A SURVEY ON UNMANNED AERIAL VEHICLES BASED ON COANDA EFFECT

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Abstract: *Lenticular aerodyne is a concept of the famous scientist Henri Coanda. The goal of his research was to develop a safe and inexpensive flying vehicle. The working principle of the proposed vehicle is based on targeting a high pressure fluid jet on a concave surface. In this way, the fluid is forced to follow the contour of the surface, engaging the air around this surface. Based on this idea, different aerodyne models were developed by various research groups, with a wide range of applicability, being used for: research/education, surveying and real-time data transmission in the field of military or civilian, mapping inaccessible areas, application in meteorology, monitoring animals in their habitat, testing aircraft prototypes in hazardous environments, entertainment, etc. In this paper, a survey of the designs of unmanned aerial vehicles, based on Coandă effect, will be presented and discussed.*

Keywords: *Coanda effect, unmanned aerial vehicle (UAV), design*

1. Introduction

The term unmanned aerial vehicles (UAV) or aerial robotics is often attributed to Robert Michelson [19], as a way to capture a new class of highly intelligent, small flying machines. However, it is clear that the range of systems and activities covered under the label aerial robotics could extend much further, and that its root scan be found far back in the beginning of the 20th century, to get her with the birth of aviation [9].

Aeromodelling is defined as designing flying or non-flying small sized replicas of existing or imaginary aircraft using a variety of materials including paper, plastic, metal, synthetic resins, wood, foam and fiberglass. Flying designs range from generic gliders to accurate scale models, some of which can be very large.

An unmanned aerial vehicle or micro aerial vehicle (MAV), commonly known as a drone is an aircraft without a human pilot on board. Its flight is either controlled autonomously by computers in the vehicle, or under the remote control of a navigator, or pilot on the ground or in another vehicle. There are a wide variety of drone shapes, sizes, configurations, and characteristics.

Historically, UAVs were simple remotely piloted aircraft, but autonomous control is increasingly being employed.

They are predominantly deployed for military applications, but also used in a small but growing number of civil applications, such as firefighting and nonmilitary security work, such as surveillance of pipelines.

2. Applications of flying vehicles

The list of possible applications of aerial robots is quite vast. According to [17, 27], such applications fall within nine categories:

- Remote sensing such as pipeline spotting, powerline monitoring, volcanic sampling, mapping, meteorology, geology, and agriculture [24, 25], as well as unexploded mine detection [23].
- Disaster response such as chemical sensing, flood monitoring, and wildfire management.
- Surveillance such as law enforcement, traffic monitoring, coastal and maritime patrol, and border patrols [28].
- Search and rescue in low-density or hard-to-reach areas.

- Transportation including small and large cargo transport, and possibly passenger transport.
- Communications as permanent or ad hoc communication relays for voice and data transmission, as well as broadcast units for television or radio.
- Payload delivery e.g., firefighting or crop dusting.
- Image acquisition for cinematography and real-time entertainment.

Military applications of aerial robots follow the same descriptive lines, with a particular emphasis on remote sensing of humans and critical infrastructure, surveillance of human activity, and payload delivery [9].

3. Flying vehicles types

Unmanned aerial vehicle designs show greater variety than manned aircraft designs because a cockpit and suitable conditions for a human pilot are not required. UAVs and MAVs presently serve in many roles and missions that are dangerous or impractical for human pilots.

3.1. Fixed-wing UAV

The majority of UAVs fall into the category of traditional, fixed-wing airplane designs. A classic example is the RQ-11 Raven, pictured in Figure 1 that has been deployed for U.S. military operations. Fixed-wing UAVs have a speed range centered on their most efficient cruise speed, with limited minimum and maximum flight speeds. For example, the RQ-11 Raven has a minimum speed of 20 mph and a maximum speed of 50 mph [4]. While this type of configuration is suitable for long endurance flight, the minimum speed restricts its ability to inspect a fixed target on the ground.

Figure 1: *Fixed-wing UAV, AeroVironment RQ-11 Raven [3]*

3.2. Hovering UAV's

In regards to hovering UAVs, ducted fans are just one of several types of vehicles that are operating today. Other prominent approaches for hovering flight include helicopters, quadcopters, tailsitters/3-D aerobatic airplanes, and flapping wing vehicles. Each of these configurations has its own strengths, but the advantages of the ducted fan are distinct from each [22].

- *Ducted Fans*

Interest in ducted fan vehicles has grown in recent years as the UAV and MAV market has expanded and the unique advantages of this vehicle configuration have been recognized as perfectly suited for certain missions. Ducted fan UAVs take off vertically, hover, and tilt into the wind for high-speed flight in any direction. The vehicle can be used as a movable sensor, forward scout, or laser-targeting device [8], and in situations where up-close inspection of an area or object is critical. Some prominent example of ducted fan UAVs is the Honeywell RQ-16 T-Hawk (Figure 2), which has been deployed to military operations in Iraq [26].

A ducted fan produces more thrust than a free propeller of the same diameter and of equivalent power [18]. This means that ducted fans hover more efficiently than an open rotor or propeller.

Figure 2: *Honeywell RQ-16 T-Hawk [26]*

- *Helicopters*

Several basic designs of radio-controlled helicopters (Figure 3) exist, of which some (such as those with collective pitch, meaning blades which rotate on their longitudinal axis to vary or reverse lift so the pitch can be altered and can therefore change the angle of attack) are more maneuverable than others. The more maneuverable designs are often harder to fly, but benefit from greater aerobatic capabilities.

Figure 3: *Thunder Tiger Raptor [14]*

The rotor system, or more simply rotor, is the rotating part of a helicopter which generates lift. A rotor system may be mounted horizontally as main rotors are, providing lift vertically, or it may be mounted vertically, such as a tail rotor, to provide lift horizontally as thrust to counteract torque effect.

- *Quadcopters*

Quadcopter is a multicopter that is lifted and propelled by four rotors. Quadrotors are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of revolving narrow-chord airfoils. Unlike most helicopters, quadrotors generally use symmetrically pitched blades; these can be adjusted as a group, a property known as "collective" but not individually based upon the blade's position in the rotor disc, which is called "cyclic". Control of vehicle motion is achieved by altering the pitch and/or rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics.

Figure 4: *AeroQuad [13]*

- *Tailsitters - 3D Aerobatic airplanes*

Remote control (R/C) pilots have demonstrated amazing aerobatics with airplanes that have a thrust-to-weight ratio above 1.0 (Figure 5). These configurations can cruise like regular fixed-wing aircraft, but their motor will be oversized for that condition [22].

Figure 5: *Hovering aerobatic ultra-light airplane [1]*

- *Ornithopter*

An ornithopter (Figure 6) is an aircraft that flies by flapping its wings. Designers seek to imitate the flapping-wing flight of birds, bats, and insects. Because ornithopters can be made to resemble birds or insects, they could be used for military applications, such as aerial reconnaissance without alerting the enemies that they are under surveillance. As demonstrated by birds, flapping wings offer potential advantages in maneuverability and energy savings compared with fixed-wing aircraft, as well as potentially vertical take-off and landing. It has been suggested that these advantages are greatest at small sizes and low flying speeds.

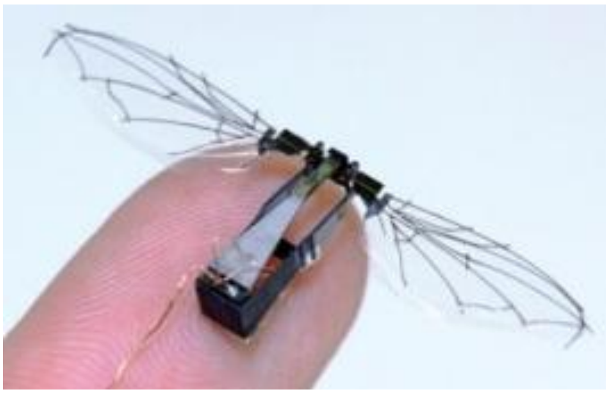

Figure 6: *Harvard microrobotic fly [2]*

- *UAV based on Coandă effect*

In the next paragraph, a detailed presentation of UAVs based on Coandă effect will be highlighted.

4. Overview on the existing projects based on Coandă effect

4.1. Coandă effect

The Coandă effect was discovered in 1930 by Henri-Marie Coandă. His patents state:

"If a sheet of gas at high velocity issues into an atmosphere of another gas of any kind, this will produce, at the point of discharge of the said sheet of gas, a suction effect, thus drawing forward the adjacent gas." [6]

"If, at the outlet of the fluid stream or sheet, there is set up an unbalancing effect on the flow of the surrounding fluid induced by said stream, the latter will move towards the side on which the flow of the surrounding fluid has been made more difficult." [6]

In simple terms, a stream of fluid at high velocity will attach to a curved surface rather than follow a straight line in its original direction. This stream of fluid will also entrain air from around it to increase the overall mass flow rate of the stream of air.

This phenomenon can be harnessed to produce lift in two ways. Firstly, it can be used to change the direction of airflow to point downwards, resulting in vertical thrust. Secondly, it can be used to entrain air from above which causes a region of low pressure above the body, which results in lift [5].

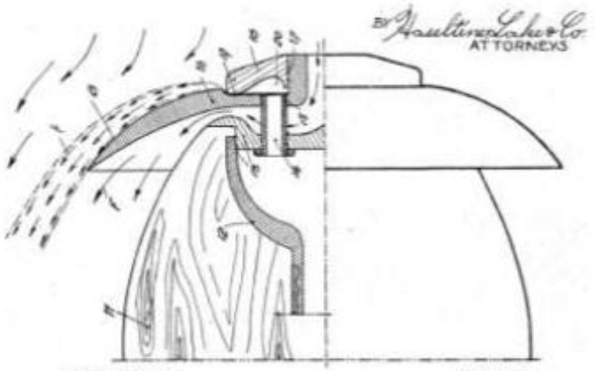

Figure 7: *Coandă effect patent image [6]*

4.2. Existing projects

In UK [7] valued Coandă effect capabilities in one of his inventions, which obtained a GB patent no. 2387158, granted in 2003.

In the design of a Coandă UAV the rotor at the center of the hollow fuselage canopy pulls air in from above the craft and blows it out radially, over the top of the curved body. Because of the Coandă effect, the airstream remains "stuck" to the canopy and follows the curved surface, leaving the body at its base.

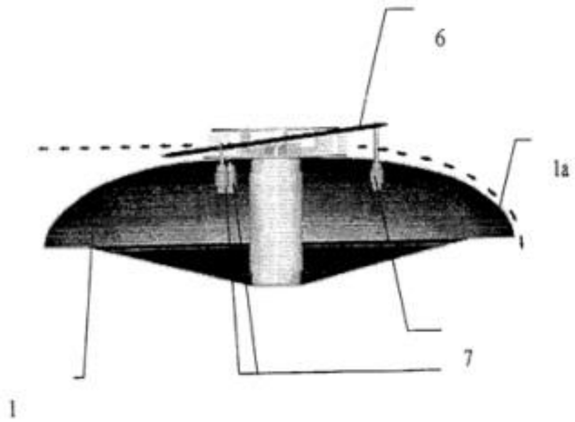

Figure 8: *Robert Collins aerial flying device [7]*

This, along with the downwards thrust of the fan, pulls the aircraft upwards (Figure 8).

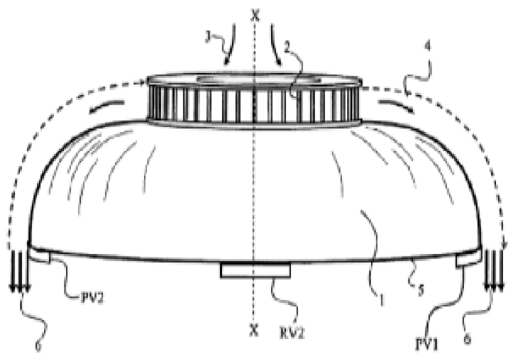

Figure 9: *First Coandă UAV of [12]*

In the 90's [12], together with the GFS (Geoff's Flying Saucers) projects team, promoted also an aerial Coandă device, with a circular shape canopy (Figure 9).

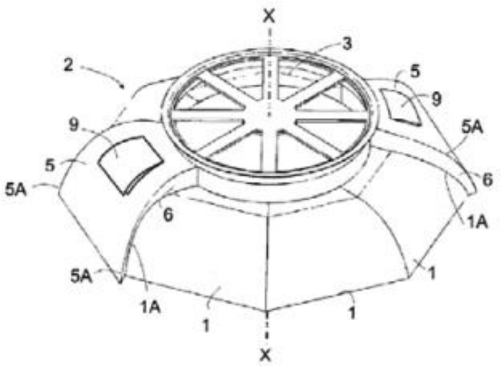

Figure 10: *Improved UAV model [11]*

When GFS projects built their first model, the circular shape turned to be octagonal, with flat flaps on four opposite sides of the trailing edge (Figure 10).

In 2006, [20] made and tested his first UAV (Figure 11 - GFS-UAV model N-01A). This one, propelled by an electric engine, was using the Coandă effect to take off vertically, fly, hover and land vertically.

The design of the GFS-UAV N-01A was based on the Geoff Hatton' flying saucer from GFS Project limited. In the next year, Jean-Louis Naudin freely published the full plan of the GFS-UAV N-01A and a detailed tutorial to help UAV fans to replicate his GFS UAV [20].

Figure 11: *GFS-UAV (N-01A) [20]*

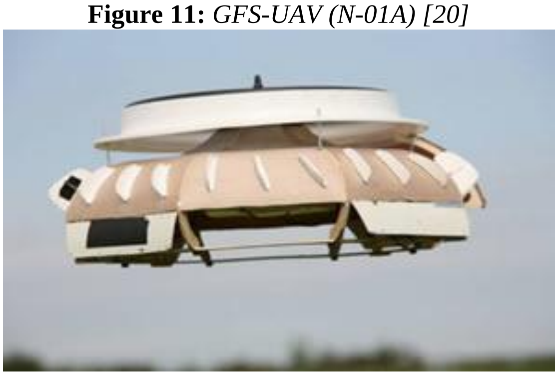

Figure 12: *Geoff Hatton's GFS-02 [11]*

In 2007, [11] presented an optimized control for his family of Coandă UAVs (Figure 12), this time improving the airflow over the outer surface, especially in open air, when it may be disturbed by a lateral wind.

Figure 13: *MEDIAS-LUAV [21]*

The MEDIAS project [21] is a VTOL (Vertical Take-Off and Landing) UAV with a hybrid design (Figure 13). The final solution of this prototype is characterized by the fact that the UAV uses the Coandă Effect and an electrically driven propeller; alongside these features, optional conversion and use of solar energy will compete at improving and increasing the UAV's mission autonomy. The helium optionally added inflatable chamber will also increase the functionality of the MEDIAS-LUAV.

Figure 14: *AESIR's EMBLER demonstrator [15]*

The AESIR [15] concept instead of a ducted fan, places a fan on top of a dome that by exploiting the Coandă effect channels the downstream air to a cone thus lifting a vehicle. Such a UAV is inherently stable because it is floating over a cone of air instead of a column like a regular ducted fan. AESIR have already made several prototypes that have demonstrated their capability for stable and controllable flight. Its initial step is the Embler demonstrator (Figure 14), a new version of the GFS design with a lighter carbon fiber airframe and improved electric motor giving about 10 minutes endurance.

Figure 15: *EMBLER demonstrator on Northrop Grumman Remotec's Wheelbarrow UGV [15]*

The AESIR design not only allows a more compact vehicle for the same equipment (or more usable volume for the same fan size) but it has much better weight distribution by placing all the heavy parts inside and at the lower part of the vehicle. Prototypes, such as EMBLER, have been used in conjunction with unmanned ground vehicles (UGV) (Figure 15).

The next member in the AERIS family was Vidar [16], a 300mm-diameter battery-powered UAV with a 15min endurance carrying a 100g payload and designed to fly inside buildings and in confined spaces (Figure 16). Next up was Odin, a 1m-diameter UAV powered by a rotary internal-combustion engine and able to carry a 10kg payload for up to an hour.

Figure 16: *Early prototype of Vidar [16]*

The third member of the family, the Hoder [16], is planned to be a multi-engined heavy-lift UAV capable of carrying a 1-tonne payload and intended primarily for cargo transport. HODER is the larger UAV from AESIR family, but it is a heavy lift craft, with two or more engines, with a mass of 1500 kg and is capable of carrying a 1000 kg as a payload, for up to eight hours (Figure 17).

Figure 17: *HODER UAV [16]*

Conclusions

Unmanned aerial vehicles represent a very interesting and exciting area of robotics, involving very dynamic platforms whose size ranges from a few centimeters to several tens of meters. It seems highly probably they will continue to see new applications, beginning with those that happen in relatively unpopulated areas and relatively high altitudes. The current applications of aerial robots are focused primarily on military operations. In this paper, a survey of the designs of unmanned aerial vehicles, based on Coandă effect, was presented and discussed.

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