IN FOCUS: UAV engineers can learn from bumblebees, the masters of lift

By: Dan Thisdell London
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Naturally taking inspiration from birds, many early attempts at flight involved flapping-wing vehicles. A string of human-powered efforts dating back at least to Leonardo da Vinci in 1485 failed until 2010, when a University of Toronto project called Snowbird managed, after a towed launch, to sustain flight for 145m (475ft) for 20s.

The Toronto team went to extreme lengths for even this limited success - Snowbird had the wingspan of a Boeing 737 but weighed only 43kg (95lb).

Motor power changes the game, but apart from toys and a few special-purpose projects such as AeroVironment's radio-controlled pterosaur for the 1997 IMAX movie *On The Wing* or its 2010-2011 nano-hummingbird demonstrator for DARPA, the absence of "ornithopters" says much about the relative practicality of conventional fixed- or rotary-wing designs. However, ongoing research at Harvard University suggests practical, insect-scale flappers are within reach.

One team built an insect-size flapping-wing robot based on a fly's morphology, weighing only 80mg. Kevin Ma, Pakpong Chirarattananon, Sawyer Fuller and Robert Wood, of the engineering department's Wyss Institute for Biologically Inspired Engineering, were able to demonstrate "tethered but unconstrained stable hovering and basic controlled flight manoeuvres". As reported in the 3 May issue of *Science*, "the result validates a sufficient suite of innovations for achieving artificial, insect-like flight".

Wyss Institute

However, Ma and his team clearly acknowledge the challenge they face. Flying insects, they write, "are able to perform sophisticated aerodynamic feats [but] how they perform these feats - from sensorimotor transduction to the unsteady aerodynamics of their wing motions - is just beginning to be understood".

Their "robobee" features two independently actuated wings controllable for stroke rate and amplitude, and fore-aft angle. Without controlling angle of attack, flights of up to 20s achieved stable hovering about a fixed point and lateral manoeuvres.

Separate research carried out on real bumblebees by Andrew Mountcastle, a postdoctoral fellow in Harvard's Combes Lab for study of the biomechanics and behavioural ecology of insect flight, suggests that advancing to practical insect-scale UAVs will demand the unlocking of the mysteries of insect flight which are only beginning to be understood.

Mountcastle, working with Stacey Combes, notes that "insect wings are flexible structures that passively bend and twist during flight". However, most research has ignored this flexibility and modelled wings as rigid planes instead or studied air flow and forces over wings of varying stiffness.

Mountcastle's work, published in the *Proceedings of the Royal Society's Biological Sciences* journal on 27 March, studied live bumblebees - after stiffening their wings.

The experiment was as complicated as it sounds. A bee's wing is a framework of veins, and Mountcastle immobilised one of the joints that allows much of a wing's chordwise flexibility using a piece of glitter.

After bees had been cold-anaesthetised at -15˚C (5˚F) for five to 10min, this "microsplint" was superglued in place and the bees fitted, near their centres of mass, with a noose of fine string, weighted with beads.

For control, some bees' wings had the glitter, which added 5% to wing mass, attached to a point adjacent to the joint. Other bees got a sham treatment, undergoing the anaesthetisation, feeding regime and pre-flight recovery but no splinting.

What Mountcastle discovered was that all the bees subsequently flew with the same wing stroke amplitude and frequency, but the bees with stiffened wings put out 8.6% less vertical lift force. Angle of attack could not be measured directly, but Mountcastle could infer it remained unchanged.

No flying machine can tolerate much inefficiency, but insect-scale ornithopters may prove especially demanding if they are to be of any practical use. As Ma notes: "Flapping-wing flight is energetically costly."

But now, at Harvard's microrobotics laboratory, adaptations of the robobee are being prepared to study flexible wings in an attempt to reproduce the enhanced aerodynamic performance Mountcastle measured.

Tests will begin in the next few weeks. According to Alexis Lussier Desbiens, improvement on the order of the 8.6% suggested by Mountcastle looks feasible - the robobee wing's lift coefficient is about 1.2, while a real bee's is about 1.6, "so there is quite a bit we can get there".

But while observing nature is valuable, he warns, the detail remains daunting. Where, for example, should the centre of mass of an engineered wing be?

Overall, Lussier Desbiens says, the key is to maximise lift and minimise drag, a goal helped by the fact flexibility introduces wing camber. But to fly demands that camber be reversed with each stroke, and in a robot it is "very complex to achieve this".

He acknowledges that improvement on first attempt will involve some luck: "Aerodynamics at that scale is very complex." However, he is optimistic that, eventually, the practical challenges of building robots on an insect scale with flight endurance of several minutes can be overcome.

Getting there will require new battery technology to pack the 200V needed by piezoelectric "muscles" into a unit that weighs only about as much as the 80mg robot - current robobees get their power from a tether - as well as a rethink of manufacturing techniques.

Gyroscopes, accelerometers and other electronics need to be miniaturised, too; the Harvard researchers must decide how far to go in-house, as opposed to waiting for improvements in off-the-shelf components. Meanwhile, the team is working on a "slightly larger" version of robobee.

In Lussier Desbiens' vision of the future, useful missions for such robots could include, obviously, surveillance. But, he muses, a robobee capable of navigating complex mazes through small openings could play an important role in search and rescue.