Da Vinci's dream machine

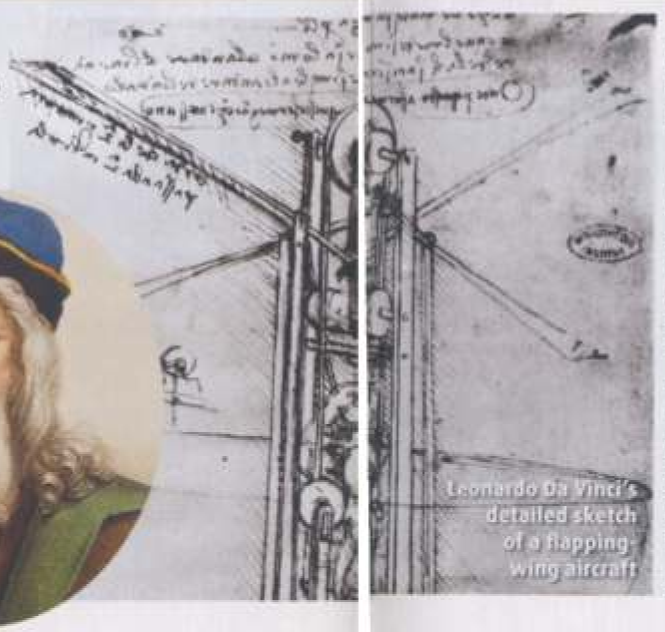
The Flapper ornithopter in the air on its maiden flight in July 2006

In 1490, Leonardo sketched an aeroplane that flapped its wings, like a bird. Five centuries on, the Renaissance polymath's loftiest idea has become a reality, as **Robin Hague** discovers

On Saturday 8 July 2006, a small, oddly proportioned aircraft was wheeled out onto a runway at Downsview Park near Toronto. After taxiing up and down a couple of times, pilot Jack Sanderson lined up at the end of the runway, throttled up, and the little aeroplane was in the air for the very first time.

Even the fact that the plane made it successfully off the ground is the realisation of a dream pursued by humanity for centuries and by Dr James DeLaurier, the aeronautical engineer behind this project, for more than 30 years. This is no ordinary plane: it's an 'ornithopter'.

An ornithopter is an aeroplane that flies by flapping its wings, like a bird. Birds are logical flying models to copy – they do it so well, after all. Many early aviation attempts involved flapping wings; for centuries, people have been throwing themselves off high places with wings strapped to their arms.



Leonardo Da Vinci's detailed sketch of a flapping-wing aircraft

However, the first person really to think seriously about powering the wing beats was Leonardo Da Vinci. In 1490, he produced a detailed design for a human-powered ornithopter, with the wings activated by the pilot bending and straightening his legs – pedals weren't invented until the 1850s. Da Vinci specified a membrane wing surface, showing his appreciation that feathers aren't necessarily needed for flight. While birds use feathers as separate aerofoils, bats and insects fly perfectly well without them.

Despite Da Vinci's early start, the first time anyone got close to actually building a real flapping winged aircraft wasn't until the 1890s. German aviation pioneer Otto Lilienthal had been captivated by the storks near his home since he was a little boy. His early interest in their flight led to him becoming a trailblazer of practical aircraft construction and an inspiration to the famous Wright brothers, who themselves constructed the first powered aeroplane in 1903.

Bad start

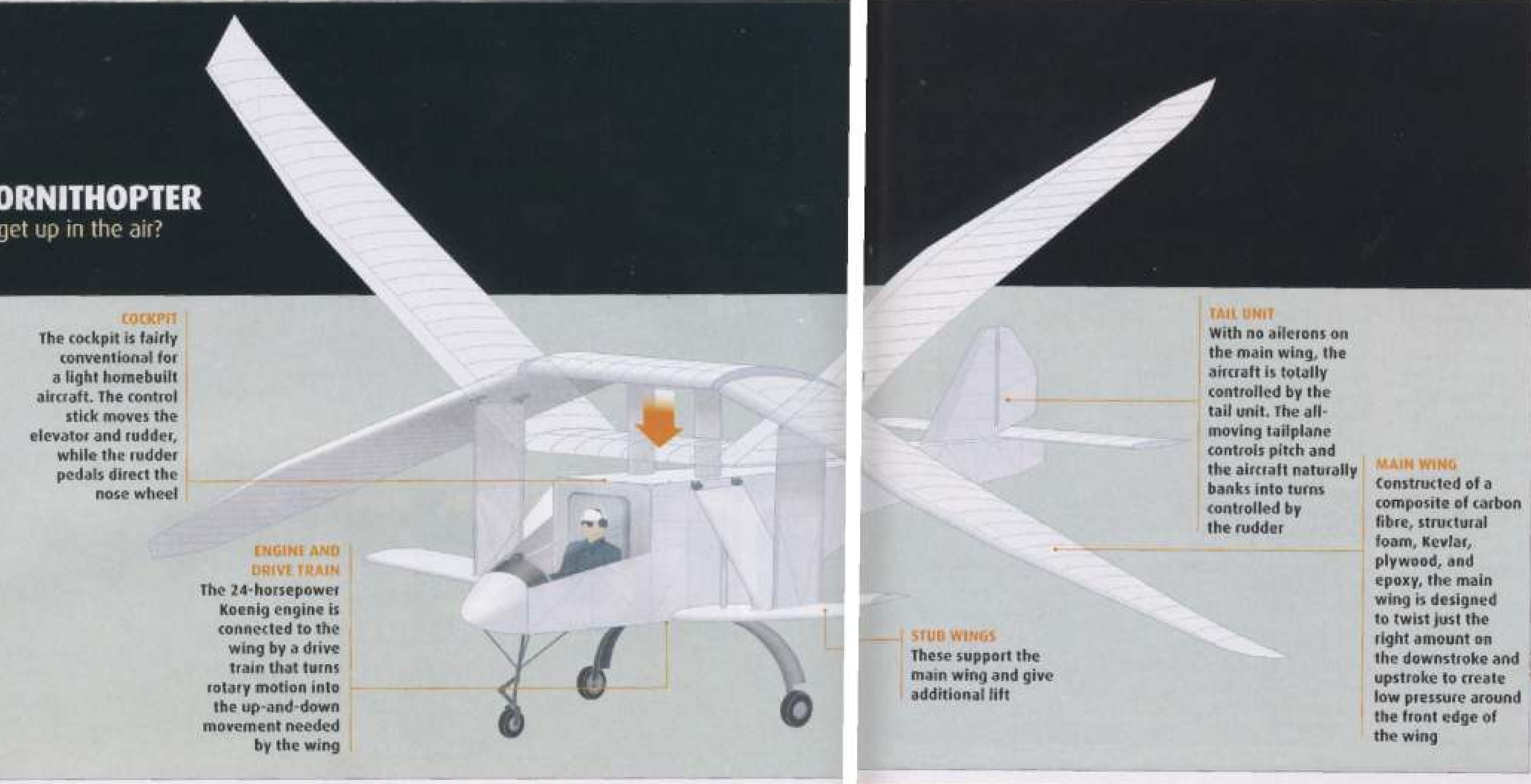
If it hadn't been for a tragic accident, that first aeroplane might have been an ornithopter of Lilienthal's designing. He was interested in reducing the power required for flight, and thought propellers were an inelegant approach to propulsion. He harnessed his extensive study of birdflight to design a new aircraft with engine-powered flapping wingtips. It was complete apart from an engine when Lilienthal suffered a stall on a glider flight in 1896 and was killed in the crash.

In the meantime, fixed-wing aircraft designs were improving and interest in ornithopters waned but for curious aeronautical engineers who wanted to see whether the technique would work. Throughout the 20th century there were a few attempts. In the early 1940s, Adalbert Schmid, another German engineer, succeeded in adding flapping wings to an existing glider. These didn't replace the main wings but acted as a kind of thruster, propelling the glider forward once it was already up in the air.

ANATOMY OF AN ORNITHOPTER

Just how does the Flapper get up in the air?

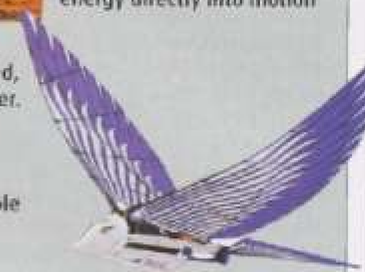
The DeLaurier Ornithopter is a small monoplane 8 metres long, with a wingspan of 12m. It carries a single pilot, features a conventional tail unit and an especially tough tricycle undercarriage. The main flapping wing is supported by uprights either side of the fuselage, which are themselves supported by small, fixed stub wings that also contribute to the total lift. The aircraft is propelled by a 24-horsepower Koenig engine, which turns a 60:1 four-stage chain-and-sprocket drive train that pushes and pulls on the centre section of the wing.



FLAPPIN' HECK...

Teams around the world are working on a host of ornithopter designs

ENTOMOPTER
Robert Michelson's team at Georgia Tech is working on tiny insect-inspired ornithopters with Cambridge University. They are unique in using chemical 'muscles' that convert chemical energy directly into motion



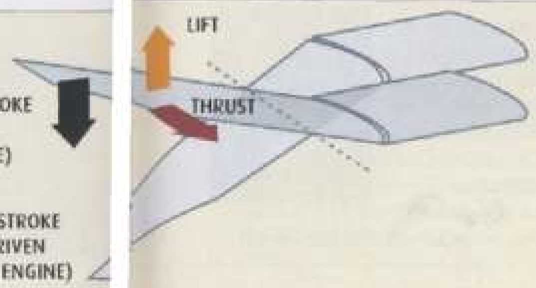
CYBIRD
Cybird is a battery-powered, radio-controlled ornithopter. It has a basic two-channel radio control that varies thrust and tail angle, for turns. The Cybird is available from www.flyabird.com for $140 (£76)

AERONVIRONMENT PTEROSAUR
This 5-metre-span model of a dinosaur was developed by the Smithsonian Institute and the people behind the Gossamer Albatross, the first human-powered aeroplane to cross the English Channel

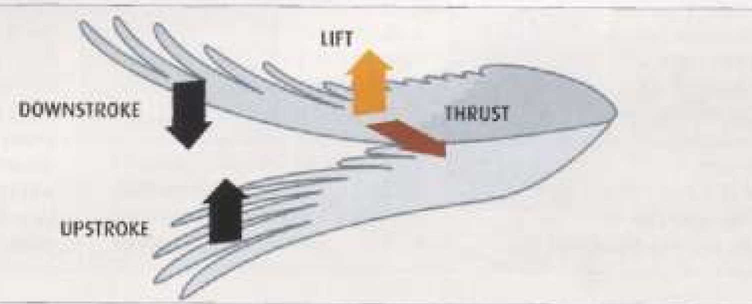
HOW THE FLAPPER'S WINGS SHAPE UP

FIXED WING
This generates lift by accelerating the air over its upper surface; this causes the air pressure above the wing to drop, 'sucking' the plane up

ORNITHOPTER WING
This generates lift and thrust as it sweeps downward. The motion helps to create low pressure around the leading edge, which sucks the wing forward and upward



BIRD WING
Birds combine the basic up-and-down movement with twisting, bending and back-and-forth movement, to even out lift and control direction



➡ Flapping flight presents a number of challenges. Simply powering the wings at all is difficult. All available engines produce rapid rotational motion, and finding a lightweight, reliable way of turning this into a comparatively slow up-and-down movement is quite a challenge. A flapping wing provides both lift and thrust at the same time, which must balance out. Then there's the minor issue of actually getting the thing off the ground at all without the wings driving the fuselage into the runway in the process.

The lead-up to this summer's successful flight began in 1973 when Jeremy Harris and James DeLaurier met at Battelle Memorial Institute in Ohio, USA. They were working as research engineers and began designing ornithopters as a hobby. "Although we started with models, our efforts were always directed towards achieving full-scale flight," says DeLaurier.

As the scale of the task involved in flapping flight became apparent, Harris and DeLaurier became increasingly committed to Project Flapper, and continued despite DeLaurier relocating to the University of Toronto, Canada, in 1974. By 1985 they were ready to carry out their first test flight of an engine-powered model with a wingspan of 1.5m. But the test

A different kind of launch in the UK in 1905

This 1902 ornithopter is made of willow, silk and feathers

showed their design could not generate enough thrust for sustained flight. The question was: why not.

Remote possibilities

Harris and DeLaurier continued to modify their design, carrying out wind tunnel testing and detailed computer analysis. By 1991, their fourth model had been recognised by the Federation Aeronautique Internationale (FAI), the body that records aviation records, as the first successful engine-powered, remotely piloted ornithopter capable of sustained flight – the craft could stay up in the air for as long as the fuel lasted.

The model laid the ground work for building the first full-sized Flapper. Construction began in 1995, and the first taxi tests, where the plane is driven along the runway, were in 1996. The Flapper could soon accelerate to lift-off speed of around 88km/h by flapping power alone, even starting to hop off the ground in 1999. But the big challenge with building a full-scale craft is the stress on the airframe – the mechanical structure of the aeroplane – since the wings and other moving parts are bigger and heavier than on models. One by one, the team, largely made ➡

ASK THE EXPERT

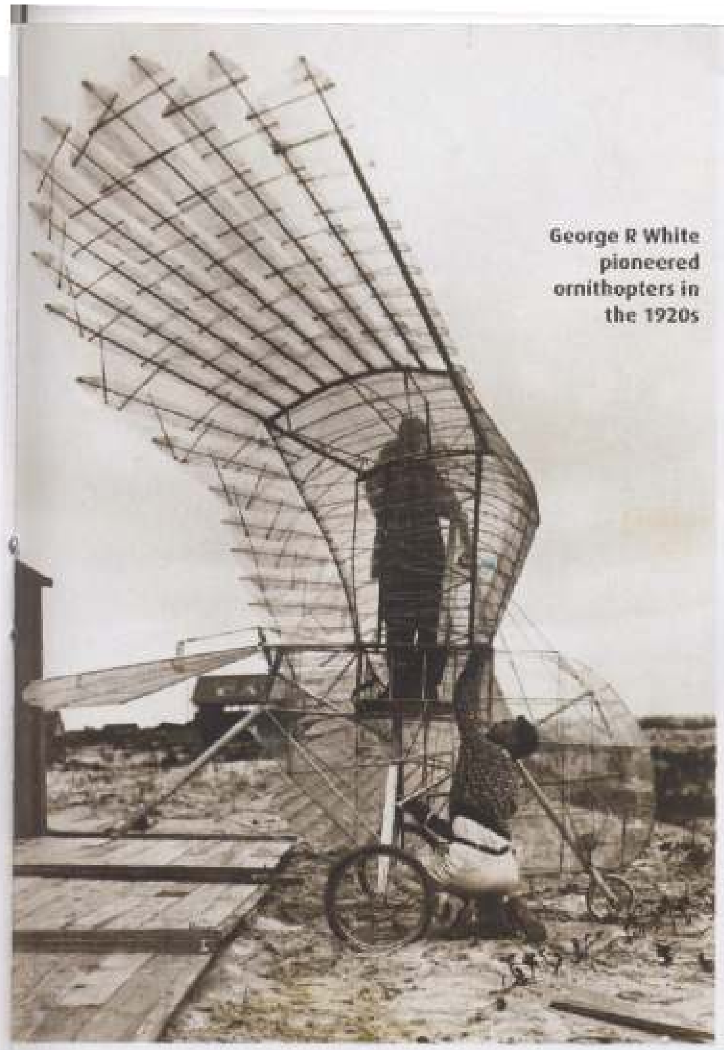
Dr James DeLaurier, designer of the first successful jet-assisted ornithopter, the Flapper

What were the main technologies that you needed for the Flapper to achieve sustained flight?
An important technology was the three-panel wing design, where the outer panels move opposite the central panel. This reduces the shaking that the pilot feels as the wings move up and down. The wing itself is a patented 'Shearflex' wing whose structure allows it to aeroelastically twist, while at the same time incorporating a thick, efficient wing shape. We had an efficient system that incorporates four stages of chains and sprockets and terminating in a special crank mechanism for oscillating the wings.

Will the ornithopter fly again?
In ten years of research and testing it has become clear how a new and improved wing should be designed. The aircraft is now heavier, due to modification and development, than the current wing was designed for. Flapping wings do not like to operate at off-design conditions, so the performance margin is narrow. If the funding for the new wing became available, it would be built and flown.

If you build a Flapper Mark II, what other changes would you make?
I would like to explore an alternative drive that more directly converts fuel energy into flapping work. Internal combustion engines use pistons that move up and down which, through rod and crank, give a high-speed rotational motion. The purpose of the current drive is to reconvert this back to up-and-down motion, which adds weight and complexity. The ideal situation would be to utilise the fuel energy to directly produce the low-frequency oscillatory motion; such a system promises to be simpler and lighter. If ornithopters are to have any future at all, this has to be accomplished.

What do you feel the future prospects for ornithopters are?
It is difficult to envision large ornithopters replacing any current aircraft; but the future may hold surprises. In the near term, ornithopters would be profitable for exhibition and air shows, which was likewise the case for early aeroplanes. Small-scale ornithopters seem to be uniquely suited for micro air vehicles, which are tiny insect-like spy planes a few centimetres across.



George R White pioneered ornithopters in the 1920s

FLAPPIN' HECK... (continued)

KARURA
A team at Kyoto University in Japan is working on a human-powered ornithopter. In the Karura design, the pilot uses a rowing motion to power flapping wing tips through a system of pulleys

TRUEFLY
Truefly is a model ornithopter styled after a toucan. Developed by amateur enthusiast Albert Kempf, it is powered by an electric motor. It manages a natural-looking flight with no bobbing of the body

FALCON
When the Colorado Division of Wildlife recently started studying sage grouse, capturing the birds for study proved tricky. Raptor expert Jerry Craig is now testing an ornithopter 'falcon' to scare the grouse onto the ground

» FIND OUT MORE

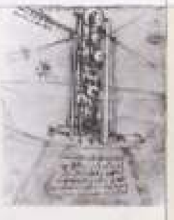
www.ornithopter.org
A flapping flight forum with extensive news and links

www.ornithopter.ca
Project Ornithopter's homepage

www.flightgear.org
If you fancy flying your own Flapper you can download an open source flight simulator and ornithopter plug-in here

HISTORY OF BIRD-LIKE FLIGHT

1490 First



Leonardo Da Vinci designs a human-powered ornithopter in 1490. Studies show that, while it is a well thought-out design, it is not capable of flight

1874 First flying models

Alphonse Pénaud creates the first model ornithopter. Its pattern is still used today in toy birds. While usually powered by rubber bands, one early French model is powered by gunpowder

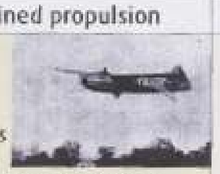
1890s First serious attempt

The great Otto Lilienthal believes in flapping wings. He studies birdflight extensively, makes more than 100 glides and has built an aircraft with flapping wingtips when he is killed in a glider crash

1929 First person aloft

Dr Alexander Lippisch builds a human-powered ornithopter that, while not capable of level flight, makes flap-assisted glides after being towed into the air

1942 Sustained propulsion



German engineer Adalbert Schmid installs additional flapping propulsion wings to a Grunau Baby glider. This aircraft is capable of level flight after being towed into the air

1973 Beginnings of the Flapper

The seed of the current project form in Battelle Memorial Institute in Ohio, when James DeLaurier and Jeremy Harris start looking at ornithopter wing design in their spare time

1991 Successful model flight

The DeLaurier/Harris engine-powered, remotely piloted model achieves sustained flight. This lays the groundwork for the full-sized Flapper. The Flapper makes the world's first flap-powered acceleration to lift-off speed in 1999

2006 The Flapper takes off

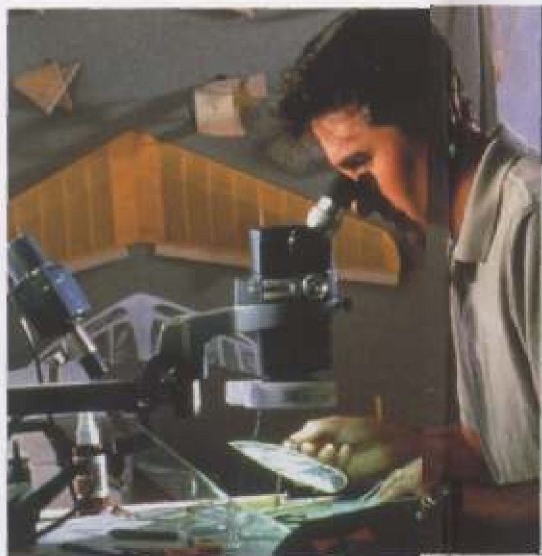
The addition of a model aircraft jet engine helps the Flapper off the ground for the first real flight of an ornithopter at 10.16 on 8 July 2006

➡ up of successive graduate students, worked through the problems.

By 2005 they had one major challenge left to overcome. The intensity of flapping at full throttle meant that during the crucial time when it was just leaving the ground, the wings kept driving the undercarriage back on to the runway, damaging the plane's structure. The breakthrough finally came when DeLaurier visited a friend who owned a model shop. Somebody joked that one of the micro-jet engines, used in large model planes, should be fitted to the ornithopter. DeLaurier took the joke seriously. A small jet engine to help during take off, he reasoned, would require less flapping power, which should stop the problem. It worked.

On 8 July this year, after 33 years of research and 11 years of construction and testing, pilot Sanderson accelerated the Flapper down the runway. It took off and flew majestically – for 300m and a whole 14 seconds. Then a small portion of the left wing's trailing edge buckled and caused the twisting action of the wing to jam, reducing its thrust and lift. As a result, the landing was inelegant, with the aircraft pivoting around and collapsing its nose wheel.

But the team was ecstatic. After all, their Flapper had flown further than the Wright brothers' first flight of 36m in 14 seconds. "It is a surreal experience to know that you are being propelled along by flapping wings," says Sanderson.



FLAP TO THE FUTURE

Flappers have advantages over normal fixed-wing planes in many situations

Although ornithopters aren't likely to ever carry you and 499 other people to the other side of the world on a long-haul flight, they do have many advantages that might make them more common in future than you'd imagine. Ornithopters work by accelerating a large mass of air to a low speed; in contrast, jet engines accelerate a small mass of air to a high speed. This means ornithopters are potentially much quieter and more efficient than current aircraft. Given time, it's possible that quiet, fuel-efficient ornithopters may one day play a significant part in the light aviation scene. They would also be suited to such work as long-range patrols, cruising along borders, watching traffic and patrolling coast lines.

But did it count as a true ornithopter flight, if the take-off was achieved with the help of the model jet engine? DeLaurier is adamant that it did. "It is important to remember that, while the aircraft needed the jet, the jet couldn't have come close to flying the aircraft by itself," he says. "The flapping really did all the work, so we can consider this the first sustained flight of a jet-assisted ornithopter."

Harris and DeLaurier undertook their project largely to see if flapping winged planes can work, but ornithopters do offer some potential advantages over fixed-wing aircraft. Ultimately, they should be more fuel-efficient than small fixed winged planes. It's unlikely they'll ever replace bigger fixed-wing planes, however – they would be too heavy and put too much strain on the wings for flight.

The next task for DeLaurier's team is to prepare the Flapper for display in Toronto's aerospace museum. DeLaurier's not saying at this point whether this one will make further flights before being confined, but he's hopeful of securing further funding to modify the wing design and fly it again – and further. Just keep watching the skies...

Robin Hague is a journalist and former rocket scientist