THEORETICAL ANALYSIS REGARDING THE ASYMMETRICAL FLUID FLOW APPLIED TO HELICOPTER AERODYNAMICS

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Abstract. The main topic of the present paper is the asymmetrical fluid flow application with the purpose of finding the best solutions to replace the anti-torque rotor of single-rotor helicopters using the Coandă Effect. This would significantly increase the flight performances. The research mainly aims at obtaining a controlled lateral force due to the Coandă flows through the tail boom, a force which would be useful for the stabilization of the lifting rotor applied to the flight of single-rotor helicopters.

Keywords: Coandă effect, helicopter aerodynamics, jet thrusters, lifts

1. Introduction

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

The lateral pressure that urges the flame of a candle towards the stream of air from a blowpipe is probably exactly similar to that of the pressure, which gives an easy inflection of a current of air near an obstacle.

If you bring a convex body into contact with the side of the stream and the place of the dimple will immediately show that the current is deflected towards the body; and if the body works free moving in every direction, it will be urged towards the current.

Henri Coandă identified an application of the effect during experiments with his Coandă -1910 aircraft. The motor-driven turbine pushed hot air rearward, and Coandă noticed that the airflow was attracted to the nearby surfaces. He discussed this matter with leading aerodynamicist Theodore von Kármán who named it the Coandă effect.

In 1934 Coandă obtained a patent in France for a "Method and apparatus for deviation of a fluid into another fluid". The effect was described as the "Deviation of a plain jet of a fluid that penetrates another fluid in the vicinity of a convex wall" [1, 2].

The Coandă effect is a natural phenomenon with action on the flow attached to a divergent wall characterized by high asymmetry.

In Figure 1 is presented the main effect flow of a fluid characterized by the following aspects:

a. The depressed zone that determines: *flow acceleration upstream in the slot*, without increasing upstream pressure or temperature and *the displacement of the local fluid*.
b. Detaching and re-attaching is characterized by hysteresis (the re-attaching is producing at smaller angles than the detaching).
c. The global flow that results from the mixture between the main flow and the displaced one is situated in the de-pressurized zone and is characterized by lower temperature.

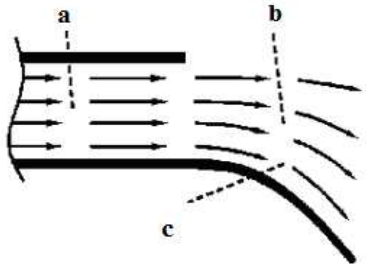


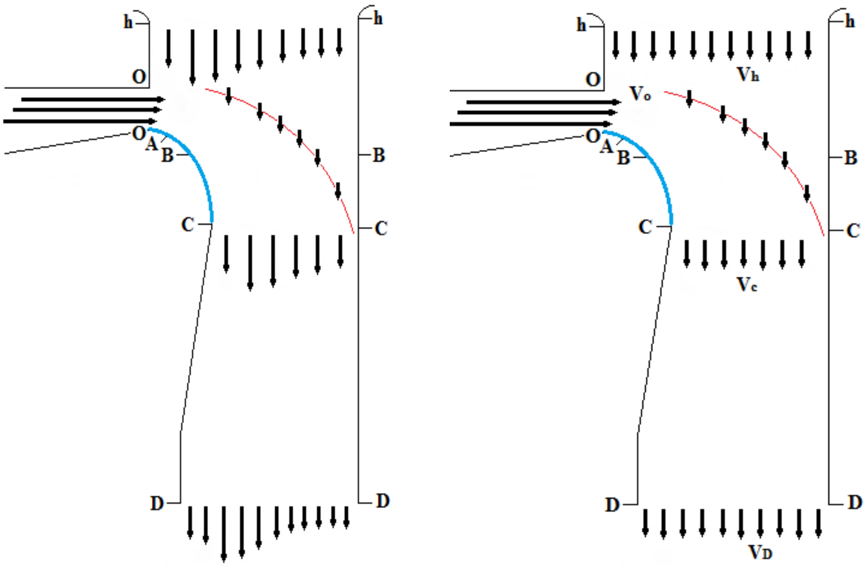
Figure 1. Coandă effect flow (2D)

2. Theoretical aspects of the Coandă effect

For weaving the Coandă effect, an ejector is considered, where the primary flow is introduced in the inlet (section 0-0), by compression, or acceleration, or through absorption, directly from the environment (Figure 2).

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 equal with that of the environment, i^*_H. The place around A is considered the longitudinal spot from the tail boom, 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 the place 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.



a) *b*)

Figure 2. Coandă ejector with: a) non-uniform speed distribution, b) uniform speed distribution

The area h-0-C-B-h is considered to be the flow is $i^* = i^*_H$. Area 0-ABC-C-0 is considered that of the junction where the both ejector with non-uniform and variable speed distribution, in the D exit section, has the static absorption area, where the total enthalpy, i^* of 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 does not necessarily mean an increase of the propulsion force [3, 4].

The increase of force will have to take into consideration the entire geometry of the air ejector [5, 6]. The known factors are:

- ✓ geometry of the air ejector in its sections (Ah, A0, AD),
- ✓ the slot conditions (p^*, p_0),
- ✓ environmental conditions (p_H, ρ_H, i^*_H).

For this global analysis of the mixture in the air ejector, the values of the energetic performances (η_C, η_D) on sections 00-CC, 00-DD, are considered to be known. A particular Coandă pressure p_D equal with the environment pressure p_H. The power transferred to the fluid in D section is:

$$P_0 = \eta \cdot P_D = \int_{A_D} \rho_H \cdot V_D(y) \cdot \left(i_D^* - i_H^*\right) \cdot dA_D . \qquad (1)$$

The gain in force is given by the difference between the two force distributions; with a maximal value corresponding to the angle *y*.

To describe a Coandă flow by using two zones, the centrifugal zone and the suction zone, each must have special properties. The equations for the centrifugal zone, associated to the mixing region 0-ABC-C-0 with the wall C-0 considered permeable, are:

$$\frac{1}{r} \cdot \frac{\partial(\rho \cdot u_\omega)}{\partial \omega} - 0 ; \qquad (2)$$

$$-\frac{u_\omega^2}{r} = -\frac{1}{\rho}\frac{\partial p}{\partial r} ; \qquad (3)$$

$$u_\omega \cdot \frac{\partial u_\omega}{\partial \omega} = -\frac{1}{\rho} \cdot \frac{\partial p}{\rho \cdot \partial \omega} ; \qquad (4)$$

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

For a small element of the jet flow (Figure 3), the radial movement equation is:

$$\frac{dR}{R} = \frac{dp}{\rho \cdot u_\omega^2} . \qquad (6)$$

For a point B_i on the Coandă profile gives:

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

and the total enthalpy is preserved:

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

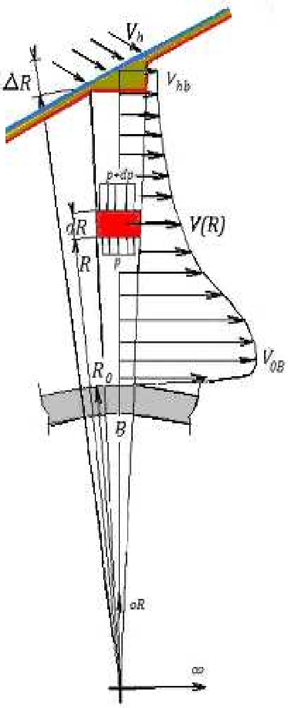


Figure 3. Jet flow elements

The static pressure is expressed by:

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

It may be noted 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. Assuming that the section of the open slot b_0 has got the normal line perpendicular to the axis and due to the Coandă profile (Figure 4) on one of its sides, there is some flow asymmetry revealed by asymmetrical distribution of the existing gasodynamic parameters within the section [3, 4].

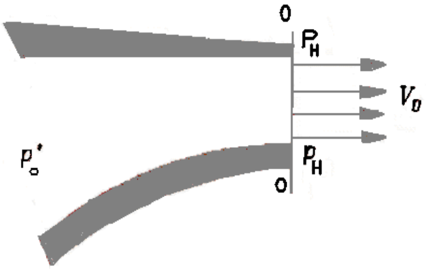


Figure 4. Free jet flow through the slot

The speed V_0 of the expansion from p^*_0 at a pressure p_H is:

$$V_0 = \sqrt{2\left(i_0^* - i_H\right)} = \sqrt{2 i_H^* \left[\left(\frac{p_0^*}{p_H}\right)^{\frac{k-1}{k}} - 1\right]} . \tag{10}$$

Speed variation along the radius is assumed to be:

$$V(R) = V_0 \left(\frac{R_0 + b_0}{R}\right)^n . \tag{11}$$

and the result is: $V_0 = V(R_0 + b_0)$.

If the radius of curvature of the slot is big enough compared to the slot opening, it can be approximated that the brake enthalpy is constant on the radius and the asymmetry is caused only by the static pressure variation from p_H in the upper part of the slot to p_0 at the wall, in the lower part (Figure 5).

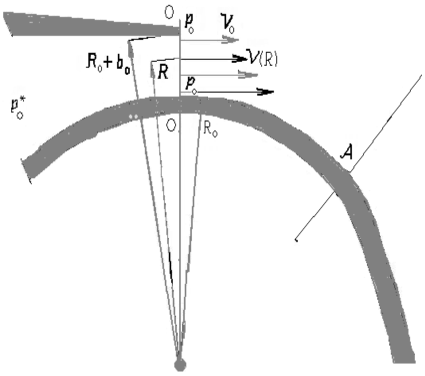


Figure 5. Coandă flow

3. Application of Coandă effect

The correct results regarding to the Coandă effect on the tail boom are reached by connecting the theoretical and computational studies as well as by putting into practice the profiles that need constant adjustments and they relate to:

- variation of the airflow generated by the main rotor (there are two variables here: the pitch angle and the rotation speed of the blades);
- variation of the air jet induced in the tail boom through the variable pitch fan;
- geometry of the profile (in our case being the tail boom);
- the number of Coandă slots and their geometry (including width δ and length *l*).

It is to be noticed that appropriate, realistic results concerning the fluid flow under the Coandă effect was reached through practical experiments by means of hundreds of convenient adjustments and changes of the variables.

The fluid flows along the tail boom and along the desired distance as well as the variation of the lateral force F due to the Coandă effect were been analyzed. This was an attempt to create an adjustable, optimum Coandă profile depending on the flows generated by the main rotor, the tail fan, and the slot geometry and position.

This optimization gives the possibility to replace the anti-torque rotor, removing its disadvantages, and creates the advantage of big (maximum) lateral forces with low-energy consumption, which are found in helicopter performance calculations. In order to obtain the biggest lateral force possible, the application of slots on the tailboom was enlarged.

This implies the modification of the force of the arm and the calculation of the application of the two slots in such a manner that the addition of the first air jet from the first slot turns into a fluid entrainment mass for the second slot.

This entrainment of the fluid increases the surface of the Coandă profile. Thus, the entrainment of the fluid through the two slots generates a Coandă flow and the air mass that “attaches“ itself to the fuselage (tailboom surface) becomes, in its turn, an adjustable surface of a new Coandă profile through the vertical flow induced by the main rotor [6]. This implies the modification of force for arm and the calculation the application of the two slots in such a manner that the addition of the first air jet from the first slot turns into a fluid entrainment mass for the second slot [7].

4. Conclusions

The values of the geometrical and input parameters were respected and the experimental results were close to the computer-simulated ones. Practically, in order to obtain a convenient force generated by the Coandă effect, a force which can be easily modified, some directional adjustable elements need to be placed on the length of the slots.

The force detected on the profile in each area of the Coandă flow is the difference between two distinct forces: one on the upper side and one on the lower side, of different strengths, the same direction and opposing directions, which are significantly affected by the geometry of the chosen profile.

The computational simulation of the tail geometry based on the optimal use of the two longitudinal Coandă slots, permits the realization of a Coandă flow, controllable via the speed of induced jet and the flow resulted from the main rotor of the helicopter, which result a lateral force of a magnitude according the work regime of the monorotor helicopter.

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