

Investigating the Use of the Coanda Effect to Create Novel Unmanned Aerial Vehicles

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Abstract

In recent years the demand for Unmanned Aerial Vehicles (UAV's) has increased rapidly across many different industries and they are used for various applications. Such systems have the ability to enter dangerous or inaccessible environments and allow vital information to be collected without human risk.

In order to carry out a task, a UAV has to face many different challenges. This has led to the development of novel platforms that move away from traditional aircraft design in order to make them more capable. A good example of this type of craft is one which uses the Coanda Effect to assist propulsion. This effect was discovered in 1930 by Henri-Marie Coanda who found that if a thin film of air is directed over a curved body, then the air follows the curve. When used to propel a UAV, the Coanda Effect also entrains air from above and lowers the air pressure in this region, which in turn generates more lift.

Many organizations have attempted to use this phenomenon to aid the lift of various unusual air vehicles.

Keywords: Coanda Effect, UAV, Airfoil, Eppler 423, Ring Wing.

Introduction

This paper will discuss the limitations of currently marketed UAVs and explore the potential of using the Coanda Effect in building more capable systems.

The current main market for UAVs is in defence, with 57% of UAVs being classed as military [1]. They are often used to spy on hostile situations from a distance, to watch the area around a soldier and have the potential to search for IEDs (Improvised Explosive Devices). This eliminates the need for the soldier to take any unnecessary risks. 71% of all UAVs are fixed-wing [1], this means they have to keep moving to stay in the air. A more desirable capability for a UAV in many of these situations is VTOL (Vertical Take Off and Landing) which gives the ability to hover and perch, and monitor an area from a fixed position, but this usually results in reduced flight times.

A small VTOL UAV will often have the capability to carry a significant payload. This gives the opportunity for it to carry:

- High definition video & stills.
- Thermal imaging and infra-red cameras.
- Explosive equipment.
- Small delivery packages.
- Listening devices.
- Mine detectors.

"The ability to detect your enemy before he sees you is a significant force multiplier. If this capability can be deployed to the front line fighting forces as an asset that can be used by troops it becomes even more valuable." [2]

The main problems for a UAV during a mission include:

- Payload.
- Endurance.
- Search & avoid strategies.
- Wind gusts.
- Communications.
- Manoeuvrability.
- Autonomy.
- Stealth.

With so many restrictions for the pilot of a UAV to consider, in an ideal world UAVs would operate without the requirement for human control. Many companies are in development of autonomous UAVs but so far there are few UAVs on the market which are fully autonomous. Autonomy is a very challenging solution from the developers' perspective but it will ultimately lead to the most efficient systems.

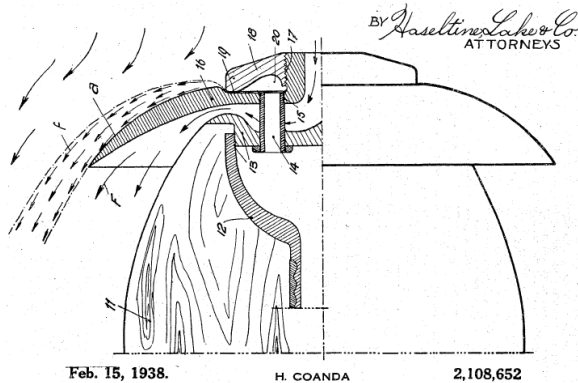


Figure 1. Henri Coanda's patent for a propelling device [3].

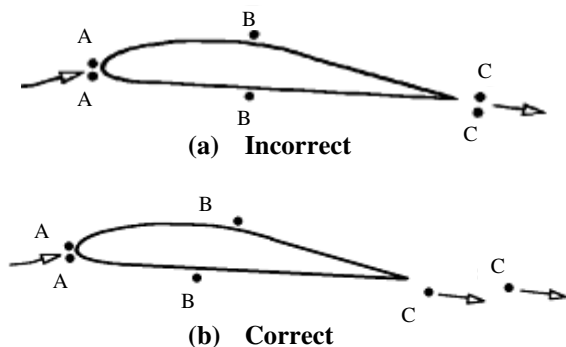


Figure 2. A common misunderstanding regarding flow over an airfoil [4].

The Coanda Effect and lift

Henri Coanda's patents on the Coanda Effect 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." [5]

"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." [5]

In simple terms, a stream of air at high velocity will attach to a curved surface rather than follow a straight line in its original direction. This stream 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.

Conventional fixed wing design

It is a common misunderstanding that the resulting lift of an airfoil can be explained using the Bernoulli Equation. The explanation is often quoted by academics erroneously, stating that because the distance over the top of the airfoil is greater than the underside, the air over the top goes faster than the underside air to rejoin at the trailing edge and thus the increased speed reduces pressure above causing lift [4]. This is in fact only half true as the air does not rejoin the same airstream at the trailing edge (see Figure 2).

Lift on a conventional airfoil is generated by circulation around the wing (see Figure 3). As air is accelerated downwards, it causes the pressure below the wing to increase, and the pressure above to decrease, resulting in lift [6].

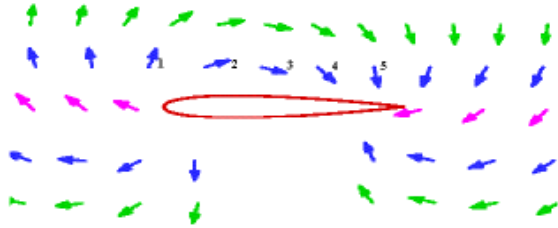


Figure 3. Air circulation around a conventional airfoil in forward flight [6].

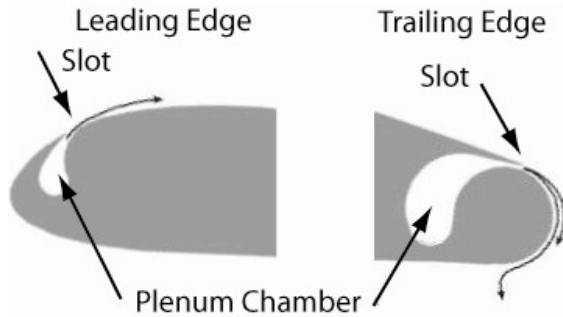


Figure 4. Using the Coanda Effect to aid lift of a conventional wing [4].



Figure 5. Aesir Coanda Effect UAV [2].

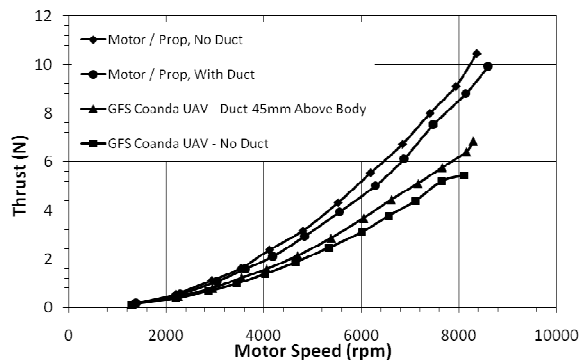


Figure 6. Performance of the GFS-UAV N-01A body and AXI 2217 /20 motor & GWS 1060 prop.

The Coanda Effect can be applied to a conventional fixed wing aircraft, to improve lift by up to 300% [4]. By storing compressed air in a plenum chamber (see Figure 4) at the leading and/or trailing edges of a wing, a narrow high-pressure jet of air is forced over the surface, thus preventing flow separation.

Current Coanda systems

A UK based company; Aesir (formerly GFS Projects Limited) are developing a UAV which is based on the Coanda Effect:

"By creating an air velocity in the centre of the craft with the aid of a fan and then directing the air flow out of the outlet it will follow over the curved surface. The amount of lift generated is dependant upon the velocity, mass and density of the air." [7]

Figure 6 shows the results from an experiment conducted at Middlesex University, where we tested an AXI 2217/20 motor & GWS 1060 prop mounted on the publically available GFS-UAV N-01A body [8] against a setup with the same motor and prop with no restricting body. We found that it produced less lift with the body in place. At 8000 rpm, the propeller and motor on their own with no restricting body produced 9.4 N whereas with the body in place only 6.2 N of thrust was obtained.

This suggests that there is negligible lift generated from entrainment through the Coanda Effect, and that the majority of the lift is from the downwards-pointing airflow at the perimeter of the craft. One of the few advantages of this design is the ability to easily manipulate the airflow from a single fan to control pitch, roll and yaw. The reduction in lift is partially caused by the concave portion of the body producing negative lift [9].

Robert Collins of Blumlein HF Limited in the UK holds the international patent for several aspects of Coanda-propelled flight [10]. One of his concepts is an Unmanned Disk Aircraft System (UDAS) (see Figure 7) which utilises a low profile Disk Gas Turbine (DGT) power unit.

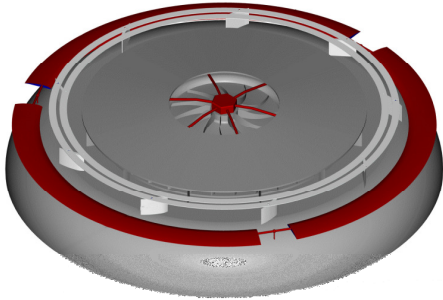


Figure 7. Robert Collins' UDAS (Unmanned Disc Aircraft System) [11].



Figure 8. Dyson Air Multiplier™ [12].

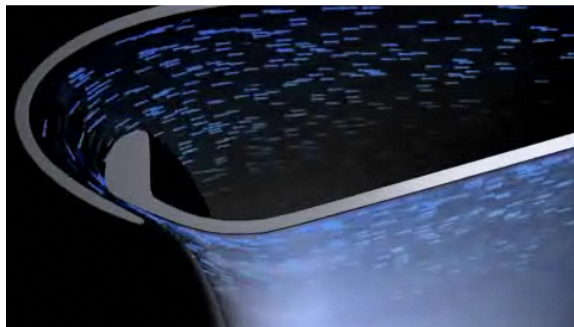


Figure 9. Cross-section of Air Multiplier™ showing acceleration of air [12].

GWS 1060 3 blade prop and
AXI 2217/12 brushless motor



Figure 10. Linear airfoil experiment.

"The DGT has a low profile, balanced contra-rotating compressor and turbine arranged in a plane configuration which overcomes any tendency for the platform to rotate about its vertical axis" [11].

Another advantage of this system is that it has no external moving parts, which is safer for civilians when used in an urban environment, and helps to keep the craft airborne in the event of a collision.

A very recent and unusual application of the Coanda Effect is Dyson's Air Multiplier™ desktop fan. This device uses several phenomena that we wish to apply to a Coanda vehicle. It does away with conventional fan blades and instead forces air through and over a ring with an airfoil section.

"Air is accelerated through an annular aperture. It passes over a 16° airfoil-shaped ramp, which channels its direction. Air behind the Dyson Air Multiplier™ fan is drawn into the airflow through a process known as inducement."

"Air around the machine is also drawn into the airflow, through a process known as entrainment, amplifying it 15 times." [12]

The ring wing airfoil concept

We can apply the above theories to a VTOL craft by taking an airfoil section and rotating it around the leading edge through 360 degrees to form a ring. We can then simulate the conditions that an equivalent straight wing would encounter during forward flight by blowing air radially from the centre of the craft.

There are several uncertainties that need to be verified in order to achieve maximum lift with the ring wing configuration:

- Shape of the ring airfoil.
- Angle of Attack (AOA), α .
- Height of attack.
- Source of air propulsion.
- Air velocity required at air source.

We chose to use the Eppeler E423 airfoil profile because it is designed to operate at a low Reynolds Number [13], which is ideal for low speed UAVs.

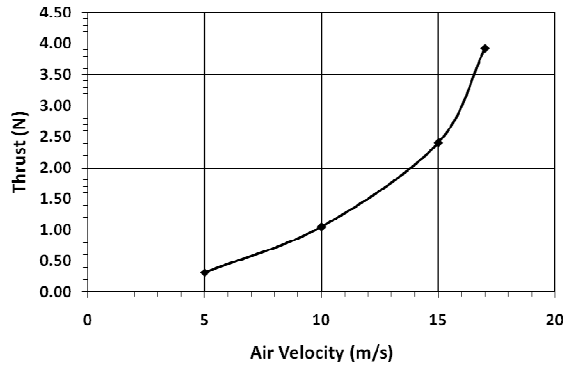


Figure 11. Performance of the E423 Airfoil.

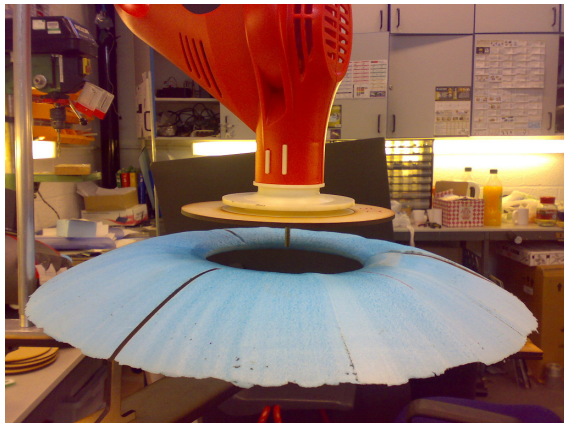


Figure 12. 10° AoA Ring Airfoil test rig.

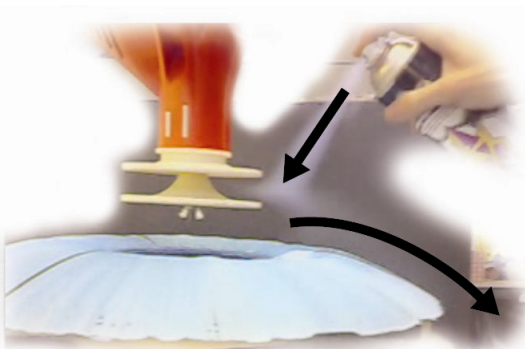


Figure 13. Airfoil testing showing the entrainment on the top surface.

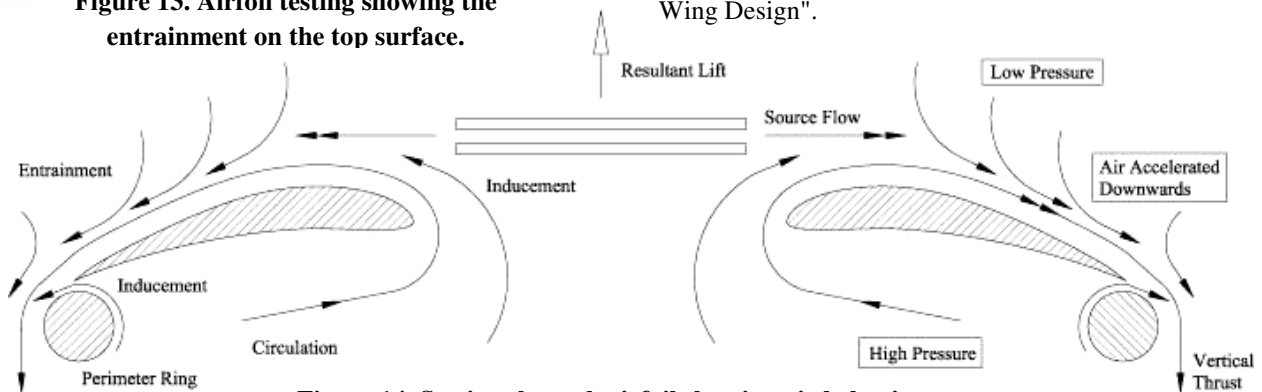


Figure 14. Section through airfoil showing air behavior.

To identify the angle and height of attack we built a test rig with a linear E423 airfoil and axial fan arrangement (see Figure 10). With a neutral height of attack, we adjusted the angle of attack and measured the amount of lift generated. The most suitable AoA was found to be 10°. The foil was then set at this angle and the height adjusted until the maximum lift was achieved. We carried out further tests involving ducting and varying the distance between the fan and airfoil, and found that the greater the air velocity over the foil, the greater the lift.

This coincides with the lift equation:

$$L = \frac{1}{2} \rho v^2 A C_L$$

Where:

L = Lift (N)

ρ = Air Density (kg/m^3)

v = Air Velocity (m/s)

A = Top surface Area (m^2)

C_L = Coefficient of Lift

From the results of this experiment, we obtained the necessary information to produce a ring wing for testing. During this experiment we found that a drop in lift occurs when the nozzle is in the neutral position, which is caused by the leading edge of the airfoil to behaving as a wall, restricting and slowing down the airflow.

The most efficient method of circulation on the airfoil was found to be when the nozzle is blowing only over the top surface and inducing air through the central hole in the ring wing to boost circulation around the bottom surface, (see Figures 13 & 14). This method of achieving lift on an airfoil is very similar to the effect of circulation on an airplane wing, as discussed in the section "Conventional Fixed Wing Design".

Once this configuration was found, we began to experiment with ways of using the Coanda Effect to increase lift efficiency. A perimeter ring of circular cross section was positioned below the trailing edge of the ring airfoil in a position where it can use the Coanda Effect to entrain more air, and direct the air leaving the trailing edge so that it is more effective at producing vertical thrust. By experimenting with the gap between the airfoil trailing edge and this new ring, we were able to increase the lift by around 3%.

Conclusion

With the current prototype, only a small amount of lift can be achieved, which would not be sufficient for the UAV to take off. More experiments need to be carried out to apply the theory in this paper to our prototype in order to increase lift to an acceptable level.

One proposed experiment involves using a fan to increase the velocity of air circulation around the wing, as we know that lift increases with air velocity squared.

More experimentation is needed with the perimeter ring to use the Coanda Effect to redirect the air at the trailing edge more effectively.

Also the introduction of Coanda jets similar to figure 4 should, in theory, increase the amount of entrainment from above the wing.

Once these experiments are carried out, and with other institutions such as Delft University of Technology in The Netherlands investing a lot of time into similar research [14], the feasibility of using the Coanda Effect for a commercial Unmanned Aerial Vehicle should soon become more apparent.

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