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COANDĂ EFFECT USED TO IMPROVE THE EFFICIENCY OF A ROTARY WING AIRCRAFT

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ABSTRACT

Coandă effect is a well-known fluid mechanics phenomenon in which a jet flow attaches itself to a nearby surface and remains attached even when the surface bends away from the initial jet direction and the jet is deflected closer to the surface, up to attaching to it. Using Coandă effect, the anti-torque NOTAR system replaces the use of a tail rotor on a helicopter. A fan inside the tailboom creates a large volume of low-pressure air, which exits through two slots and creates a boundary layer of airflow along the tailboom, due to the Coandă effect. The interaction of this air flow with the downwash from the main rotor creates a force oriented as an anti-torque force, an opposed to that of the main rotor. The airflow escapes the slots tangential to the external surface of the tailboom in a parallel direction to that of the external flow. The final result is the deflection of the external flow and generation of lift forces.

Keywords: Coandă effect, NOTAR, slot, attached jet, jet thruster

1. COANDĂ EFFECT AERIAL VEHICLES

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 beginning of the 20th century.

As a natural phenomenon, Coandă effect describes the tendency of a fluid jet to be attracted to a nearby surface (flaps or airfoils), consecutively its profile being characterized by a significant asymmetry [13]. 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 momentum transfer, a loss of pressure results across the jet and the jet is deflected closer to the surface, up to attaching to it.

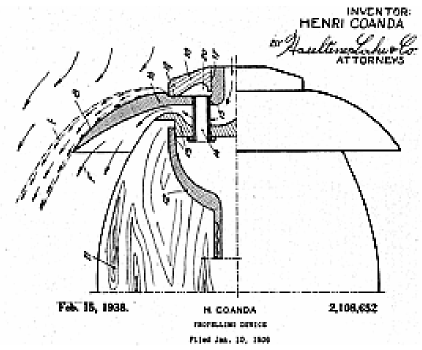


Fig. 1. Henri Coandă propelling device [3]

Coandă's legacy was valued by researchers from many countries, mostly by developments and patents on Unmanned Aerial Vehicles (UAVs). We should also mention that the first design of a Coandă UAV was created in 1932 [3], by the Romanian inventor Henri Marie Coandă.

After 2000, using mainly the Coandă effect, individual inventors as Robert Collins [6] and Geoffrey Hatton [7], companies as GFS Projects Ltd. and AESIR Ltd. (both from UK) and a Romanian academic consortium, through MEDIAS project [11], developed what we may consider a new class of aerial vehicles, the Coandă UAVs.

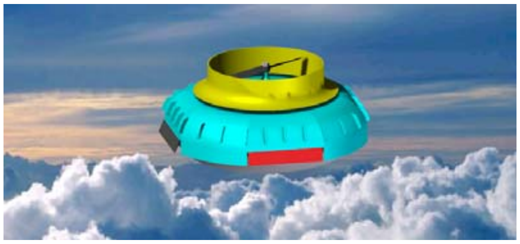


Fig. 2. MEDIAS-UAV (2009) [11]

In aeronautics, this effect is used today primarily in helicopters that have no tail rotors, as in NOTAR system [8].

NOTAR is the name of an anti-torque system which replaces the use of a tail rotor on a helicopter. It was developed by McDonnell Douglas Helicopter Systems and the name is an acronym derived from **NO TA**il **R**otor.

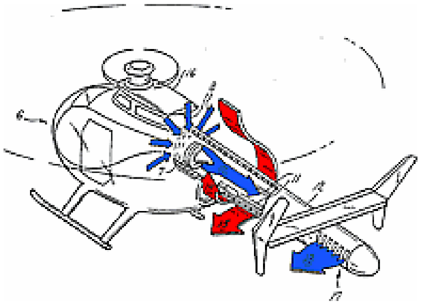


Fig. 3. The movement of air through the NOTAR system [8]

NOTAR uses a fan inside the tailboom to force a high volume of low-pressure air, to exit through two longitudinal slots and create a boundary layer flow of air along the tailboom utilizing the Coandă effect.

The boundary layer driven by Coandă effect changes the direction of airflow around the tailboom, creating thrust opposite the motion imparted to the fuselage by the torque effect of the main rotor. Directional yaw control is gained through a vented, rotating drum at the end of the tailboom, called the jet thruster. [7]

Fig. 4. NOTAR system used by NEO helicopter from YoungCopter [14]

2. A GLOBAL ANALYSIS OF THE MIXING PROCESS IN THE AIR EJECTOR

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

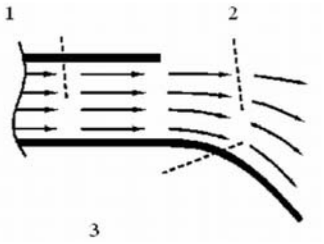
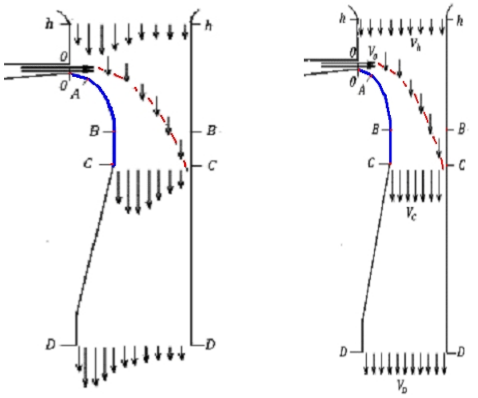


Fig. 5. Coandă effect (2D)

1. 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.
2. Detaching and re-attaching is characterized by hysteresis (i. e. the reattaching occurs at smaller angles than the detaching).
3. 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.

Let us consider an air ejector that we are going to analyse from the point of view of the mixture between two flows, the primary flow, the active one, through which energy is introduced into the system, and the secondary flow, considered to be a controlling flow (as in Fig. 6).

In Fig. 6, the primary flow is introduced in the inlet (section **0-0)**, by compression, or acceleration, or through absorption, directly from the environment.



a) b)

Fig. 6 Coandă ejector with:
a) non uniform speed distribution,
b) uniform speed distribution

The absorption section, marked with (**h**-**h**), through which the inflow only advances, may be described as having the property that the total enthalpy i^* of the inflow is the equal with that of the environment, i_H^*.

The place around **A** is considered to be the longitudinal spot from the tailboom, where the loss of pressure of the flow is maximal. Section **B**-**B** shows the end of the Coandă profile (line **OAB**).

Section **C**-**C** is where the absorption section ends and the mixing region extends to both walls. **D-D** is the exit section from the air ejector and is characterized by the fact that the static pressure is equal with that of the environment static pressure p_H.

The area **h-0-C-B-h** is considered to be the absorption area, where the total enthalpy, i^* of the flow is: $i^* = i_H^*$.

Area **0-ABC-C-0** is considered to be that of the junction where the both flows are mixing, where the whole generated flow is received through the permeable surface **C-0**.

Area **C-D-D-C** is the area of acquiring uniformity for the aero thermo gasodynamic parameters in section **C**-**C** and it usually has a divergent form, which favourably contributes to the efficiency of the air ejector. Its existence leads to the increase of the generated flow, but it doesn't necessarily mean an increase of the propulsion force.

The research on the force increase will have to take into consideration the entire geometry of the air ejector.

The known factors are:

- Geometry of the air ejector in its sections (**Ah, A0, AB=AC, AD**),
- Fuel conditions in the slot (p^*, p_0),
- Environmental conditions (p_H, ρ_H, i_H^*).

Also, for this global analysis of the mixture in the air ejector, the values of the energetic performance (η_C, η_D) on sections **00-CC**, **00-DD**, are considered to be known.

In Fig. 7 it is presented the distribution of the speed in a section of the Coandă air ejector, having two different regions, an asymmetrical one (*width*=*d*) and a uniform one (*width*=D-d), where *s* is the length of the boundary layer at the wall.

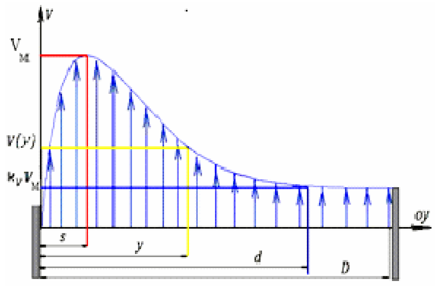


Fig. 7 Speed distribution across a section

3. CASE STUDY - COANDĂ AIR EJECTOR WITH NON-UNIFORM SPEED DISTRIBUTION

Let's analyse a particular Coandă ejector with non-uniform and variable speed distribution, according [10]. In the D exit section, the static pressure p_D equals the environment pressure p_H. The power transferred to the fluid in D section is:

$$P_0 = \eta P_D = \int_{A_D} \rho_H V_D(y)(i_D^* - i_H^*) dA_D = \frac{\rho_H V_{MD}^3 A_D \chi_{3D}}{2} \quad (1)$$

The gain in force is given by the difference between the two force distributions; with a maximal value corresponding to the A angle (as in Fig. 8):

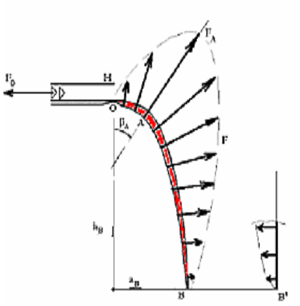


Fig. 8 Force distributions on Coandă airfoil

We may describe a Coandă flow by using two zones, each having special properties, the centrifugal zone and the suction zone.

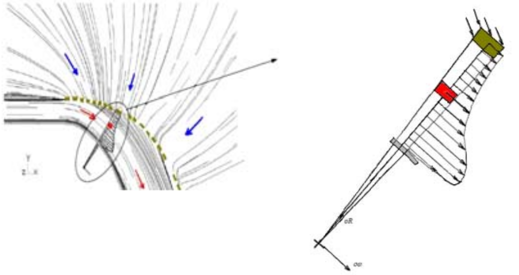


Fig. 9 Detailed analysis of Coandă flow

The equations for the centrifugal zone, associated to the mixing region **0-ABC-C-0** with the wall **C0** considered to be permeable, are:

$$\frac{1}{r}\cdot\frac{\partial(\rho\cdot u_\omega)}{\partial\omega}=0 \tag{2}$$

$$-\frac{u_\omega^2}{r}=-\frac{1}{\rho}\frac{\partial p}{\partial r} \tag{3}$$

$$u_\omega\frac{\partial u_\omega}{\partial\omega}=-\frac{1}{\rho}\frac{\partial p}{\partial\omega} \tag{4}$$

$$i^*=i_H^*\left(\frac{p}{p_H}\right)^{\frac{k-1}{k}}+\frac{u_\omega{}^2}{2} \tag{5}$$

For a small element of the jet flow (fig.6), the radial movement equation is:

$$\frac{dR}{R}=\frac{dp}{\rho u_\omega^2} \tag{6}$$

For ***B***

For $\boldsymbol{B_i}$ on the profile:

$$u_\omega=u_{\omega 0}f_u(R)\,;\;u_{\omega 0}=u_0 f_{u0} \tag{7}$$

and the total enthalpy is preserved:

$$i^*(R)=\frac{[u_\omega(R)]^2}{2}+\int\frac{[u_\omega(R)]^2}{R}dR\Big|_R+i_c^* \tag{8}$$

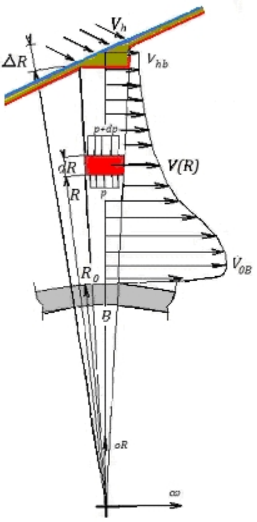


Fig. 10 Jet flow elements

The static pressure is expressed by:

$$p(R)=p_H\left(1+\frac{1}{i_H^*}\int\frac{[u_\omega(R)]^2}{R}dR\Big|_R\right)^{\frac{k}{k-1}} \tag{9}$$

and the static parameters, as density and temperature, are:

$$\rho(R)=\rho_H\left(1+\frac{1}{i_H^*}\int\frac{[u_\omega(R)]^2}{R}dR\Big|_R\right)^{\frac{k}{k-1}} \tag{10}$$

$$T(R)=T_H\left(1+\frac{1}{i_H^*}\int\frac{[u_\omega(R)]^2}{R}dR\Big|_R\right)^{\frac{k}{k-1}} \tag{11}$$

The gain in force at $\boldsymbol{B_i}$ is:

$$\varphi_{Bi}=\frac{1}{b_0}\int_{R1}^{R2}\left(1+\frac{1}{i_H^*}\int\frac{[u_\omega(R)]^2}{R}dR\Big|_R\right)^{\frac{k}{k-1}}\cdot f_{u0}^2 f_u^2(R)\,dR \tag{12}$$

and the corresponding efficiency is:

$$\eta_{Bi}=\frac{1}{b_0}\int_{R1}^{R2}\left(1+\frac{1}{i_H^*}\int\frac{\left[u_\omega(R)\right]^2}{R}dR\Big|_R\right)^{\frac{k}{k-1}}\cdot f_{u0}^3 f_u^3(R)\,dR \quad (13)$$

We may note that the attached flow is situated in the depressurised zone, (area defined by the slot exit frontier, **0-0**, **B-B** section and **D-D** exit) having a maximal value in **A**.

4. FLOW MODELING AND SIMULATION WITH COMPUTER ASSISTED COANDĂ EFFECT

Coandă Effect Small Appliance is an experimental validation of using Coandă effect on the helicopter tailboom.

A helicopter structure consists of two main components: a cabin and a tailboom of composite materials (glass and carbon fibre).

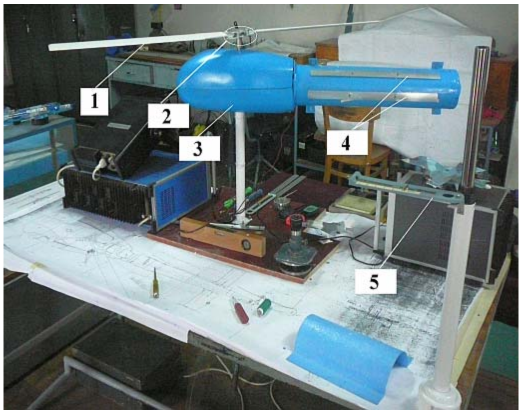


Fig. 11. Experimental device: 1-NOTAR carbon fibre helicopter blades, 2-hub pitch, 3- fiberglass helicopter structure, 4-Coandă slots, 5- dynamometer

In the Fig. 11 may be seen the hub pitch and the blades of carbon fibre. This experimental model aims to highlight the Coandă effect and to measure the performance of propulsion.

With this purpose in mind, the beam parameters were gradually modified, seeking to acquire a lateral force F as big as possible.

The experimental device will show the fluid flow along the tailboom. This was simulated on a Coandă profile optimally adjustable, depending on the flows data load-bearing rotor, the intubated fan from the tailboom, and the location and geometry of the slot.

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.

In order to model the Coandă effect onto the flow from the helicopter tailboom, computer simulation was made using Solid Works 2007 software; the theoretical results we obtained may be seen in the following pictures, tables and diagrams (Fig. 12, Fig. 13 and Fig. 14).

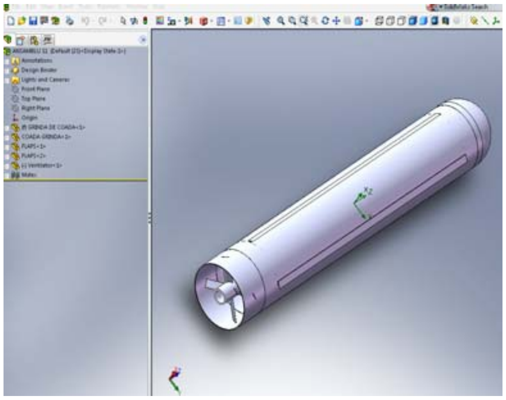


Fig. 12. 3D model of the helicopter tailboom

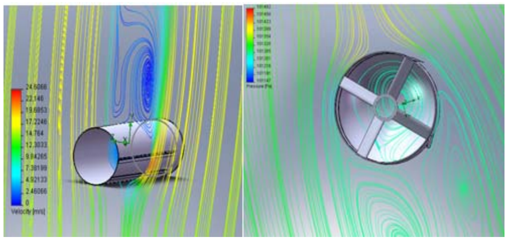


Fig. 13. A 3D view of Coandă effect flow through tailboom

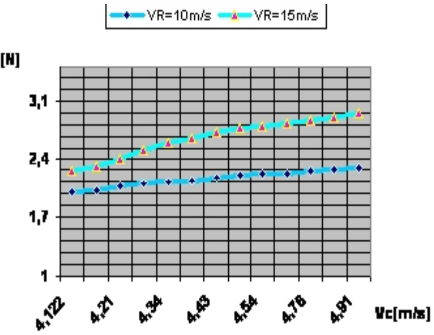


Fig. 14. The lateral force F, depending on the speed V_c, having a constant main rotor speed of V_R=15m/s, respectively V_R=10m/s.

5. CONCLUSIONS

This study was conducted in the idea of highlighting the usefulness of the devices developing a force due to the Coandă effect.

To conclude, we may state the following:

1. For the same available energy P_0, the D_f *force* gain may be obtained by decreasing the speed $V_D<V_M$ and increasing in the same time the ejected air flow.
2. In order to obtain the highest possible force for an available amount of energy, it is advisable to entrain into motion the highest fluid flow possible at a lower speed, instead of a small amount of fluid entrained into motion with a higher speed.
3. 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 manoeuvrability and stabilizing in the same time the aerial platform created by a flying mono rotor helicopter.
4. The numerical results that were obtained are close enough to those we obtained through computational studies, taking into account the geometry of the tailboom and the fluid velocity inside the intubated tailboom rotor that generates the main carrier flow.
5. The study shows also the smooth growth index values $\mathbf{E_{fc}}$ with a sharp increase in force **F**, which requires finding an optimal position for the slot; this may be done with a pretty fair approximation of a helicopter (1:1 scale model).

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