Some experimental results on Coanda effect with application to a flying vehicle

O Crivoi¹, I Doroftei²

¹Mechanical Engineering, Mechatronics and Robotics Department, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania
²Mechanical Engineering, Mechatronics and Robotics Department, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania

E-mail: crivoiovidiu@yahoo.com

Abstract. In this paper some experimental results related to the Coanda effect are presented. The idea is to use them to build and control a flying vehicle. Our experiments have been done on a laboratory testing device. From the first obtained results we have seen some advantages and disadvantages to applying Coanda effect to a flying vehicle. The advantages are: reducing the pressure near the of the convex surface, protected screw, vertical takeoff and landing. The main disadvantage is the cost of the fuselage and the extra weight that he has. Our conclusion at this time is that this technical solution can bring some benefits through a suited sizing and geometry with vehicle mass.

1. Introduction.
Coanda effect is defined as a phenomenon that is manifested by a tendency of a fluid jet to attach a convex wall placed close proximity and to attract fluid from the surrounding environment (figure 1.b).

![Figure 1](image)

**Figure 1.** Fluid jet in open space (a), and fluid jet in near convex wall (b).

This effect has been applied in many areas till now. Most often it is used in aeronautical design of the wings and fuselages of airplanes and their turbines. A less known way of using the Coanda effect is a convex circular profile, known as the aerodyne. Its operating principle was firstly proposed by a Romanian inventor, Henri Coanda (1886-1972). He patented in 1932 in France a propulsion system (see figure 2.a), [1]. Starting from this propulsion system in the 90s, based on the Coanda effect, some researchers have developed and innovated new models of flying vehicles. They included: R J Collins (figure 2.b), [2], George Hatton (UK), [3], Jean Luis Naudin (France), [4], and F Nedelcut, G Balan, B
Ciobanu (Romania), [5]. These pioneers of research have brought a new family member in flying vehicles, based on the Coanda effect. The operating principle has been confirmed by experimental flying models.

Figure 2. The first Coanda effect patent [1] (a), R J Collins controlling lift (b) [2].

2. Some equations of the Coanda effect
We consider a stationary two-dimensional flow of an incompressible fluid coming out of the nozzle and remains adherent to a surface curve of radius $R$ by the Coanda effect. In this case, one can assume a polar coordinate system such as the one identified in Figure 3.

Figure 3. Polar coordinate system adopted (a), the layers flow (b)

It also requires that slot nozzle outlet has a height $b$, which is much smaller than the radius $R$. Several authors [3, 6] have also analyzed mathematically, this effect. They managed to give an interpretation of pressure variation. Rate phenomenon in terms of the pressure forces is as a ratio between the pressure forces and the centrifugal forces, acting on a volume of fluid. Ecuation of continuity:
\[
\frac{1}{r} \frac{\partial V_\theta}{\partial \theta} + \frac{\partial V_r}{\partial r} + \frac{V_r}{r} = 0
\]  \hspace{1cm} (1)

Conservation of momentums:

\[
V_r \frac{\partial V_\theta}{\partial r} + V_\theta \frac{\partial V_r}{\partial \theta} = \frac{1}{\rho} \frac{\partial \tau}{\partial r}
\]  \hspace{1cm} (2)

Conservation of energy:

\[
\rho \frac{V_\theta^2}{r} = \frac{\partial p}{\partial r}
\]  \hspace{1cm} (3)

In the case of laminar motion, it may be assumed that:

\[
\tau = \mu \frac{\partial V_\theta}{\partial r}
\]  \hspace{1cm} (4)

In the work of Sawyer [8] it has been defined a drive parameter \( A \), which is a quantity of fluid entrained flow. It determines the physical size of the region of attachment to the Coanda effect. The driving parameter can be defined by the following equation:

\[
A = \frac{1}{U_j} \frac{d}{R d\theta} \int_0^\infty V_\theta dy
\]  \hspace{1cm} (5)

Velocity components for laminar flow:

\[
V_r^* = -\frac{1}{4} \theta \frac{2}{3} (f - 3\eta f')
\]  \hspace{1cm} (6)

\[
V_\theta^* = \text{Re} \theta \frac{1}{2} f'
\]  \hspace{1cm} (7)

where \( \text{Re} \) is Reynolds number, and it is relate to the cylinder radius \( R \):

\[
\text{Re} = \frac{U_j R}{v}
\]  \hspace{1cm} (8)

where \( U_j \) is the speed of the jet leaving the nozzle \((\theta = 0)\) and \( v = \eta/r \).

For turbulent flow, is defining an approximate solution Coanda adhesion for turbulent regime in the following equation:

\[
V_r^* = -\theta \frac{2}{3} (f - 3\eta f')
\]  \hspace{1cm} (9)

\[
V_\theta^* = \frac{4 \text{Re}}{3 \sigma} \theta \frac{2}{3} f'
\]  \hspace{1cm} (10)

3. Experimental tests

To investigate the Coanda effect we have been built a simplified experimental device. It is made from the nozzle (2) through which the air flow is directed to (1) tangential to the flexible wall (3) fixed to a frame (4), figure 4. We chose a technical solution with a flexible wall so we can see the Coanda effect in a dynamic way with the changing radius wall.
The experiments have been done at a speed of air flow 10 m/s. In the first stage the wall airflow is tangent (3) and was kept rectilinear shape, it was observed by the wall effect, and gradually reduced to the radius of the wall, it has been noticed that the smoke marker follows the curvature of the wall.

**Figure 4.** Sketch of the experimental Coanda effect device a), stand pattern during testing with smoke marker b), device with experimental radius R=300mm and one deflector c), and version with three deflectors d)

**Figure 5.** Distribution absorption of the air from the environment a), optimized profile b)
When the curvature of the wall reached R=350 mm, smoke marker began to detach from the wall and not to follow its contour. During the experiments we observed that a large radius wall (R=1500 mm) gives better results than lower radii. The air near the wall is drawn by the airflow, more near the nozzle and decreases along the wall (figure 5.a). Between the environment and the air flow tangential to the wall forming a separation area and mixing with the air in the environment gradually expands. This results in decreased speed and quantity of air that follows the contour of the wall. To decrease the effect of detachment we tried to use deflectors in different points (figure 4.d).

4. Conclusions
When designing a flying vehicle based on the Coanda effect we must take into account that its mass must be proportional to the speed and quantity of air flow tangential to the active surface. Having as starting point the diagram of the air quantity attracted by the airflow along the convex wall, it follows that an optimum profile of the wall is a parabolic segment similar to the figure 5.d. To be effective, the air must pass through an area of lamination before exiting from the nozzle and get out in a thin layer in relation to the length of the convex wall. The angle of the airflow entering to the convex wall has to be less than 90 degrees from the vertical axis. If we have a circular aerodyne, an area of low pressure air forms under the platform that impedes the lifting. To prevent this, it should be rounded the profile towards its ending inside of the curve with a radius (R), figure 5.d. The fuselage material should be light, so additional weight that is loading the aircraft will be smaller than the additional raising which is obtained by the Coanda effect.

5. References
[1] Coandă H M 1935 Brevet d’invention France no. 796,843 /15.01.1935
[2] Collins R J 2003 Aerial Flying Device UK Patent Office no. 2,387,158/08.10.2003
[3] Hatton G. 2007 Thrust vertical-take-off air vehicle with lift created by a rotary impeller causing air to flow over convex outer surfaces, UK Patent Office no. GB 2,452,255/28.08.2007
[4] http://jnaudin.free.fr/gfsuav/coanda/
[5] Nedelcut F, Balan G, Ciobanu B and Florescu I 2009 Specifications for an UAV for scientific research in the field of monitoring environmental parameters, 3rd International UAV World Conference - UAV Technologies and Missions Frankfurt/Main, Germany
[6] Crivoi O, Doroftei I and Adascalitei F 2014 Preliminary Ideas on Designing an Unmanned Aerial Vehicle Based on Coanda Effect Advanced Materials Research 837 pp. 573-576
[7] Englar R 1975 Experimental Investigation of the High Velocity Coanda Wall Jet Applied to Bluff Trailing Edge Circulation Control Airfoils Report 4708, David W Taylor Naval Ship Research and Development Center
[8] Sawyer R A 1963 Two dimensional reattaching jet flows Including the effect of Curvature on entrainment Journal of Fluid Mechanics 17(4) pp 491-498