ATMOS: TRANSITIONING THE FUTURE

The design of an autonomous UAV system that effectively combines VTOL and cruise flight

In the fall of 2011 ten students started with the design of a UAV for their Design Synthesis Exercise. Just a few months later, they saw their self-built and designed UAV compete in the prestigious UAVForge challenge. This article tells the story of team ATMOS and what made their UAV stand out.

TEXT **Jurjen de Groot and Sander Hulsman, Students Aerospace Engineering, Co-founders of ATMOS**

The DSE assignment description was very straightforward: design a UAV capable of competing in the UAVForge challenge, an international competition organised by the American defence research agency DARPA. In short, the UAV must take off vertically from a starting location, fly out to an observation area, perform observations, return to the launch site, and land vertically. Additionally, the complete system (including the ground station) has to fit in a backpack and still be operational while facing winds of up to 15 knots.

Taking all the requirements in account, the students began work on this extensive assignment and after ten weeks presented their final design. The results were promising and both the project supervisors from the faculty's Micro Aerial Vehicle lab (MAVlab) and the students were very enthusiastic about the possibilities of their design. As a result, the students decided to continue with the project on their own with the goal of actually competing in the UAVForge challenge. This was the start of team ATMOS (Autonomous Transitioning Multi-rotor Observation System).

DESIGN

One of the innovative aspects of the ATMOS UAV is its hybrid flight mode design. It combines the vertical take-off and hover ability of a helicopter with the extended range and cruise speed of a flying wing. The vehicle (or ATMOV, as it is called by the team) takes off with the four engines pointed upwards and is also able to hover this way. Once in the air, the complete vehicle rotates ninety degrees forward, a manoeuvre where the ATMOV gradually transitions from hover flight to a much more efficient horizontal cruise flight. Although this clever combination has numerous advantages, it did lead to some serious challenges in the design of the propulsion and autopilot systems.

PROPULSION SYSTEM

The main problem is that propellers optimised for hover flight differ significantly from propellers that are efficient in cruise flight. This is to be expected since hover propellers operate in air with a free stream velocity close to zero while cruise propellers encounter an airflow equivalent to the cruise speed. Selecting a single type of propeller would result in poor hover performance, poor cruise performance or both. The solution was to have a separate set of propellers and engines for the different flight modes. In hover, the majority of the lift is generated by the big engines and propellers located on the vertical stabilizer. The small engines on the wingtips are used mainly for stabilising and control in this case. When the UAV transitions to cruise flight, the wing takes care of the lift and the wingtip engines alone provide all the thrust needed. The bigger hover engines are now turned off and the propeller blades fold backwards to decrease the air drag.

Another noteworthy aspect is the placement of the small cruise engines at the very tip of the wings as a means of reducing induced drag. Instead of using winglets that complicate the structure, the wingtip propellers rotate in the opposite direction of the wingtip vortices. The propeller induced vortices therefore actively cancel out most of the induced drag.

AUTOPILOT

Like most drones, the ATMOV uses an autopilot to control and stabilize the aircraft that is unstable by nature. The team decided to use Paparazzi, a powerful open source autopilot system that uses an Inertial Measurement Unit (IMU) that measures accelerations and rotations, compares these with the desired aircraft state and corrects all deviations using the control surfaces and propellers. In case of a transitioning UAV however, a challenge arises with processing the angles that determine the attitude. The conventional method used in autopilots for these calculations is Euler based, which would be perfectly suitable for any other fixed or rotary wing. Yet when the entire aircraft rotates ninety degrees about one axis, the Euler based attitude definition will encounter the so-called singularity point. The mathematical representation of the location of a singularity point is ambiguous, which basically means there is no difference between forward and backward flight.

The answer for this problem is a quaternion based angle definition. In this method all rotations of the vehicle remain perfectly defined. The team therefore decided to rewrite every module of the autopilot, exchanging Euler angles for quaternions. This time-consuming task certainly lifted the paparazzi project to a higher level, but above all provided the possibility to customize and tweak the software for the ATMOS project.

Table 1. ATMOS design specifications

ATMOS specifications	
Wingspan	1.34m
Weight	1.4kg
Max speed	20.2m/s
Cruise speed	15m/s
Max hover endurance	17min
Max cruise endurance	35min
Max range	30km

Figure 1. The ATMOV IV transitioning to horizontal flight

PRODUCTION

Just as any aircraft, the structure has to be as lightweight as possible while still being strong enough to withstand the flight loads. Furthermore, the UAV had to be crash resistant to a certain degree, given the experimental nature of the project. In the ATMOVs this is realised by using a sandwich type structure with a foam core and aramid composite skin. Aramid (or Kevlar as it is known commercially) is a very tough, light-weight material, and in contrast to the more commonly used carbon it is transparent to radio signals. An additional challenge was the requirement that the whole system had to fit in a backpack. This meant that the wings had to be detachable from the aircraft. Although structurally more complex, this modularity actually created a whole range of extra opportunities for the system. For example, a different set of wings could easily be installed for different mission requirements. Another exciting option is the possibility of combining several aircraft or parts in to one flying contraption, limited only by your imagination.

The entire production process of the prototypes is done by the students themselves and they quickly found out that a nice theoretical design does not necessarily translate into an easily constructed prototype. As such, there had to be some significant tweaks and changes in the design before the building could even start. But, after a crash course on CNC machines, hot-wire foam cutters and lamination techniques, the students managed to produce four complete prototypes in time for the challenge.

UAVFORGE CHALLENGE

Leading up to the UAVforge challenge, a series of knockout rounds were organized in order to reduce the initial amount of 140+ competitors to ten finalists. Team ATMOS was selected to be amongst the top ten and was invited to the UAVforge final fly-off event, held in Georgia, USA.

In this fly-off event, the teams were given the possibility to show their UAV in action and take a shot at the mission objectives. It turned out that the mission itself was far more difficult than expected as not a single team was able to complete the entire course successfully. Still, ATMOS managed to leave quite an impression with their unique transitioning vehicle which also turned out to be the only vehicle that was able to fly in full autonomy. The flights performed by the team were actually the first fully autonomous flights with a transitioning vehicle ever! All together ATMOS was rewarded with a respectable third place.

FUTURE

Although the team has already shown the potential of the UAV, the system is far from a finished product. And besides, there are still so many applications that ATMOS could be used for that have not been fully investigated. Possible future application could be emergency service assistance, offshore inspections or fire detection, just to name a few. This is the reason that ATMOS will continue as a student project similar to Nuna, Formula Student and DelFly. New Bachelor and Masterstudents will have the possibility of participating in the future development and optimisation of ATMOS, lifting the design to an even higher level. And in the long run this will hopefully lead to a versatile, reliable and widely used UAV system.

If you are interested in joining the team or if you want more information about ATMOS, contact us at info@teamATMOS.nl

References

Atmos website: http://teamatmos.nl

UAVForge competition: http://uavforge.net