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Benjamin J. Goodheart

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**TRACING THE HISTORY OF THE ORNITHOPTER: PAST, PRESENT, AND FUTURE**

Benjamin J. Goodheart

Since the earliest recorded history, humans have shared a nearly universal desire for the freedom of flight. This obsession with escaping gravity's unblinking gaze to somehow slip aloft, even for a fleeting moment, has inspired many to wax poetic about the dream of flight. Looking to nature's design, man for years attempted to replicate the flight of the bird, and even its predecessor, the pteranodon, in many a bid to break free of his earthly bonds. Though science eventually shifted its focus to balloons, and then to fixed-wing flight, as a means of sustaining flight, the freedom and effortless grace of birds is as captivating now as it ever was. From the earliest days of man's dreams of launching himself skyward to today's advanced designs, flapping-wing craft, known generally as ornithopters, have held a constant place in the quest to achieve the flowing elegance of flight so easily mastered by nature's own aeronauts. In the past several years, aircraft which capitalize on the mechanics of bird flight have enjoyed a renaissance of sorts. From the recent first flight of a human-powered ornithopter, to flapping-wing designs incorporated in nano-scale unmanned vehicles, aviation design has in many ways come full circle. This paper examines the history of, and influences on, ornithopters and their design, and investigates developments and future trends of this uniquely inspired aircraft.

**A Storied History****Infancy**

The earliest of those to experiment with flapping wing devices are often referred to by aviation historians as "tower jumpers" (Brady, 2000). In keeping with their title, these aspiring aviators typically followed the approach of the mythical Daedalus, often building a set of wings from actual feathers. Though records of attempts to fly in this manner exist as early as A.D. 60, perhaps the first attempt to be met with some success was that of Eilmer, a Benedictine monk who was seriously injured after gliding about 200 yards from the tower of Malmesbury Abbey in 1060 (Alexander, 2009). Many years later, the art of flight had not advanced appreciably, as in 1742, the Marquis de Bacqueville met

with a fate similar to his monastic predecessor when he too leapt from a tower to fly across the river Seine. His attempt fell short, and he had only covered half the distance across the water when he fell to a passing boat below.

As early as the thirteenth century, the scientifically inclined Franciscan monk Roger Bacon suggested a flying machine that was propelled by "artificial wings to beat the air," offering what is likely the first written record of an ornithopter (Wegener, 1997, p. 9). Bacon was probably the first to formally breach the subject of ornithopter flight; and little else exists in the literature until around 1486, when Leonardo da Vinci, the Florentine scientist and painter, sketched in his notebook a device (Figure 1) designed to be powered by a man (Anderson, 1997).

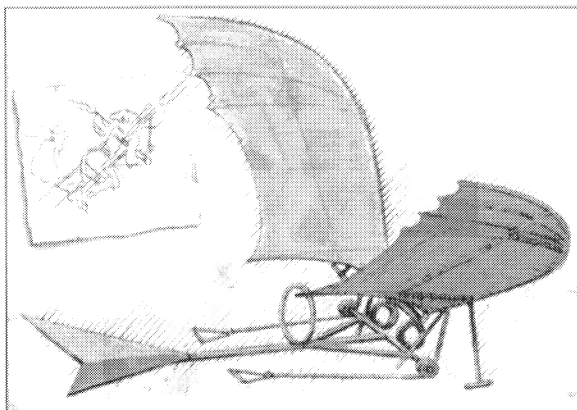


Figure 1. Da Vinci ornithopter.

Da Vinci's ideas set him apart from his predecessors in that, rather than simply strapping a set of wings to a man's arms, they called for a machine that would carry a man while efficiently harnessing his power. Da Vinci's variety of ornithopter designs called for a pilot either prone or standing and operating the flapping wings by alternately pushing or pulling on several levers. In each of his sketches, the pilot was to provide the motive power by which the machine would achieve lift as well as propulsive energy (Anderson, 1997). His designs even included a transmission of sorts to convert a rowing motion into a vertical flapping movement (Alexander, 2009). In addition to his drawings of flying machines, da Vinci also sketched an elaborate device whereby an ornithopter wing could be tested. The operator was to stand on one pan of a scale, balanced by weights, and flap the wing. The resulting imbalance caused by the wing's lift would cause the weighted pan to lower (Anderson, 1997). The thoughtful nature with which da Vinci pursued his study of flight was further revealed in his examination of retractable landing gear and hinged valves by which air would flow freely through the wings during the upward stroke (Anderson, 2002). Though da Vinci's drawings now seem contrary to modern scientific knowledge about the mechanics of flight, they represent the first serious, logical

investigations of a flapping wing flying machine.

#### **Developments in the Nineteenth Century**

Apart from a few ill-conceived and unsuccessful attempts at flight, progress in aviation remained largely stagnant after da Vinci until the beginning of the 19th century (Berget, 1911). Though the popular image of a flying machine remained deeply rooted in the flapping wing designs exemplified by da Vinci, many in aviation were distracted by the enthusiasm for ballooning that had taken hold by the end of the 1700s (Anderson, 2002). At a loss for a practical means of generating propulsive force in heavier-than-air craft, balloons provided a simpler means by which the bond of gravity could be overcome. Balloons, however, contributed little to the development of heavier-than-air flight, and probably delayed advancement of the airplane as well as the ornithopter (Anderson, 1997).

Balloons did inspire Sir George Cayley, whose interest in flight was piqued by the invention of the hot air balloon by the Montgolfiers. After conducting some experimentation with flying helicopter models, Cayley shifted his focus to fixed-wing designs (Brady, 2000). In 1799, Cayley etched his ideas on a silver disc, clearly depicting for the first time an airplane with separate sources of lift and thrust, as well as a tail that foreshadowed the design used in most modern

aircraft (Anderson, 1997). Cayley's research led him to believe that many experimenters had been pursuing flight in ways unsupported by science. Writing on the subject, Cayley issued the following prophetic words that were to predict the future of aviation, and signal the eventual demise of the ornithopter, and especially the human-powered ornithopter, as the primary design on which aircraft were to be modeled:

The idea of attaching wings to the arms of a man is ridiculous enough, as the pectoral muscles of a bird occupy more than two thirds of its whole muscular strength whereas in man, the muscles that could operate upon the wings thus attached, would probably not exceed one tenth of the whole mass. There is no proof that, weight for weight a man is comparatively weaker than a bird; it is therefore probable, if he can be made to exert his whole strength advantageously upon a light surface similarly proportioned to his weight as that of the wing to the bird, that he would fly like a bird ... I feel perfectly confident, however, that this noble art will soon be brought home to man's general convenience, and that we shall be able to transport ourselves and our families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour. To produce this effect it is only necessary to have a first mover, which will generate more power in a given time, in proportion to its weight, than the animal system of muscles. (Gibbs-Smith, 1962, pp. 213-214)

Cayley's prediction did not explicitly denounce the ornithopter as a viable means by which flight could be achieved. However, his experimentation and subsequent designs made significant advances in the understanding of how fixed-wing aircraft fly (Brady, 2000). It is safe to say that just as balloons temporarily distracted aviation enthusiasts from heavier-than-air flight, Cayley's work substantially shifted the focus from ornithopters to fixed-wing craft (Anderson, 2002).

Undaunted, or perhaps unaware of the aeronautical developments around him, a Vienna clockmaker named Jacob Degan built an ornithopter with strange, umbrella-shaped wings. To help support the weight of his machine, Degan affixed a small hydrogen balloon to the contraption and managed to get a few feet off the ground in an 1810 attempt (Alexander, 2009). Probably spurred on by the burgeoning industrial revolutions in England and Western Europe, there were many attempts to fly human-powered

ornithopters in the first half of the 19<sup>th</sup> century (Alexander, 2009). By mid-century, ornithopter design had become significantly more complex but not more successful. Jean-Marie le Bris, a French sea captain, built two ornithopters between 1855 and 1868. The sophisticated craft had boat like fuselages and large flannel-covered wings which were flapped by a pilot through a series of levers and pulleys. Neither of the machines flew, and both were eventually damaged in crashes while being towed by horses in attempts to gain the forward speed necessary for flight (Alexander, 2009). Looking to da Vinci's drawings for inspiration, Belgian Vincent de Groof built an ornithopter that resembled some of da Vinci's designs, with the operator standing below a set of flapping wings and pulling levers to provide power to the machine. Unable to convince authorities on the continent to let him attempt a flight there, he took the machine to England in 1874. Once there, he had the machine carried aloft by a balloon. When he cut the rope tethering him to the balloon, the machine broke, and he fell to his death. Another Belgian followed in de Groof's footsteps, though with somewhat greater success. Adhémar de la Hault, an engineer by trade, built a complicated machine to imitate the flight of birds. It was well-researched and widely admired for its mechanical ingenuity (Berget, 1911). As late as 1908, de la Hault was able to rise visibly and even leave the ground for a moment, but further experiments appear to have been squelched by persistent failure of the machine's many parts (Berget, 1911). Edward Frost, who would later become the president of the Royal Aeronautical Society, built a beautiful ornithopter in 1902, of willow, silk, and feathers (Kulfan, 2009). Despite its outward appearances and its striking similarity to a bird, the entire contraption was too heavy to fly, and Frost built his last ornithopter, again an unairworthy design, in 1904, a year after the Wright brothers' first flight (Kulfan, 2009). Of particular significance, especially because he is generally known for his successful glider experiments, is Otto Lilienthal's keen interest in the development of an ornithopter (Anderson, 1997). Lilienthal's ultimate desire was the production of a manned, engine-powered flying machine. To this end, he strayed from his innovative work with gliders and instead focused on the ornithopter as a model for powered flight (Anderson, 1997). His flapping wing designs were not entirely new territory for Lilienthal, as he had built several full-size models with his brother Gustav years before fully immersing himself in the design of gliders (Jakab, 1997). Lilienthal's later ornithopter design was to have been powered by a single cylinder engine driving the flapping motion of the outer portion of each

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wing. He patented the machine in 1893, and despite repeated failures of the carbonic engine he intended to use for power, Lilienthal began building a second ornithopter, this time with a new engine and a larger frame (Anderson, 2002). Though his focus on ornithopters rather than his gliders is sometimes criticized, Lilienthal was captivated by a longing to fly as birds do, saying:

With each advent of spring, when the air is alive with innumerable happy creatures - then a certain desire takes possession of man. He longs to soar upward and to glide, free as the bird, over smiling fields, leafy woods and mirror like lakes, and so enjoy the varying landscape as fully as only a bird can do. The observation of nature constantly revives the conviction that flight cannot and will not be denied to man forever. (Kulfan, 2010, p. 14)

Otto Lilienthal was killed before he could finish his second machine, and with his death, the ornithopter would experience many years in the shadow of the fixed-wing airplane.

### The Flight of Birds and the Aerodynamics of the Ornithopter

Though many early experiments with flapping wing aircraft ended in failure, the aerodynamic principles behind the ornithopter are sound. As demonstrated by birds, flapping wings offer tremendous potential advantages in maneuverability and propulsive efficiency. Aside from the many would-be fliers whose attempts were at best unscientific attempts to gain the freedom of flight, real scientific study of nature's aviators was undertaken by a few of the early proponents of flapping-wing flight. Those early innovators laid a foundation on which a more complete knowledge of the aerodynamics of flight could be understood, and on which future developments could be based.

#### Da Vinci and Borelli

Da Vinci, as one of the first to scientifically investigate the art of flight, made a lifelong study of not only the movement of birds in flight, but of airflow as he perceived it to pass around the birds' wings and body (Kulfan, 2010). In his many manuscripts, da Vinci gives one of the first written accounts of the manner in which birds describe a circular path in flight by changing the geometry of their wings (McCurdy, 1910). Da Vinci wrote at length concerning the use of the bird's tail as a means of achieving stability as well as arresting speed and descent in flight (McCurdy, 1908). Of emulating the flight of birds, da Vinci said, "a bird is an

instrument working according to a mathematical law, which instrument it is within the capacity of man to reproduce with all its movements...." (McCurdy, 1908, p. 152). Though da Vinci himself would later adopt the idea that man does not possess strength in adequate supply to sustain flight like a bird, his research into the fundamental principles of animal flight would influence many future designs for aircraft of fixed- and flapping-wings (Brady, 2000).

Borelli, in the mid-17<sup>th</sup> century, published his masterful work addressing the subject of flight, *De Motu Animalium* (a book of the same name was previously published by Aristotle). In contrast to Aristotle's, and many other's, ideas on bird flight, Borelli noted as did da Vinci that the tail moved up and down in flight to assure pitch control (Kulfan, 2010). Borelli's many sketches of birds in flight showed his understanding of the dynamics involved in maneuvering flight as he observed that birds could change their horizontal direction by beating one wing at a different rate than the other, much the same as a "rower alters course by pulling harder on one oar than the other" (Borelli, 1710, p. 191). Though Borelli's contributions to understanding the science of avian flight were important, it was also his assertion that man could not hope to support his weight in air without the benefit of mechanical assistance that would discourage to some degree the continued development of the ornithopter.

#### Lilienthal

As was previously discussed, Otto Lilienthal, though most recognized for his developments in gliding, made several flapping wing machines (Figure 2). Lilienthal, like his predecessors, was inspired by birds. Spellbound by the grace and freedom of bird flight, Lilienthal and his brother had from a young age spent hours observing and analyzing the creatures' wing movements in an effort to discern the secrets of natural flight. As one of the first to document observations of bird wings in flight, in his 1889 opus, *Birdflight as the Basis of Aviation*, Lilienthal presented a well-reasoned thesis replete with data collection techniques, analyses, and graphic depictions of information gathered from his study of birds as well as his own glider flights (Jakab, 1997; Strang, Kroo, Gerritsen, & Delp, 2009). His many studies were supported by tests completed in devices of his own design, including a flapping wing test stand built in 1867 (Hirschel, Prem, & Madelung, 2004). Lilienthal, despite his careful observations, lacked the tools to fully understand the mechanics of a bird's wing; and further scientific analysis in an aerodynamic sense would not come for nearly four decades.

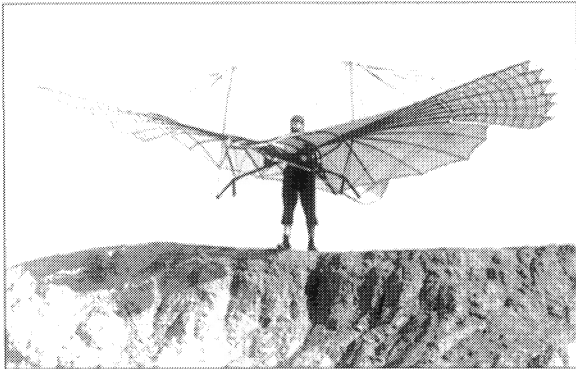


Figure 2. Lilienthal with small flapping wing glider.

### Modern Flapping-Wing Aerodynamics

An accurate understanding of how a bird is able to achieve forward thrust by way of flapping its wings was not gained until the early 1900s, when Knoller, in 1909, and Betz, in 1912, partnered to explain the phenomenon that had for so long escaped comprehension of human aeronauts (Platzer, Neace, & Pang, 1993). Working independently, Knoller and Betz were the first to observe that a flapping wing creates an effective angle of attack, and in doing so generates a normal force vector of both lift and thrust components (Jones, Dohring, & Platzer, 1998). Their work was largely theoretical, and it would be roughly a decade until another researcher, Katzmayr, would experimentally confirm the previous work of Knoller and Betz and identify the actual conditions under which a flapping airfoil generated thrust. Until Garrick (1936) published his analysis of flapping wing aerodynamics, little else had been done in terms of true, scientific investigation (and computational solutions) of the means by which both lift and thrust could be achieved in a mechanical replication of the avian wing (Strang, et al., 2009). In his studies, Garrick hypothesized that flapping airfoils could produce thrust throughout the range of oscillation, and could thus theoretically be used as a substitute for a propeller as a thrust-producing device (Jones, et al., 1998). His predictions were experimentally verified in 1939, and were given further credibility by Kuchemann and Weber (1953), whose research involved observation of flapping wing propulsion in nature and

suggested that oscillating airfoils were inherently more efficient than a propeller, primarily as the result of avoidance of vortex-related drag.

Standing well apart from the purely theoretical efforts of those whose investigations centered primarily on mathematical explanation of the ornithopter as well as those unscientific dreamers and tower jumpers who preceded him was Alexander Lippisch. Lippisch, a talented engineer who would go on to design the rocket-powered Messerschmitt ME163 Komet, was intrigued by the efficiency of a flapping wing design (DeLaurier, 1994). In 1929, Lippisch built and successfully flew a human-powered ornithopter in a series of tow-assisted glides (Rashid, 1995). His efforts in designing this craft led him to improve his original wing design, which had flexible outer sections designed to twist slightly in the down stroke, and thus create thrust in accordance with Katzmayr's earlier discoveries (Lippisch, 1960). When the resulting thrust did not meet Lippisch's expectations, he turned back to nature, and added a flexible trailing edge to the outer wing sections. Though the change to the wing was small, its effect on the propulsive action of the flapping wing was considerable (Lippisch, 1960). Among other contributions to the efficient design of an ornithopter wing, Lippisch pioneered the use of a fixed inner wing with only the outboard section used for propulsion through flapping. This design allowed for more efficient design of a propulsive flapping section by decreasing loading, while the inboard wing provided only lift (Lippisch,

1960). While this design improved by an order of magnitude the flight duration of Lippisch's previous designs, and similar unmanned models, it failed to accurately reproduce the dynamics of a bird in cruising flight (DeLaurier, 1994).

#### **Learning from Birds**

In examining birds for cues on how a mechanical device might better replicate their flight, Jeremy Rayner postulated that birds, as well as bats, partially collapse their wings on the upstroke, and in doing so create neither lift nor thrust during that phase of the flapping cycle (Rayner, 1979). Subsequent research proved however that in order to sustain flight, birds must create some lift on the upstroke. As a consequence of this study, the researchers found that in nature, wings are of variable span, collapsing at least partially as they are drawn upwards and in so doing, producing some measure of lift (Lighthill, 1990). Lighthill's (1990) work also described the advantage of a variable-span flapping wing in retaining vortices, thus increasing lift coefficient and overall efficiency of the wing. This research was the impetus for current designs which address both spanwise aeroelasticity in smaller models, and semi-span flapping in larger aircraft that can operate efficiently such that the thrust from the flapping wing propels it sufficiently to ensure lift based on its aerodynamic design (DeLaurier, 1994).

Dr. James DeLaurier, basing his principal research on the aforementioned design principles, has been an outspoken proponent of a human-carrying, engine-powered ornithopter, and to this end has produced what may be some of the most well-researched and successful explorations into modern ornithopter aerodynamics and design. A professor at the University of Toronto's Institute for Aerospace Studies, DeLaurier has focused much of his recent research on the aerodynamics of a wing designed specifically for flapping flight. Since Alphonse Pénaud's 1874 ornithopter model, in which the wing was designed with a single covering attached only at the leading edge, with stiffening ribs extending chord wise, most flapping wing designs have been constructed similarly (DeLaurier, 1993; Gibbs-Smith, 1953). While this method of construction enjoyed limited success in designs such as Pénaud's, the actual function of this type of wing is not ideal for the combined production of lift and thrust, as chord wise rigidity is not maintained; and propulsive efficiency is only sufficient for small craft which are even then required to be trimmed at a high pitch angle to sustain flight (DeLaurier, 1993). Instead, DeLaurier's design calls for a solid, double-surface airfoil which can be incorporated into a torsionally compliant structure, thereby maintaining the simplicity of the Pénaud-style wing while

allowing efficient thrust and lift to be maintained even at low pitch angle (Isogai & Harino, 2007). DeLaurier's innovative approach to ornithopter design has not been limited to the actual production of a wing, but also produced a design program, known as ComboWing, using strip theory in an aerodynamic context to determine optimum aeroelastic design of a flapping wing (Isogai & Harino, 2007). DeLaurier's advancements in the design of ornithopter wings have revealed many of the elements that eluded his predecessors for centuries. In his relentless pursuit of further understanding of principles associated with efficient ornithopter flight, DeLaurier has not only unlocked many of the age-old mysteries of mechanical emulation of bird flight, he has provided the metaphorical "Rosetta Stone" that will allow others to advance the science of flapping wing flight. Not only has the study of the aerodynamics of flapping wing flight seen a recent resurgence of interest, it has in many ways inspired traditional aerodynamicists to reevaluate the accepted notions of design and to look at nature's methodology as a means of inspiration for future concepts. Recently, many noted aerodynamicists have begun to reexamine the roots of their discipline as having not come from scientists such as da Vinci, but instead from the true pioneer of aeronautics, nature. McMasters and Cummings, both well respected in the field of aerodynamics, addressed this holistic view in a 2004 presentation to the American Institute of Aeronautics and Astronautics. They point to recent developments in unconventional areas of the field, such as ornithopters, as having not only made remarkable progress toward the dream of bird-like flight, but also having inspired more traditional practitioners to consider contributions outside of military and commercial applications as valuable additions to the body of knowledge (McMasters & Cummings, 2004).

#### **Modern development of Flapping Wing Aircraft**

Although widespread experimentation with ornithopters as a means of achieving manned flight largely faded after the Wright brothers' successful flight at the turn of the twentieth century, it never died out altogether. Many of the resulting efforts by those marginalized proponents of flapping wing flight were ill-fated, unscientific trials. A few stalwart visionaries, however, continued to work toward successful flapping wing flight, both human and engine-powered, and through patient and analytical study, made substantial contributions to the development of the ornithopter.

#### **Manned Flight and the Realization of the Human-Powered Ornithopter**

Alexander Lippisch again surfaces as a pioneer in ornithopter flight in the context of human-powered, flapping

wing flight. Lippisch was intrigued by the work of Brustmann, who he had seen with a rudimentary ornithopter at a technical contest sponsored by the German “Forschungsinstitut” (Lippisch, 1960). Lippisch and Brustmann together developed a plan to produce a human powered aircraft. They settled on an ornithopter because of the potential benefit the design provided in terms of

efficiency and weight (Lippisch, 1960). Lippisch designed their craft based on his previous work with gliders. Unique to the wing design was an enlarged, flexible trailing edge (Figure 3) that was based on the shape of the *Zanonia* seed (Kulfan, 2009; Mueller, 2001).

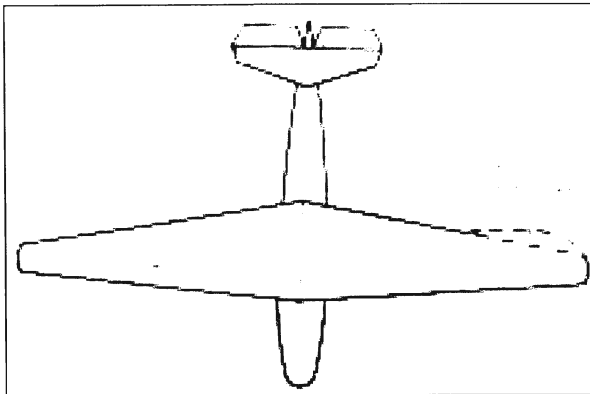


Figure 3. Lippisch ornithopter.

Although their ornithopter achieved what may be considered remarkable success, with the pilot, Hans Werner Krause maintaining a powered glide for over 300 meters on one of his final flights, the results of the tests were never published (Lippisch, 1960). Lippisch and Brustmann felt that because their experiments remained incomplete after an unsuccessful modification of the ornithopter, the study could not be successfully circulated (Lippisch, 1960). Reflecting on his work nearly 30 years later, Lippisch said, “Today I am still inclined to think that wing flapping actually gives better efficiency, but our knowledge of how to design a highly efficient flapping wing is very limited” (Lippisch, 1960, p. 396).

A decade later, a young aircraft designer named Adalbert Schmid designed and built his own human-powered ornithopter. Although he had already designed a high-wing

conventional monoplane, Schmid felt that the future of sport aviation lay in the ornithopter concept (Bedwell et al., 2009). In 1942, Schmid’s flapping wing aircraft reportedly flew over 900 meters under human power while maintaining its height above the ground (Schmid, 1950).

#### **Flight by Engine Power**

Few examples of successfully flown, engine-powered ornithopters exist, and those that do are scarcely documented. In the mid 1950s, Percival Spencer designed and built a biplane, engine-powered ornithopter, but it reportedly suffered from too little power to ever become airborne (DeLaurier & Harris, 1993). In 1946, Adalbert Schmid installed a motorcycle engine in his previously human-powered ornithopter. The resulting aircraft was reportedly able to take off unassisted and fly for 15 minutes, though no objective evidence is available to support this



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claim. Schmid was called into wartime service before his later, more powerful designs could be tested.

Some time passed before any further powered ornithopter experiments were undertaken, but in September 1991, a quarter-scale proof-of-concept, engine-powered ornithopter was successfully flown for nearly three minutes (Meuller, 2001). The aircraft, known as “Mr. Bill,” was designed and built under the direction of James DeLaurier at the University of Toronto and was the culmination of over six years of flight testing and experimentation (DeLaurier & Harris, 1993). The flight of Mr. Bill is recognized by the Fédération Aéronautique Internationale (FAI) as the first of a successful, engine-powered, remotely-piloted ornithopter (Rashid, 1995).

Building on the over two decades of research that went into the successful flight of the Mr. Bill ornithopter in 1991, DeLaurier and Harris continued to develop the theories they had reached during analytical testing of their quarter-scale model. They, in conjunction with the University of Toronto, designed a full-scale, piloted version of the aircraft called

“Big Flapper” (Figure 4). While the Big Flapper was constructed with many ultralight aircraft principles in mind, it was also built so that it would meet Transport Canada load factor criteria for general aviation aircraft with the hope that it might someday materialize into a commercially viable vehicle (DeLaurier, 1999). The wings, driven by an internal-combustion engine coupled to a complex transmission, oscillated through an arc of almost 54 degrees. The full-scale aircraft began flight testing in 1996, and during several taxi tests between 1996 and 1998, the ornithopter was able to self-propel to near takeoff speed of about 50 miles per hour, finally achieving it in 1999. With pilot Jack Sanderson at the controls, Big Flapper flew for 14 seconds on July 8, 2006 before a structural deformation on the left wing necessitated an early termination of the flight test (Sanderson, 2006). This flight, beyond achieving many technological goals of the team, shattered a psychological barrier, proving that piloted ornithopters are indeed a viable technology on a large scale.

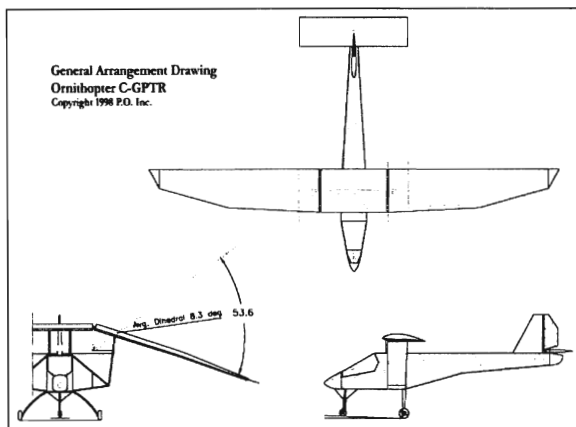


Figure 4. Three-view of full scale ornithopter, “Big Flapper.”

### University of Toronto “Snowbird”

The University of Toronto Institute for Aerospace Studies (UTIAS) Human-Powered Ornithopter (HPO) project began in 2006 under the leadership of Dr. James DeLaurier (Robertson, 2009). The goal of the HPO project was, as the name suggests, designing and developing an ornithopter (Figure 5) to “achieve one of humanity’s oldest dreams with the successful flight of a human-powered, flapping-wing aircraft, the last of the aviation firsts” (“Human Powered,” n.d., para. 1). The HPO team designed the Snowbird to fly as slowly as possible to capitalize on the limited power available from the human engine. To minimize weight, the wing structure was created from a carbon fiber spar and reinforced foam ribs covered in a lightweight, flexible skin (Robertson, 2009). Because weight was critical to the success of the Snowbird, no provisions for self-launch were made. As such, the aircraft had to be towed to launch speed by a car. The Snowbird was designed to be powered by its principal designer, University of Toronto Ph.D. student Todd Reichert (Robertson, 2009). On August 2, 2010, just

after sunrise, the Snowbird lifted off, released from the tow rope, and flew under human power for 19.3 seconds (“Human Powered,” n.d.). Officials from the FAI were on hand to observe the flight, and the GPS records submitted for certification by the sanctioning body indicated that under human power, the Snowbird actually gained altitude during the first few flaps, and it maintained speed and altitude for nearly 500 feet (“Human Powered,” n.d.). During its last flight of the day, the Snowbird was already showing signs of wear, a side effect of extreme efforts to maintain its light weight of 95 pounds. Despite retiring the craft earlier than expected, Todd Reichert, James DeLaurier, and the rest of the HPO project team shattered many preconceived notions of the possibility of human-powered ornithopter flight (“Human Powered,” n.d.). In doing so, they have revitalized interest in flapping wing technology and captured the imagination of many who never dreamed that such a flight was possible.

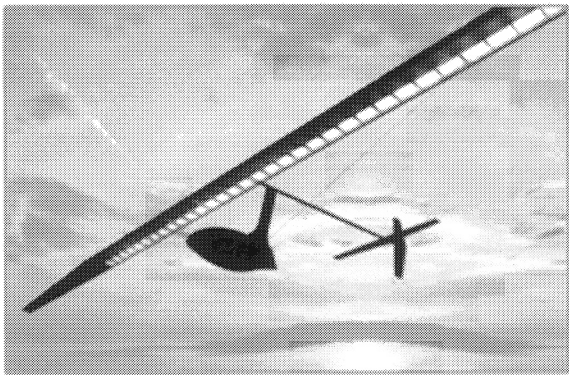


Figure 5. Human-Powered Ornithopter project *Snowbird*.

### Future Applications of the Ornithopter

The ornithopter, though firmly rooted in the psyche of many aerospace designers as ancient technology, has much to offer as a means of advancing the science of aerial vehicles. As scientists like Dr. John McMasters have observed, “a door is finally opening to the realization that there may be much more to learn in further, truly multidisciplinary investigations of the biomechanics of flight as it may relate to a wide range of practical aircraft types” (McMasters & Cummings, 2004, p. 3). In the burgeoning field of unmanned micro air vehicles, ornithopters have found a niche for which they are especially well suited.

### Unmanned Aerial Systems

One of the principal advantages of an ornithopter as an unmanned aerial system, especially one used for surveillance purposes, is the low aeroacoustic signature of such an aircraft (DeLaurier & Harris, 1993). Compared with fixed-wing, propeller-driven aircraft, and even those with high-efficiency, slowly rotating propellers, ornithopters have the potential to be the quietest of any aircraft design (DeLaurier & Harris, 1993).

In addition to low audio profiles, ornithopters are inherently well suited to small scale aerial vehicles because of their aerodynamic properties. A flapping-wing aircraft has considerable advantages in small-scale designs because of efficient operations at low Reynolds numbers combined with the ability to fly by thrust alone (Shkarayev & Silin, 2009). Though the small size means that micro ornithopters are more susceptible to wind gusts than larger vehicles, the potential for enhanced maneuverability, including hovering, and even backward flight, makes flapping wing designs a subject of keen interest (Shyy et al., 2010). Micro Aerial Vehicles (MAVs) currently in development, such as the Microbat, are proof that ornithopter technology, though still in the early stages of development as a technology, has much to contribute to the science of aerial remote sensing (Singh & Chopra, 2008).

### VSTOL Applications

Flapping wing designs have the potential to not only revolutionize the field of micro-sized aircraft, but to drastically change how Very Short Take Off and Landing (VSTOL) aircraft are utilized. Though most research in ornithopter flight has dealt with the dynamics of cruise flight, it is not unreasonable to speculate that flapping wing technology contains the elements necessary to support not only VSTOL capabilities, but also the possibility of high speed subsonic flight (DeLaurier & Harris, 1993).

Unquestionably, myriad other applications for flapping wing technology exist that have yet to be identified; and even some that have, such as continuously variable-span wings based on those of gliding birds, have yet to be solved (McMasters & Cummings, 2004). The prospect of quiet, efficient, and maneuverable aircraft technology capable of applications of any size is reasonable assurance that ornithopter development will continue well into the future.

### Conclusion

Inspired by nature, ornithopters were long considered the only viable means by which man could achieve the freedom of flight that proved so elusive. As lighter-than-air and eventually fixed-wing machines overshadowed the development of flapping wing aircraft, ornithopters were marginalized and often discounted as a futureless technology. Examining the past for inspiration and developmental breakthroughs in ornithopter design shows that flapping-wing flight is far from the pipe dream it has been often characterized to be. Instead, ornithopters occupy the rare position of being critical to the formative stages of aviation as well as to its future. As technology unflinchingly advances and aerospace designers continually seek new ideas, the ornithopter once again has emerged as a kind of technological chimera, combining seemingly incongruous elements of aviation’s distant past and inspiration from nature with revolutionary technology to create an adaptable solution to the needs of the ever-developing science of aviation. →

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**Benjamin (B.J.) Goodheart** is an aviation professional with over 15 years of experience in the field. His diverse background began in aviation line service and has expanded to roles in aviation safety and loss control, training, and professional flying. His career has spanned from tiny operators to major airlines, and has afforded him a wide variety of opportunities to practice within his passion. He holds a B.S. in Aeronautical Science and a Master of Science in Safety Science from Embry-Riddle Aeronautical University, several professional aviation certifications, and Airline Transport Pilot and flight instructor certificates. B.J. also serves as president of an aviation nonprofit organization, Mercy Wings Network. B.J. is currently pursuing a Ph.D. in Aviation at Embry-Riddle.

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