REVIEW OF APPLICATIONS ON COANDĂ EFFECT. HISTORY, THEORIES, NEW TRENDS

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***Abstract**: The Coandă effect is an interesting phenomenon in fluid mechanics discovered by the Romanian inventor Henri Marie Coandă. The physics of the Coandă effect is based on the property of a jet flow to attaches itself to a nearby surface and to remain attached even when the surface bends away from the initial jet direction. In free surroundings, a jet of fluid entrains and mixes with its surroundings as it flows away from a nozzle. The final result is the deflection of the external flow and generation of lift forces. After 2000, the Coandă legacy was valued by researchers from many countries, mostly by developments and patents in the field of small Unmanned Aerial Vehicles (UAVs).*

***Keywords**: Coandă effect, attached jet, ejectors, UAVs, lift forces.*

1. INTRODUCTION

The purpose of this article is to highlight that the utilization of the Coandă effect is still a present-day subject in the propulsion area, in spite of all the theoretical and experimental analyses conducted the last years we cannot claim that a definitive conclusion has been made regarding the capabilities, the application possibilities and the performance of the devises that use the Coandă effect.

Henri Coandă (1969) defined the phenomenon: "… the Coandă effect relies on the principle of creation a depression zone in the air, along a wall, which allows the fluid to project itself onto and take the direction of the wall were the depression was generated… which can be used in various applications…"

Coandă effect is a classic phenomenon in fluid mechanics and one of the fundamental discoveries of the Romanian inventor Henri Marie Coandă (1886-1972). Henri Coandă was a Romanian inventor, aerodynamics pioneer and the designer and the builder of the world's first jet powered aircraft, the Coandă-1910, a revolutionary plane of the 20th century beginning.

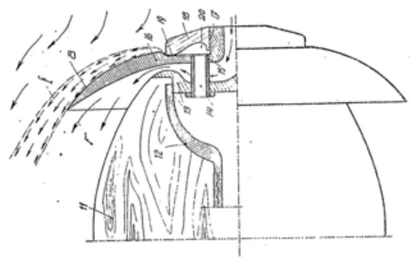


Fig. 1 Coandă patent "Perfectionnement aux propulseurs" [4]

In his first patents related to Coandă effect applications, in order to generate the jet of fluid over the upper surface of the fuselage, H. Coandă was using mainly other means than a rotor, i.e. a burner or a combustion chamber. But in a patent he obtained in 1935 [4], he was enumerating the possibility to use also a centrifugal fan for supplying the necessary air flow.

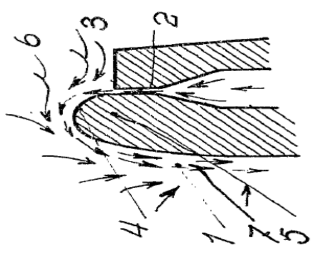


Fig. 2 Coandă patent "Procédé et dispositif pour faire dévier une veine de fluide pénétrant dans un autre fluide" [6]

Immediately after the phenomena discovery, the inventor H. Coandă took into consideration the problem of physical and mathematical modeling of the effect in order to control and to determine its limitations.

The phenomena being extremely complex he had to seek aid from renowned theoreticians of that time. In the chronological sense it was the first attempt of theorizing the phenomena. In aeronautics, this effect is already used to expand the performances of small helicopters, in the no tail rotor (NOTAR system) configuration [13].

2. BASIC THEORETICAL ASPECTS

We are considering that the opening slit width of the section is b_0, it has its normal line perpendicular on the jet axes (Fig. 3) and because of the presence of the Coandă profile on one of its sides that limit's it an asymmetrical flow appears (Fig. 4) which remarks itself trough an asymmetrical distribution of the gasodynamic parameters in that section.

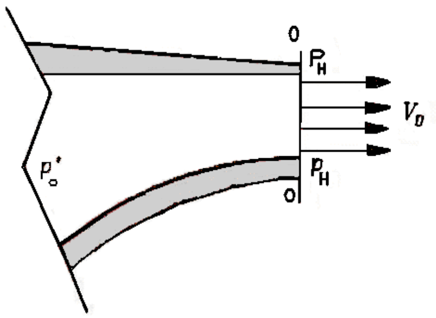


Fig. 3 Slit flow of free jet

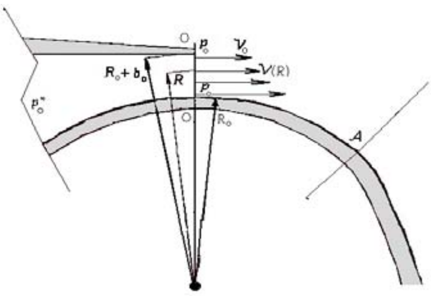


Fig. 4 Flow with Coandă effect

The distribution of the speed of slackening V_0 from p_0^* to the ambient pressure p_H is:

$$V_0 = \sqrt{2\left(i_0^* - i_H\right)} = \sqrt{2i_H^*\left[\left(\frac{p_0^*}{p_H}\right)^{\frac{k-1}{k}} - 1\right]} \quad (1)$$

The variation of speed depending on the radius, it is thought to be:

$$V(R) = V_0\left(\frac{R_0+b_0}{R}\right)^n \text{, and we have}$$

$$V_0 = V\left(R_0 + b_0\right) \quad (2)$$

In the case were the radius of the slit curb is bigger compare to the slit opening, we can make the approximation that the brake enthalpy is constant on the radius and the asymmetrical effect is caused by the variation of the static pressure from p_H in the upper part of the slit, till p_0 on the wall in the lower part of the slit.

3. THE PHYSICAL-MATEMATICAL MODELS OF THE COANDĂ EFFECT

As a natural phenomenon, Coandă effect describes the tendency of a fluid jet to be attracted to a nearby surface (flaps or airfoils), consecutively his profile being characterized by a significant asymmetry.

In free surroundings, a jet of fluid entrains and mixes with its surroundings as it flows away from a nozzle. When a surface or another stream is placed close to the jet, this restricts the entrained air flow from surroundings into that region. As flow accelerates trying to equalize the transfer momentum, a loss of pressure results across the jet and the jet is deflected closer to the surface, up to attaching to it.

The global stream that results from the mixing between the main flow and the displaced one is adherent to the wall and is characterized by a lower temperature than the initial one.

When studying Coandă effect, it is possible to notice the following aspects (Fig. 5):

The depressurized zone (3) has as effects:

- Flow acceleration upstream in the slot (1), without increasing upstream pressure or temperature,
- Displacement of the local fluid.

Detaching and re-attaching is characterized by hysteresis (i. e. the reattaching is produced at smaller angles than the detaching).

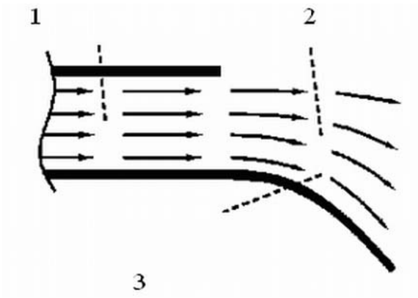


Fig. 5 Coandă effect (2D)

3.1. Metral Model (1938). From all the effects generated by the asymmetrical flow (Fig.6), this study focuses mainly on "increasing the flow speed of a fluid which passes from a pressure p_R in a reservoir, to a pressure p_0 in another fluid environment, without increasing its original pressure or temperature", as mentioned before the starting the analysis, namely on the acceleration of the flow in the channel situated upstream to the split.

The calculation assumptions were those of a perfect and incompressible fluid, for a 2D flow. We can claim that: "it is useless to determine the thrust of the ejection device through the integration on the pressures along the flap". It will be sufficient because the analysis is made on a static fluid (environment), to calculate the impulse per second on a cross section of the jet speed V_0:

$$M = b \cdot h \frac{V_{01}}{V_0} \sqrt{2\rho_H (p_{01} - p_0} = p_H \cdot b \cdot h \frac{V_{01}}{V_0} V_0 \quad (3)$$

where M is the mass flow [kg/s], h is the gap width [m] (perpendicular to the horizontal plane):

$$F = M \cdot V_0 = p_H \cdot b \cdot h \frac{V_{01}}{V_0} V_0^2 \quad (4)$$

F = thrust of the ejection device [N]

$$P = F \cdot V_0 = p_H \cdot b \cdot h \frac{V_{01}}{V_0} V_0^3 \quad (5)$$

P = necessary power [W]

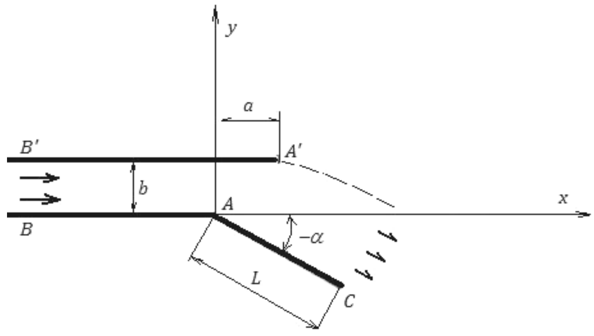


Fig. 6 The flow scheme and notations used by Metral

We can point out the mode in which the calculation of the ejection device is made, taking in account only the rise in flow inside the slip alimentation channel, but not the interaction between the primary fluid and the environmental one.

Actually this aspect derives from the working conditions.

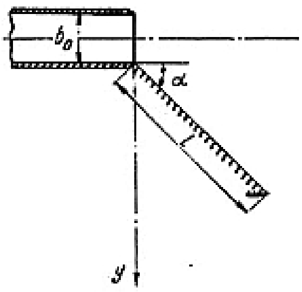
The idea that can be extracted here is that "the ejection device produces the same thrust as a tube at which the opening (slip) is with V_1/V_0 bigger", therefore it necessitates an analysis in which the compressibility factor is taken into account, as it will be the case later.

3.2. Teodorescu-Țintea Abordation (1965). In the Teodorescu-Tintea model, (1964) presented in Fig. 7, the trajectory of the curved jet axes was studied, and the gasodynamic forces, the center of pressure and the acceleration of the flow in the channel were all determined, this leading to a rise of flow which .

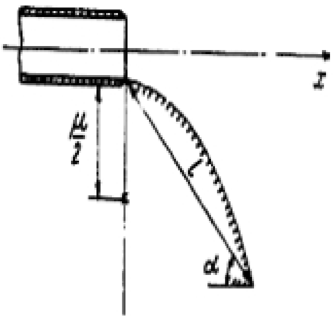
In the study of the equilibrium condition for the circular flap is noticeable that the centrifugal force and the pressure force are in equilibrium. According this, the condition for radial equilibrium looks like:

$$dm \frac{V^2}{R} = R \cdot d\theta \cdot dp \quad (6)$$

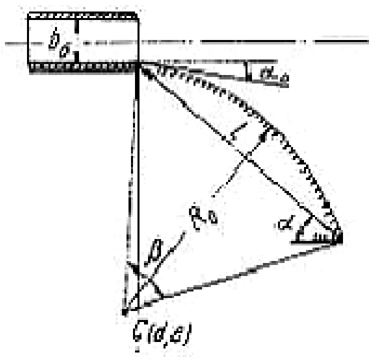
The conclusions are that the jet trajectories are parabolic and the flow characteristics and the forces that stress the flap are affected by the initial parameters of the flow and the flap form.



a) planar flap



b) parabolic flap



c) circular flap

Fig. 7 The trajectory of the curved jet axis

3.3. The Medeot approach (1971). In his paper (1971), Renzo Medeot, researcher at the Research Center in Padua, Italia, studied the phenomenon of jet attachment for a device which allows the obtaining of a combustion with a bluish flame produced without any mechanical parts in motion (the drawings in Fig. 8 are those of the author).

$$\frac{dp}{dR} = \frac{\rho \cdot V^2}{R} \tag{7}$$

Supplying with pressure from usual blowers (40 mmH_2O) it is possible to produce a sufficient recirculation for obtaining bluish flame combus.

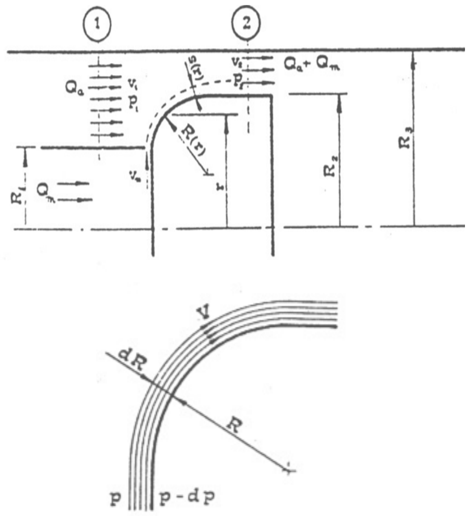


Fig. 8 The Medeot approach

4. MODERN APPLICATIONS OF COANDĂ EFFECT

Flaps and wing flow control based on Coanda effect.

In 1964 - the original Boeing 387-80, the prototype of the famous 707, in a very easy flight uses, for the first time, flaps driven by the Coandă effect (Fig.9).

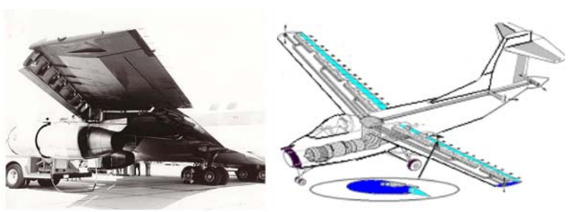


Fig. 9 Flaps driven by the Coandă effect

2004 - In [11], Rogers and Donnelly presented experiments of controlling the flow on the wing, using the Coandă effect (Fig. 10).

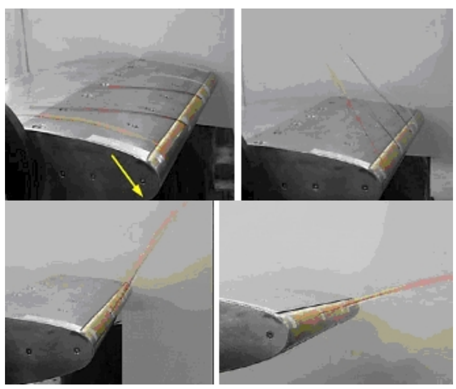


Fig.10 View of the resulting trajectory (Rogers, et al. 2004)

No tail rotor. December 1981 – NOTAR (No Tail Rotor) system helicopter (MD Helicopters, NOTAR 1981) is a prestigious accomplishment of McDonnell Douglas Helicopter Systems in the application of Coandă effect (Fig. 11).

In 1992, took place the first NOTAR helicopter flight. The air pumped through the tail beam exits through slits forming two jets which together with the airflow induced by the lift rotor form a boundary layer's had takes the beam tail, creating an area of depression on the right side.

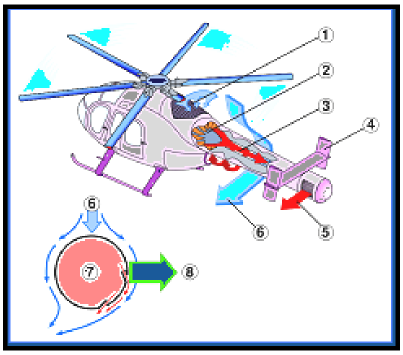


Fig. 11 The NOTAR system: 1 - air admission, 2 - fan pitch, 3 - beam slits, 4 - stabilizer, 5 - directed jet, 6 - air induced by the main rotor 7 - low pressure air through the tail beam, 8 - anti-torque force

The advantage of this system is that the anti-torque force is directly proportional to main rotor lift, the system has self compensation, resulting from the fact that when the rotor produces a higher moment, results in a stronger downward current, resulting in amplification of anti-torque force (Fig. 12).

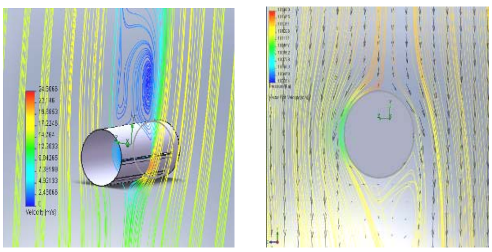


Fig. 12 The NOTAR system - 3D view of the Coandă effect on the flow on the tail beam

This optimization allows the suppression of the anti-torque rotor, thus eliminating its disadvantages.

This leads us to benefit from a new favourable arrangement for creating higher lateral forces with lower energy consumption, compared to those data used in basic formulas describing the efficiency of the helicopters .

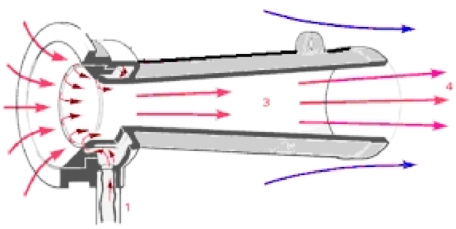
The boundary layer driven by Coandă effect changes the direction of airflow around the tailboom, creating a lateral force F, high enough to oppose to the torque effect created by the main rotor and to the motion imparted to the fuselage.

Directional yaw control is gained through a vented, rotating drum at the end of the tailboom, called the jet thruster [9].

Coandă ejectors, 2001. Disposal of smoke and toxic air is another one of the Coandă ejectors applications (Fig. 13).

a) Internal DC with two steps

b) Section throughout a Coandă ejector



c) Operating principle of a Coandă ejector

Fig. 13 Coandă ejectors

Lack of mechanical moving parts enables the movement of various categories of contaminated air, without danger of destroying the ejection device. Contamination may therefore be the result of the existence of:

1. Toxic gases: paint fumes, alcohol, adhesives, fuel fumes, vapours of various

chemicals, effluents of sewage, smoke, automobile gas and other undesirable emanations;
2. Suspended solids: powder, rubber, plastics, cement, wood, grasses, paper, flour, detergents, coal mines air;
3. Air with an excess of temperature.

a) level ejection device

b) cylindrical ejection device

Fig. 14 Ejection devices

Such a system has recently (2001) been conceived by a Romanian private company (AERODIN srl) and has obtained at 4.7 bar a flow of 2750 m^3/h at a medium pressure loss of 90 mmH2O having an ejection coefficient of 60 (4) [10].

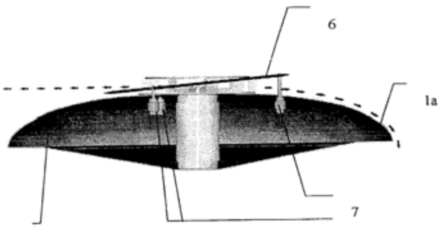


Fig.15 Robert Collins's GB patent no. 2387158, granted in 2003, for a Coandă effect aerial Vehicle

Fig. 16 Geoff Hatton and his VTOL Coandă UAV

Applications on small unmanned aerial vehicles (UAVs). After 2000, individual inventors and innovative SMEs developed a new class of aerial vehicles, based on the use of the Coandă effect. Among them, are Robert Collins (Fig15) [7], Geoffrey Hatton (Fig. 16) [12], GFS Projects Ltd., and AESIR Ltd. The MEDIAS-UAV (Fig. 17) concept is developed by a Romanian academic consortium [13].

In 2006, in France, Jean-Louis Naudin made and tested his first GFS-UAV (N 01A).

This one, propelled by an electric engine, was using the Coandă effect to take off vertically, fly, hover and land vertically.

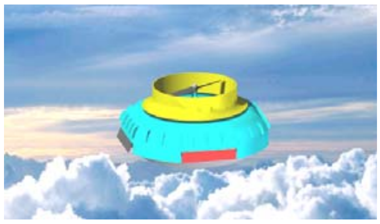
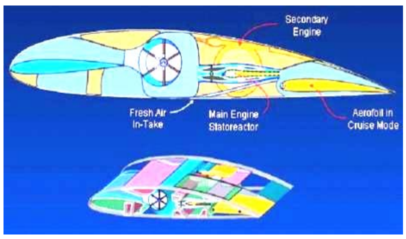


Fig. 17 The Romanian MEDIAS-UAV Coandă effect aerial vehicle meant for environmental surveillance (2009)

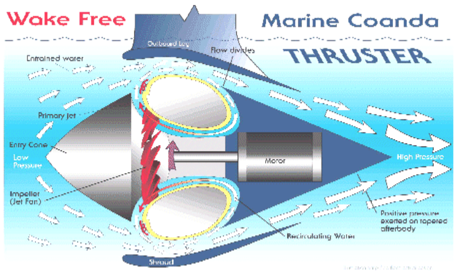
Other applications are dedicated to the ground effect vehicles (GEV). The KM Ekranoplan (Fig. 18) is also based on Coandă effect, because the water acts as a limiting wall in a Coandă flow and therefore the ground effect vehicle is moving as a wing at a certain distance of several meters above the water.

Fig. 18 KM Ekranoplan

In conclusion, ground effect vehicles are considered to be good transportation vehicles, fast and economical. Other emerging applications are (Fig. 19).



a) Flying device using the Coandă ejection device



b) Underwater propulsion system based on the Coandă effect

Fig. 19 Future projects using the Coandă effect

At these projects we can firstly observe the highlighting of the flow using the Coandă effect.

5. CONCLUSIONS

The theoretical models of Coandă effect should also be continuously developed, in order to allow the complete understanding of this important fluid mechanics phenomenon.

This useful phenomenon is therefore not yet used at its full potential and capabilities.

Coandă Effect applications developed so far proved to be very efficient from energetic point of view. In the conclusion we can state that for the same energy available P_0, the D_f force gain can be obtained by decreasing the speed $V_D < V_M$, similarly to an increase by ejection of the mass flow evacuated.

In order to obtain the highest force possible for an available used energy it is preferable to put into motion the highest amount of fluid possible with the lowest speed possible instead of a small amount of fluid put into motion with a high speed.

From the energetic point of view, for a helicopter, Coandă effect is a more efficient method than the tail rotor to obtain the lateral force needed to control the horizontal maneuverability and stabilizing in the same time the aerial platform created by a flying mono rotor helicopter.

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