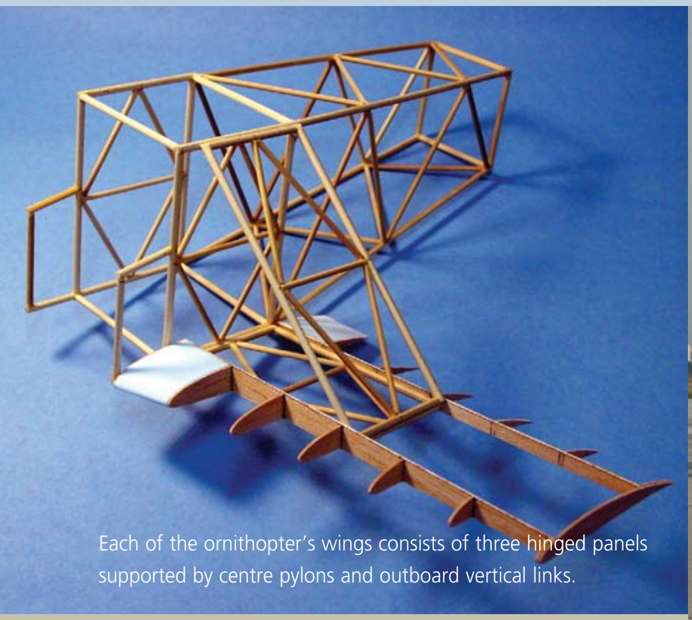
Flying

OUT OF & INTO THE HISTORY BOOKS

Da Vinci's aeronautical dream takes flight with Canadian 'Project Ornithopter.'



Each of the ornithopter's wings consists of three hinged panels supported by centre pylons and outboard vertical links.

Originally a Leonardo Da Vinci invention, the ornithopter gains both lift and thrust from the craft's bird-like flapping wings.

An inside view of the ornithopter's one man cockpit.

By Treena Hein

Perhaps the sweetest experience an engineer can hope to have is to successfully design something many others, over many centuries, have failed to create. It is even sweeter when that success is something many believed utterly impossible.

Dr. James DeLaurier, an aeronautical engineer and professor emeritus at the University of Toronto's Institute for Aerospace Studies, is tasting that sweetness. On a sunny morning in July, after years of testing and modification, he and his colleagues gathered at Downsview Park near Toronto as their dear ornithopter was brought out of the hangar once again and sent down the runway. It was a critical moment in many ways, not least because it was the eve of DeLaurier's retirement. Everything pointed to success, but the engineer was well aware that yet another glitch could easily rear its ugly head. There were never any guarantees. Even a mishap leading to pilot injury was possible…

But on July 8th, 2006 at 10:20 AM, "the Flapper," as it's affectionately known, easily flew about one meter above the ground for about 14 seconds, covering a distance of over a third of a kilometer – beating the first flight of the Wright brothers' powered plane in 1903 by two seconds. The fifth run of the morning was the charm – the first flapping-wing full-scale jet-boosted sustained airplane flight under pilot control in history. Sweetness indeed.

It was more than half a millennium ago, in 1490, that Leonardo Da Vinci visualized the first ornithopter, human-powered with membrane wings. His design illustrated how humans had always pictured themselves flying through the air – like birds – and for centuries; flapping was the only way inventors pictured humanity reaching the sky.

> "We are doing it for the beauty of it. We are doing it to make history."
> *—Dr. James DeLaurier*

However, all that changed in 1799. Sir George Cayley of England realized that lift could be engineered separate from thrust, a paradigm shift which allowed designers to successfully create fixed-wing aircraft. Flapping-wing flight was thus largely forgotten, and has remained both humanity's oldest aeronautical dream and last historic aeronautical frontier. That is, until now.

Over the last thirty years, DeLaurier never stopped believing it was possible. And, although the project has presented valuable data on several aspects of engineering, he knew his research on the ornithopter was never a matter of future commercial possibilities. "We are doing it for the beauty of it," DeLaurier says. "We are doing it to make history."

From Da Vinci to DeLaurier

In normal fixed-wing aircraft, the powerful thrust of the engines causes massive airflow over the wings, which in turn is used to produce the lift. But in birds, bats, butterflies and ornithopters, the flapping of the wings must generate both lift and thrust. "However," says DeLaurier, "the challenge of achieving both efficient lift and thrust with flapping wings was far greater than simply using the wings for lift and providing thrust with a separate propulsor."

Da Vinci's model, although a brilliant design which used a system of pulleys and ropes to make use of both arm and leg muscles, most likely never made it off the page. It was to be over three and a half centuries later, in 1874, that he first documented flights of a mechanical flapping-wing aircraft took place. France's Alphonse Penaud's rubber-powered design "established the template for subsequent model ornithopters, differing only in detail and materials," says DeLaurier.

In 1929, a human-powered ornithopter created by Dr. Alexander Lippisch was towed into the air and performed powered glides over Germany; in 1959, Emil Hartman of England repeated the feat. A few years later, during the 1960's, American Percival Spencer created a series of engine-powered free-flight ornithopter models in various sizes.

In 1973, James DeLaurier met Jeremy Harris when both were working as research engineers at Battelle Memorial Institute in Columbus. Harris stirred up DeLaurier's latent interest in ornithopters which had languished since building rubber-powered models as a teen. Soon the men were working together on design possibilities as a hobby. "We were just a couple of young guys with engineering educations," says DeLaurier, "and we thought that it would be kind of cool to revisit this age-old challenge and just determine whether it really was possible or not." However, he admits "I didn't anticipate it would take nearly this long…It was really difficult. We had not realized the extent of technology that had to be developed in order to fully address this question."

Even though DeLaurier moved away in 1974 to Toronto, he and Harris continued to collaborate. By 1985, they conducted the first tests of an engine-powered, remotely-controlled ornithopter and extended the research into computer analysis and wind-tunnel testing. In 1991, sustained flights of an improved-scale model were achieved, which DeLaurier considers "really important. It showed us that yes, you can successfully fly a

Morning rollout of the affectionately known "Flapper" on July 8th, 2006. More than half a millennium in the making, the day would see the first sustained flapping-wing, full-scale, jet-boosted airplane flight under pilot control in history.

Team Ornithopter 2006: (From left) Michael Lazich, James DeLaurier, Ben Cho, Jack Sanderson (pilot), Jonathan Warkentin, Jennifer Elliot, Jack Humphries, Arnaud Bally, Patrick Zdunich, Derek Bilyk

full-scale aircraft. It is very important to have proof-of-concept watersheds along the way." The aircraft was recognized by the Fédération Aéronautique Internationale (World Airsports Federation) as the first successful engine-powered remotely-piloted ornithopter.

Design and Construction

DeLaurier and Harris knew the time had come to set the models aside. Development of a full-scale aircraft began and by 1995, was under construction. Although he eventually withdrew from the project, Harris donated $100,000, which was matched by the Canadian government's Industrial Research Assistance Program; other funding was also obtained. Crucial storage and workspace was provided by the Toronto Aerospace Museum and Bombardier provided use of their runway.

The design process focused on the goal of building a single-seater aircraft powered by a 24-hp König engine, popularly used in ultralight aircraft. By choosing this engine, it was felt that "an 'ultralight philosophy' would prevail, resulting in an aircraft of sufficient simplicity and compactness to be achievable with a small team and a limited budget," says DeLaurier. The finished model weighed about 710 pounds with pilot and fuel, although it gained about 50 pounds later on. The fuselage measures 24.5 ft and the wingspan 41 feet.

Many ornithopter designs have been created, including one with wings whose inner half was fixed and outer half flapped, and one with flapping wings at the rear of the plane and fixed wings at the front. The Harris-DeLaurier model sports fully flapping wings, which, though they appear similar to those of a normal aircraft, are much stronger because of the much greater stresses that must be withstood. The wings join at a centre section which moves up and down by pylons connected to the drivetrain. Carbon fiber and Kevlar were chosen for the wing composite, lightweight and strong ingredients without which DeLaurier says constructing a piloted ornithopter would not be possible.

Each wing consists of three hinged panels supported by centre pylons and outboard vertical links. The centre panel is driven in sinusoidal up-and-down motion that, in turn, drives the outer panels in flapping. "Harris's three-panel feature is patented because it has the merit of reducing the unbalanced oscillatory force applied to the fuselage, which is important for a piloted ornithopter," DeLaurier says. "Also, three-panel flapping evens out the instantaneous power required throughout the flapping cycle…The wings' thrust is due primarily to a low-pressure region around the leading edge, which integrates to provide a force known as 'leading-edge suction.' The wings also passively twist in response to the flapping, due to a structure that is torsionally compliant in just the right amount to allow efficient thrusting (called aeroelastic tailoring)."

Testing

By October 1996 the first taxi trials were conducted, which showed that the aircraft was capable of accelerating under its own power. By 1999, the Flapper accelerated by flapping alone on flat ground to lift-off speed: 51 mph at a flapping frequency of about 1.05 Hz. However, getting off the ground was proving elusive for several reasons.

"First of all, it takes a goodly amount of runway to get to lift-off speed, and we don't have that much runway," DeLaurier notes. "The flapping alone produced an oscillating vertical force of approximately plus-or-minus 300 pounds. As the aircraft approaches take-off speed, and the average lift builds up, it rises off the ground during the wing's downstroke and comes back down during the upstroke…this bouncing or 'boinging,' as we call it, is not only extremely stressful to the structure, but it also causes the acceleration to cease."

Luckily, fate then lent a hand. While visiting his favourite hobby store in Unionville in 2004, DeLaurier was intrigued by mini jet engines that had just become available. His suggestion to the owner that one of these would most likely allow the Flapper to take off was a joke at first, but then became a serious possible solution. The current simulation was modified to incorporate the jet boost, and showed the Flapper would be readily able to take off with a lower flapping frequency and minimal boinging. Once the aircraft was flying, DeLaurier says "the frequency would be increased to its full value and the aircraft would then fly solely with its flapping wings." The team chose a model made by AMT Jets of Holland, weighing 6.3 pounds and producing 51 pounds of thrust. DeLaurier notes that although it is only the size of a melon, "it is a true turbojet with a compressor and impeller, burner cans and variable throttle."

Testing had been put on hold since 2002 due to a fractured weld. This turned out to be a positive development, because although it took until 2005 to repair it and do some other reinforcing, close inspection of the main undercarriage at that point revealed delaminating cracks.

"The 2003 season was used to locate a trustworthy composite-structure shop, and to redesign the main undercarriage so as to minimize the internal shear stresses," DeLaurier says. In 2004, the team had trouble with electromagnetic interference from the main engine's ignition affecting the Electronic Control Unit (ECU). Inspection of the flapping wings that year found worn wing-hinge plates, bolt holes and bushings. The July 2005 tests were also postponed due to engine trouble, leading to the replacement of the ECU. In early August, a faulty glow plug halted testing, but fortunately this occurred after brief liftoffs and some verification of calculations were attained.

This summer, however, all seemed ready. After preliminary testing in June, July 8th was chosen as the big day. The first run reached 50 mph with wings flapping at 0.8 Hz and a few brief liftoffs. The second run was similar but faster with some sustained air time. Runs 3 and 4 achieved some very large hops, but the engine was throttled back to put an end to the pattern. In Run 5, the pilot went full throttle, soon flapping at a rate of 1.0 Hz and taking to the air. "Evidently," laughs DeLaurier, "I went nuts."

The 14-second flight ended, however, with a sudden hard landing which broke a wing tip and had the plane leaning on its nose. Originally thought to be due to a cross wind, the accident was in fact due to a bulge which formed during the downstroke on the left wing's trailing edge. DeLaurier notes "the shearflexing action was jammed up, thus reducing the aeroelastic twist and causing flow separation with resulting loss of lift and thrust." The right wing withstood the strain because it had been rebuilt in 1999 with a higher buckling load.

The flight confirmed many speculations and provided lots of future direction for those who wish to improve upon the accomplishment. Most of all, the flight proved the ornithopter able to take off from a ground roll without bouncing "largely due to using a boost from the jet engine," says DeLaurier, "but in all fairness, I should say that the jet alone could not even come close to sustaining the aircraft. The flapping still did most of the work." The ornithopter will be repaired and take a place of honour in the Toronto Aerospace Museum at Downsview Park.

Flying into the future

Besides experiencing the beauty of successful flapping wing flight, DeLaurier says the personal gratification he has feels over the accomplishment is enormous. He not only has the respect of the engineering community, but has been able "to be on the edge of technology, to go through the same thing that [early aircraft designers] had gone through…When a new technology is just emerging and no one knows for sure what final form it's going to take, that's always the most exciting for a research engineer." He calls his involvement in making aviation history "a privilege…Trying at times, stressful at times, but nonetheless, a worthy quest." He also considers the interest from school children, adults and even a Toronto songwriter "very important to me."

On the practical side, several aspects of the ornithopter research have proven valuable. For example, data gathered on unsteady aerodynamics will be used in flapping-wing micro-aircraft design. DeLaurier also has gathered important information on aeroelastic tailoring as well as the use of composite materials under stress. Additionally, he says "It's been a great educational tool for my students. They've actually been able to go out and be involved with the development of a brand new aircraft, to conduct test procedures, to work in a team. These are all very important skills for an engineer."

Others in the field take a more grand view. Dr. Andrew Nahum, Principal Curator of Technology and Engineering, The Science Museum, London England says DeLaurier's accomplishment could signal a new era in aeronautics.

"I believe this accomplishment points to a coming transition in aeronautical engineering and a new biotechnic approach to aircraft design," he says. "In the future, aircraft will become more flexible, more adaptive and will use supple movements of the whole wing and structure to expand the speed range and maneuverability. Jim DeLaurier's team has pointed the way."

There are aspects of the project, however, DeLaurier won't miss. For instance, the stress of operating on an unbelievably tight budget. He estimates that the next step, involving bigger wings to sustain flight without a jet engine will require about $100,000. Begging people for help or a bit of money was difficult, DeLaurier admits.

"If there were a future where I didn't have to do that and I could carry on with this, that would be great," he says, "but if not, this is a nice place to bring it to a conclusion. If that's the only legacy I leave, I will be happy about that."

"The flight on July 8 crosses a psychological barrier regarding the feasibility of a full-scale flapping-wing aircraft," he concludes. "The Flapper's few seconds of sustained flight brings this notion from the realm of fantasy into the realm of reality." **de**

www.ornithopter.ca