vertebrae.[26]

Li et al.[67] investigated an exceptional specimen of *Microraptor* (BMNHC PH881) uncovered from Jianchang, western Liaoning (shown in Figure 10

Figure 10. *Microraptor's* fossil (BMNHC PH881) (Left); reconstructed model of *Microraptor* by Li et al.[67] (Right).

(Left)). The feathers are so exquisitely preserved than even tiny melanosomes, the light-absorbing organelle in animal cell, are fossilized, giving precious indication about the color of the feathers of *Microraptor*. The feathers of *Microraptor* were reconstructed (shown in Figure 10 (Right)) as black glossy structures and were asymmetrical on both forelimbs and hindlimbs. The iridescence in *Microraptor* might be helpful in hiding from enemies, giving a signal, or melanosome alignment strengthening the feathers.[68] The feathers on the tail might be just embellishment in primitive coelurosaurs later modified into the bony structure in paraves.[69] *Microraptor* (BMNHC PH881) had few serrated teeth and the caudal vertebrae were longer than those of the anterior dorsals.[60]

With the passage of time new and complete specimen had been discovered, such a new specimen was described by Gong et al.[70] The anatomical details, morphological characteristic, and gliding behavior of *Microraptor hanqingi* (the new name given by them) were discussed and explained. The holotype of *Microraptor zhaoianus* was incomplete and lack many important features and also some parts of *Microraptor gui* were extremely damaged and difficult to reconstruct. *Microraptor hanqingi* was 95 cm in length with a total mass of 2 kg, which made it larger than both of the other specimens. Four-wing plays an important role in the evolution of flight and is considered to be like a bridge from primitive non-volant dinosaurs to modern volant birds.[70]

Flight of Microraptor

Birds have different kinds of flights depending upon how they move their wings, most common of them are gliding and flapping. Gliding is the naivest form of flight in which the bird moves forward using its own weight to overcome the resistance of incident airflow. For gilding, the bird must reach at a certain velocity to travel a definite distance. For steady-state flight, the velocity of a bird remains constant and the sum of all forces (lift, drag, and weight) is equal to zero. Flapping of wings involves a complicated mechanism. When a bird flaps its wings, they produce lift which in turn generates a forward motion known as thrust. Flapping involves upstroke and downstroke motions. Downward stroke provides the major portion of thrust. During the upstroke, the bird slightly folds its wings inwards to reduce the metabolic energy that the bird consumes in flight. During flapping, the angle of attack constantly changes to stabilize and control the flight.

Xu et al.[26] first suggested that *Microraptor* and basal droameosaurids were arboreal animals, and that the ancestor of birds first learned to glide by taking advantage of gravity before flapping flight was acquired in birds. The four-wing configuration can be regarded as a transitional step between non-volant theropods and modern birds, which gradually lost their elongated hindlimb feathers and developed more efficient and stronger forelimb feathers.[35,47] The wings of *Microraptor* might be used as parachute, jumping from an elevated region to trap or attack on its prey.[71] However, it has been argued that *Microraptor* could not spread its hind wings straight to act like wings because of the body plan of *dromaeosaurids*.[20] *Microraptor* would have a better flight if it tucked its hind wings under its body, by doing this it would be able to take turn at the doubled speed as two-winged dinosaur.[47] All these theories can be proved via the reconstruction of the dinosaur robots and experiments in natural environments.

For flying or gliding, the asymmetry in feathers helps to increase the wing area along with the reduction in weight.[72] The asymmetrical trait in *Microraptor's* feather was not as prominent as that in modern birds and possibly overlap each other over the entire length. From gliding perspective, the orientation of the legs also plays a significant role in flight dynamics. Gliding from a tree of 20–30 m height does not require complex wing mechanism only the wing area is important in this regard.[72] *Microraptor* was supposed to glide like mammals such as flying squirrels and flying frogs but lack the true phenomena of flying. These mammals take off from the high place, stretched the membrane of their arms and legs to maneuver.[38,41,73] The gliding mammals comparable to *Microraptor* are mostly fruit eaters but because of limited airborne abilities of primitive dinosaurs, *Microraptor* seems to be a carnivorous.[74] The morphology and living manners of *Microraptor* make it similar to flying lemur (*Cynocephalus volans*), which is a gliding mammal.[70] Direct fossil evidences show that *Microraptor* was an opportunistic hunter, able to feed upon a wide variety of potential preys, including small mammals,[75] tree-perching birds,[74] and fishes,[76] in both aquatic and arboreal environments. The teeth of *Microraptor* were supposedly designed for easy swallowing food without ripping them.[77] The evidence related to the eating habits of the extinct organisms is very exceptional and difficult to find out. A few years ago scientists discovered *Microraptor's* fossils containing some fish bones in the gut.[74] The eating behavior of *Microraptor* showed that it was an adaptable feeder, which looked for different opportunities in then existing ecosystem.[70,74]

The flight feathers help in producing lift and thrust, thereby facultative flight. A lot of information can be extracted from the theropod dinosaur fossils discovered in China.[78] Previously, Xu et al.[26] believed that feathers in *Microraptor's* specimen were incomplete and might not be attached to the bone and they calculate the feather's measurement according to the assumption. Hone examined the same specimen (IVVP V 13352) under ultraviolet light and found that the feathers were attached to the bones.[65]

Aerodynamic performance of Microraptor

The capacity for aerial stability and maneuvering was evidently a major influence on the evolution of flying animals.[79] The presence of feathers along the hindlimbs and bony tail of *Microraptor* and the different possible orientations of its legs affected the stability characteristics and its flight performances. In extinct organisms, flight performances can be estimated by studying the aerodynamic and biomechanical aspect of reconstructed models. Different *Microraptor* models have already been proposed based on different fossils, to investigate the effect of aerodynamic forces, aerodynamic stability, and controlling the wings.

The feathers can be categorized into plumulaceous (that covers the body) and pennaceous feathers (attached to limbs and tail). The arrangement of pennaceous feathers on hindlimbs of *Microraptor* can be comparable to modern birds, providing some clue about the aerodynamic capability. Xu et al.[26] reconstructed limbs of four-winged *Microraptor* as tandem wings similar to those of insects and gliding fish, where all wings are spread horizontally in tetrapteryx fashion. The long asymmetric pennaceous feathers on hindlimbs first produced and later degenerated. Long feathers on hindlimbs cause resistance towards running on the ground which is a negative point towards cursorial theory. *Microraptor* and other primitive dromaeosaurids are considered to be arboreal that glide down from trees before learning how to flap their wings.[26]

Chatterjee and Templin[80] offer an alternative planform of the hindwing of *Microraptor* that is concordant with its feather orientation for producing lift and normal theropod hindlimb posture. In this reconstruction, the wings of *Microraptor* could have resembled a staggered biplane configuration during flight, where the forewing formed the dorsal wing and the metatarsal wing formed the ventral one. The contour feathers on the tibia were positioned posteriorly, oriented in a vertical plane for streamlining that would reduce the drag considerably. A computer simulation of the flight performance of *Microraptor* suggests that its biplane wings were adapted for undulatory "phugoid" gliding between trees, where the horizontal feathered tail offered additional lift and stability and controlled pitch.[28,80]

Dyke et al.[81] studied the performance of *Microraptor* aerodynamically through experiment and simulation. Figure 11 shows the reconstructed model of *Microraptor* along with the possible aerodynamic forces acting on the body. To glide more efficiently *Microraptor* needs to increase the wing area. *Microraptor* could have adjusted its wing area by changing the orientation of its legs.[72] The feathered and unfeathered model behaved similarly which shows that feathers were evolved to perform some other function rather than producing lift. The presence of five feathered elements makes the flight mechanism of *Microraptor* more complex. The gliding trajectories obtained during the experiment did not show any similarity to the flying mammals nor to modern flying birds. The presence of feathers on their hind limbs might be a stage during the process from nonflying to flying modes.[81]

Hall et al.[82] observed that the prior models for *Microraptor* flight implied a strongly abducted position of the hindlimbs that require an implausible orientation of the hip socket They suggested an alternative model in which the hindwings were generally held below the body during steady flight, but deployed unilaterally, or bilaterally, to produce additional roll and yaw during unsteady flight maneuvers, such as turning. In this way, the hindwings could serve as control surfaces, enhancing maneuverability. Deployment of the hindwings as control surfaces held below the body generates substantial potential locomotor advantage, is supported by aerodynamics and requires no unusual positioning of the hindlimb.[82]

Evangelista et al.[83] mapped on a phylogenetic tree results of aerodynamic testing to examine how

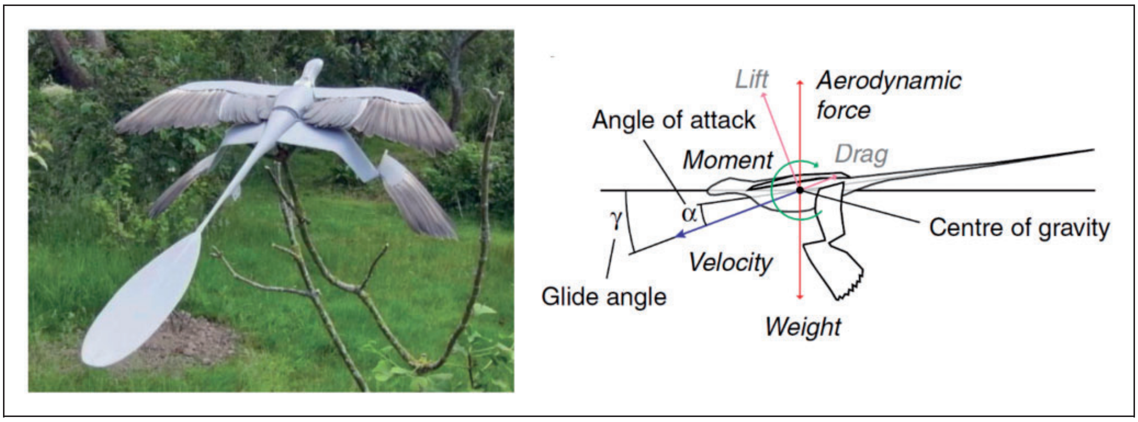

Figure 11. The three-dimensional model of *Microraptor* constructed by Dyke et al.[81] (Left); different forces and moments illustrated through free body diagram (Right).

Figure 12. A flying robot inspired by the morphology and flying mechanism of herring gull[94] (Left); biomimetic marine robot inspired by Flying Fish.[95]

maneuvering characteristics correspond to tail shortening, forewing elaboration, and other morphological features. In the evolution of Paraves, they observed shifts from static stability to inherently unstable aerial planforms; control effectiveness also migrated from tails to the forewings. These shifts suggest that some degree of aerodynamic control and capacity for maneuvering was already present in basal birds and *Microraptor*, preceding the evolution of a strong power stroke.

Besides *tree-down* and *ground-up* hypotheses, wing-assisted incline running (WAIR) hypothesis was also proposed to contribute to understanding the flight evolution.[84] In WAIR, the process of developing powered flight in young birds is observed. Young birds have thin limbs, less constrained joints, and symmetric feathers that later develop into asymmetric feathers when grown up. Juvenile birds enrich the performance of their wings and legs and ultimately learn how to attain flight capability. Legs are the important features in developing flight from nonflying juveniles to flyable adult birds and it can be connected with the development of hind wings in dinosaurs.[85]

Biomimetic design inspired by flying creatures

Biomimicry approach or brainstorming about incentive from nature and putting them in technological or mechanical design is a new technique in research. The research going on in this area unconcealed that there is a lot to be learned from birds, insects, and bats, from walking on the ground to getting enough power to be airborne. The fundamental phenomena related to flying capabilities of bird, bat, and insect were used in the development of bioinspired devices[86,87] and investigating about their anatomy,[87] aerodynamics,[81] and control.[88] Figure 12 shows some example of a biomimetic model that was developed by taking inspiration from animals. Flapping flight robots, fixed-winged flying robots, and MAVs get their inspiration from either birds or insects.[89] The concept of biology combined with mechanical design and techniques can lead us to try out hypothetical statements about the evolution and origin of flight. Biomimetic robots are strong and robust enough for the biologists to investigate the dynamic performance of biological systems of the extinct and extant living beings.[90] The biomimetic approach can also be used to solve various engineering problems. One such example is related to the turbulence of aircraft that has been solved by mimicking the flight performance of a gliding bird. The drag prompt by wingtip vortices can be decreased because of the feather arrangement of the birds and this arrangement can be used by aircraft to improve the stability and efficiency.[91]

The flapping motion of wings which is related to a broad range of flying animals produces enough lift and thrust to remain airborne. Attributes such as wing size, speed of flight, and Reynolds number play an important role not only for animals but also for the biomimetic models.[92] The FWMAV is one of the latest development in the biomimetic or bio-inspired area, which focuses on both insect flapping and bird flapping.[93] The wing design is important in FWMAV, with quality design and better driving mechanism the aerodynamic performance along with the stability of biomimetic devices can be improved.[92]

Widharini et al.[96] experimentally investigated the flapping and twisting system of FWMAV by using bird's flapping to evaluate the aerodynamic capability, frequency, and speed with double-crank driving system. The double-crank driving system with twisted and high camber wing has a larger flapping angle and generates more lift as compare to single crank mechanism. Malolan et al.[97] developed a mathematical model for flapping wing MAV at different velocities and flapping frequencies. They used a sliding link mechanism along with a moveable hinge mechanism to have a phase lag of about 17.93° and showed that incoming air velocity was directly proportional to the lift of MAV. The lift generated by an MAV greatly depends on the wing planform.

Recently UAV has achieved a lot of attention because of its diverse applications not only in the air but also in water. Yang et al.[98] worked on the biomimetic submersible unmanned aerial vehicle inspired by the gannet, which has remarkable ability to do aerial plunge diving by entering the water at a speed of 68 m/s as a seabird.[99] While doing plunge diving, the gannet experienced a lot of impact force, so the biomimetic model must be strong enough to bear the shocking. The center of this research was the impact force experienced by the biomimetic model, whose wing was designed to remain folded even under the water in order to minimize the value of drag and maximize the value of lift in air.[98] The problem with this model is that it only focuses on plunge-diving from air to water but does not consider the scenario of taking off from water to air.[100]

Liang et al.[101] made a bionic gannet by using its structural anatomy and mechanism of folding and unfolding its wings to imitate its diving process. The body structure was made of aluminum while the wings were designed taking carbon fiber as a material. The experiment was conducted to calculate its plunge velocity, underwater velocity, underwater depth, and impact acceleration. The $-167.20\,\mathrm{m/s^2}$ utmost impact acceleration, when dropped from a height of 10 m and had a 90° inclination angle, showed that large impact along the lengthwise direction of the body might cause critical damage to the structure. To avoid such structural fracture the swept-back angle of the wing should be designed with particular attention.

Liang et al.[102] made another biomimetic gannet which they called Mimic-Gannet (as shown in Figure 13). The focal point of this research was the loading on the wing while the plunge-diving action. Experiments were conducted on the biomimetic model to calculate wing loading for different incline angles, sweptback angles, and dropping heights. The radial load showed a directly proportional relation with the dropping height and inclination angle while it shows inversely proportional relation with the

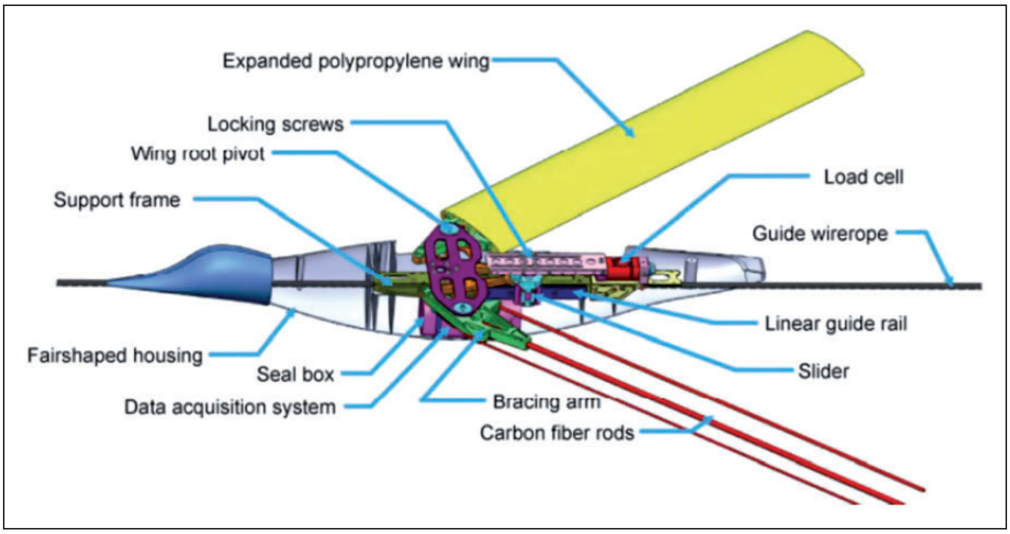

Figure 13. The complete detailed structure of Mimic-Gannet.[102]

sweptback angle. The problem with this biomimetic model was its larger structural characteristics when compared to real gannet especially the weight which greatly diverts the performance of the model from actual bird.[100]

The flight simulation model of an ornithopter (flapping-wing air vehicle) was developed using a refined flapping-wing aerodynamic model and the concept of fluid–structure interaction. An improved version of modified strip theory was chosen to model the complex aerodynamics of flapping wing. The numerical design of a magpie-sized model ornithopter was simulated to study the variables like pitch attitude, altitude, and flight speed during the trimmed flight. The physics of ornithopter trimmed longitudinal flight was explained using the concept of zero moment point and the constrained forces and moments were measured by fixing all the degrees of freedom at the centre of gravity. It was found necessary to consider the flexible multibody dynamics and fluid–structure interaction in order to simulate the trimmed flapping-wing flight.[103]

Some species of animals possess the splendid capability to move both in air and water either for shelter or for food. To replicate the behavior of locomotion in both environments is a difficult and challenging task. Chen et al.[104] designed a biomimetic flapping winged microrobot which could move both in air and water and analyzed all the challenges faced during the transition from air to water. The inertial forces abate at a very small scale which makes the microrobot more stable while experiencing an impact or collision. They used the phenomena of electrochemical reaction and increased buoyancy force to slowly drive the wings out of the water while maintaining the robot's stability. They concluded that at certain frequencies the stability of flapping winged robot become steadied during swimming process.

Perching birds usually known as songbirds can grip a perch tightly without active muscle control even when they are asleep. A passive flying robot inspired by perching birds, designed by Doyle et al, which can perch and stabilized itself on a variety of surfaces. Such biomimetic robots, when equipped with sensors and a camera, become useful and beneficial commercialized products. The design consists of perching and leg mechanism that passively actuate the foot. The results showed that the designed foot can perch on different surfaces and resist various environmental disturbances, by changing the length and sections of the foot, better grips can be achieved.[105] Colmenares et al.[106] worked on the FWMAV, mimicking the biological wings, which is driven by the motor and have the ability to take off from the ground. The results showed that the system designed can improve lift production by 53.2% when compared to the previous rigid design. Optimization of wing profiles is carried out to increase the production of the lift. There is also a decrease in the drag which in return progresses an increase in the rotation of the wing, translational and rotational lift.

Besides birds, insects are also exquisite biological creatures to develop biomimetic model imitating their aerodynamics capabilities which can be later used to design MAV. Sun et al.[107] developed a three-dimensional model of *Dorcustitanus platymelus,* a beetle, mainly focuses on the aerodynamics of its hindwings. The results obtained from flight simulation of the model showed that the pressure distribution in the veins of beetle's body, tail, and hindwings gave important and beneficial information that can be used in flight dynamics while designing MAV. The pressure of blood in veins was higher as compared to hindwing surface, which helps the beetle to have durable flight and the structural form of the beetle hindwing was malleable, which greatly affects its aerodynamic performance. Both of these aspects gave useful information about designing a biomimetic model inspired by *Dorcustitanus platymelus.*

Ha et al.[87] did static and vibration analyses of beetle, *Allomyrina dichotoma,* by focusing on its hindwings. Their experimental results show that wing area density greatly affects the natural frequencies of the wing and natural wing also acts like a cantilevered beam. A biomimetic wing was also designed, inspired by *Allomyrina dichotoma*, to evaluate its performance compared to natural wing. A four-bar linkages mechanism is designed by taking inspiration from the beetle, *Allomyrina dichotoma*, to mimic the rotational and folding/unfolding motion of its hindwing. The mechanism can fold and unfold its hindwing without any external power source and can maintain a fully unfolded position during flapping phase at a frequency of 26 Hz. The system can generate enough thrust despite having extra weight because of the artificial wing structure. The proposed mechanism is beneficial to give an understanding and vision to design an FWMAV.[108]

Unlike gliding, the flapping flight is rarely used for locomotion in the extinct organisms. Pterosaurs were the species that might have adapted the intricate morphologies and physiologies needed to have a flapping or powered flight. Fossil data discovered and recovered from the different formations in China have provided a strong view related to the transition from theropod dinosaurs to modern birds and different models were proposed to discuss and explain the origin of avian flight (discussed in ''Bird anatomy and origin of flight'' section). Study of the muscles, ligaments, and their movement are very difficult to estimate especially in extinct organisms. Exploring the flying capabilities, behavior, freedom of motion, and rolling angle of the wings of modern juvenile birds will provide a better perception about the extinct organism's flight. Biophysical phenomena, kinematics, and dynamics analysis along with the experimental results based on the reconstruction of the extinct/extant organisms will help to understand the evolution of

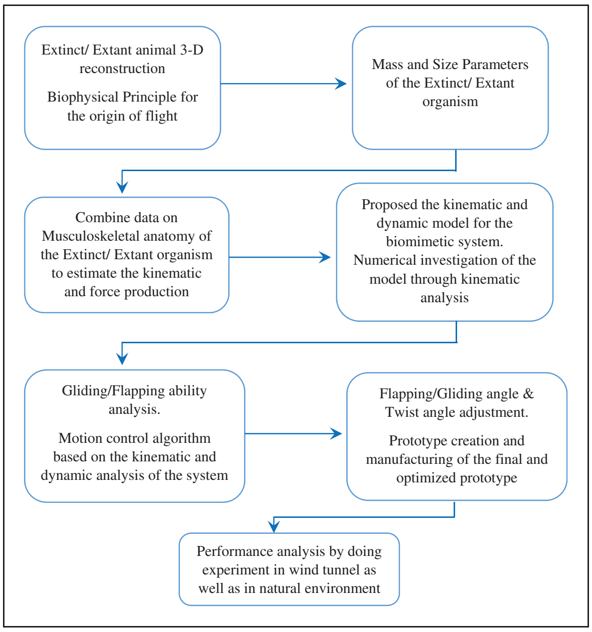

Figure 14. Flow chart of the proposed road map or route to achieve a biomimetic aerial robot.

flight better and deeper. It will further provide guidance related to the design of mechanisms for modern flapping macro and micro biomimetic aircrafts. Having all the biological and mechanical phenomena in mind the biomimetic robotic system will be analytically calculated, simulated, and evaluated based on experiments. A flow chart of the proposed road map or route to achieve a biomimetic aerial robot is provided in Figure 14.

Conclusions

It is the main objective of this review is to provide an insight into the origin of avian flight by considering the evolutionary, biophysical, and mechanical viewpoints. Biologist and engineers are working together to develop a new field of research, which uses knowledge from both fields and merge them to form beneficial output in theory and application. The study of the evolution of flight will play a great role in this field as the transition from winged dinosaurs to birds have a lot of hidden knowledge and information that will help in the development of flying and flapping vehicles. Regarding the origin of *Microraptor's* flight, scientists have been focusing on both the *ground-up* and *tree-down* scenarios, agreeing on the fact that both forewings and hindwings had asymmetrical feathers. These fossils of *Microraptor* record particular details, facts, figures and statistical data that helps a lot in defining the position of *Microraptor* in the clade and its linkage to birds and other winged dinosaurs. The morphology of the feathers and structure of claws gives it the advantage to be more closely hypothesized as flying or gliding animal. Accurate and precise morphology of feathered and winged dinosaurs is difficult to anticipate but through biomechanically and aerodynamically reconstructed model some estimated results could be achieved. The intense discussion and argument about the origin of flight give us a lot of information and evidence that birds are descendent of theropod dinosaurs. Different dynamic and kinematic models can be developed to study the morphology of extinct and extant organisms which will allow us to dig deeper into the transitional phase and help us in understanding their structure and aerodynamic abilities. Of course, these researches will enrich the design of flying robots in return.

Acknowledgement

We would like to thank Mr David Tomzik for providing the photograph taken during his visit to European Museums.

Declaration of Conflicting Interests

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by the National Natural Science Foundation of China (51575291) and the Science and Technology Major Project-Advanced NC Machine Tools & Basic Manufacturing Equipments (2014ZX04002051).

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