HUMMINGBIRD'S-EYE VIEW FOR THE US MILITARY

The US research defense agency, DARPA has once again breached the innovation barrier by developing a miniature flying robot project, a humming bird mimicking Nano Air Vehicle (NAV) with AeroVironment Inc. This bio-inspired flying machine has been recognized among TIME Magazine's 2011 best fifty inventions. The drone copies a humming bird to the extent of flying backwards, hover & rotate - all accomplished with the maneuverability of just two flapping wings.

TEXT **Lakshmi R Sabbapathy, Student Aerospace Engineering, Control and Simulation**

Bio-inspired engineering has evolved over the years to pave way for solutions to various human problems. In the effort of mimicking nature, engineering has pushed the brink to hitherto unperceived research and development. DARPA Corporation is a United States military Support research organization aimed at preventing technological threats from harming their national security and is involved in important research to support the Pentagon's classified missions.

On such a quest for 'first-of-its-kind', DARPA financed AeroVironment Inc. for the NAV program, to develop a bio-mimicry like small flying aircraft to specifications provided by the defense agency. Thus the AeroVironment Nano Hummingbird was conceived, which is a tiny remote controlled aircraft built to resemble and fly like a hummingbird. The Hummingbird drone is equipped with a small video camera for surveillance and reconnaissance purposes and, for now, operates in the air for up to eleven minutes. It can fly outdoors, or enter a doorway to investigate indoor environments.

NAV PROGRAM:

The Nano Air Vehicle program's mission was to create extremely small, ultra-light weight air systems with the ability to perform indoor, outdoor and urban military operations. The NAV proposed to explore flapping wing design to provide war fighters with unprecedented military operational configurations. Thus, the program had to push the limits of aerodynamics, power conversion efficiency, endurance and maneuverability for such small air vehicle systems.

Developed as part of the NAV program, the humming bird drone platform turned out to be revolutionary in its ability to harness low Reynolds number physics, navigate in complex environments and communicate over significant distances. The subtle technology was made possible with massive creative investments in the field of aerodynamics to achieve high lift to drag airfoils, light-weight & efficient propulsion and power systems, guidance & navigation communication subsystems, advanced manufacturing & packaging configuration layouts etc.

THE BEGINNING:

Early stages of development were marked by numerous prototype errors and crashes. The trial rooms were padded with sheets of foam and plastic to avoid critical damage to the drone during test flights. The drone was improved in incremental steps, with the first flight lasting just about twenty seconds. But the progression of propulsion and control developments culminated in a final flight of up to eleven minutes, through two and six minutes, respectively. And in the last phase, stabilization and control was achieved to the extent that the remote controller could take a few minutes off the radio to catch the drone.

THE FINAL DESIGN:

After four and a half years of funding and an intense combination of creative, scientific, artistic problem-solving skills from the AV team, the final prototype aircraft has a wingspan of 16cm tip-to-tip and has a total flying weight of 19grams, which is less than the weight of a common AA battery. This includes all the systems required for the flight; such as batteries, motors, communication systems and a video camera. The video camera angle is defined by the pitch of the Nano's body. Forward motion view is a very good navigation aid for the Operator and hovering motion is effective for surveying rooms.

The Nano Hummingbird can fly at 18km/hour and move in three axes of motion. Its backward flight speed range is 8 km/hour. It can withstand 2.5m/s wind gusts, can operate inside buildings while continuously sending back video imagery to the pilot, and has up to a kilometer range of command and control.

MIMICKING THE HUMMING BIRD:

The Aircraft is fitted with a removable body fairing, shaped to have the appearance of a real hummingbird but the drone has landing skids instead of feet and a tail. The wing is a skeleton of hollow carbon-fibre rods wrapped in fibre mesh and coated in a polyvinyl fluoride film. The aircraft is larger and heavier than an average hummingbird, but is smaller and lighter than the largest hummingbird currently found in nature.

The artificial hummingbird maneuvers using its flapping wings for propulsion and attitude control. The final craft is highly efficient owing to the biometric design which borrows some of the features found in small birds. At very small scales, the Reynolds number of a wing (the ratio of inertia to drag) is much lower than with manned aircraft. Under these circumstances flapping wings are more effective in providing lift than propellers or rotors.

The aircraft can climb and descend verti-

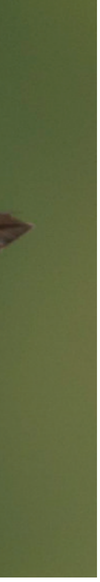

Figure 2. Demonstration of the drone by Matthew Keennon, the humming bird UAV Project manager

cally; fly sideways left and right; forward and backward; rotate clockwise and counter-clockwise; and hover in mid-air. Such a pity that it does not indulge in nectar from flowers! It is able to fly in all ways, just by changing the curvature, the shape and different aspects of the wing movement at a very high speed. In order to fly by beating its wings back and forth, the UAV creates lift by deflecting air downward, creating an area high pressure directly below the wings and low pressure above. If the nano hummingbird sharpens the angle of its right wing on each forward stroke, and does the opposite on each backstroke, the craft rotates clockwise. The wings of this drone beat symmetrically. If the angle on the wing at the end of the forestroke and beginning of the backstroke decreases, the nose dips downward and the aircraft moves forward. By increasing the angle of only its left wing, the nano hummingbird creates more upward thrust on its left side, which will cause the bird to roll to the right. This camera-equipped bird beats its wings twenty times a second, whereas natural hummingbirds clock up to eighty. Nevertheless, it can hover like the real thing, perform rolls and even fly backwards.

THROUGH THE DEVELOPMENT STAGES:

This is the first aircraft to be developed that flies with two flapping wings and it is tailless. This drone is smaller than the drones now being used by the United States military. From the first day of the mission, the biggest challenge, according to experts was to develop viable propulsion and control systems with two flapping wings and a tailless configuration.

This aircraft is designed to generate all necessary lift and control forces through the use of the only two moving aerodynamic parts: the two flapping wings. AV has tested over ninety different wing designs till date, many flapping mechanisms as well as many control configurations, most of which used only manipulations of the wing dynamics for a 'tailless' design. This configuration is inherently unstable and once flying, it immediately wants to tumble out of control, making it impossible for a human pilot to fly, without assistance from an automatic control system. Some early developmental flying prototypes used tails and propeller thrusters to research various control algorithms. Once the basic control algorithms were established, the extra control structures were removed and all control was shifted to the wings, the only active aerodynamic components on the aircraft. The above design led to the successful twenty seconds long controlled flapping flight demonstration. Once the viable propulsion system and control system was achieved, the next effort focused on optimizing the aircraft for longer flight endurances, further develop the flapping flight mechanisms, transition capability from hover to forward flight and back, as well as reducing the size, weight, and acoustic footprint. All the above are distinct technical challenges in their own right but they actually conflict with each other.

As AV continued to perform flight tests, hover and fast forward flight in a single flight with integrated aircraft was achieved using a ground control system and video display. During these flights, pure hover flight endurance, pure forward flight endurance, and hover duration against added payload mass was measured. The resulting system was then tested to assess its operational utility in both indoor and outdoor missions.

This amazing invention definitely did not succeed without significant failures and setbacks. Nevertheless, DARPA's consistent vision for groundbreaking inventions exceeded their own expectations. Some technical goals that marked the success of the project are:

- The Drone demonstrated precision hover flight within a virtual 2m-diameter sphere for one minute.
- Hover stability in a wind gust flight, which required the aircraft to hover and tolerate a 2m/s wind gust from the side, without drifting downwind more than 1m.
- Continuous hover endurance of eleven minutes with no external power source.
- Flying indoors "heads-down" where the pilot operates the aircraft only looking at the live video image stream from the aircraft, without looking at or hearing the aircraft directly.
- The aircraft flew in hover and fast forward flight with bird-shaped body and bird-shaped wings.

FUTURE PLANS FOR THE HUMMING BIRD:

The humming bird Drone's primary aim is to assist the Pentagon as an unconventional military helicopter. Its camouflaged size and appearance is believed to increase the flexibility of accessing deemed-impossible warfare and tight quarters of city environments. In the future, DARPA plans to use the teeny NAV for secret indoor and outdoor government missions, like dropping off listening devices and other cargo, and transmitting sound and video to locations as far as a kilometre away. Although there are no immediate plans to implement these drones in real-life situations, the cutting technology, which was indigenously developed to materialize this mission, could definitely be used to aptly aid other existing or future research. This bio-inspired conception has without doubt stretched our understanding of novel technology development for flight at these small sizes. In the future, DARPA has plans to invent a mechanism for these UAVs to power itself in mid-air (to increase its operation time), indoor navigation without GPS, automated collision avoidance, quieter and wind resistant systems, and improved power and communication systems; or who knows - maybe even pollinate Begonias!

References

DARPA'S funding and Mission Objectives: http://www.darpa.mil

AeroVironment technology Integration: http://www.avinc.com/nano

Specifications of the Drone: http://en.wikipedia.org