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# THE COANDĂ VTOL-UAV AEROMECHANICAL ASPECTS

**George BĂLAN *, Sorin-Gabriel CONSTANTINESCU *, Bogdan CIOBANU ****

"Dunărea de Jos" University of Galati *, "Gheorghe Asachi" Technical University of Iaşi**

***Abstract***. *The paper proposes a new concept of flight, including in the first phase of the flight, a vertical take-off, using the propulsion forces from an on-board rocket engine. The en-route phase of the flight, when moving horizontal, as the first part of the approach for landing, are conducted more similar with a rotary-wing flight. Also, the UAV sustentation comes from his aero dynamical shape. Especially designed to overcome the air resistance, the aerial vehicle has an appropriate design of the fuselage, which comply with a Coandă aerodynamic profile. Landing is assisted with the help of the same rocket engine, used for take-off. Up today, in our efforts to optimize the design of this VTOL-UAV, we made a first experimental model at a reduced scale. Moreover, aerodynamic researches have been conducted on it, in a wind tunnel, to enable optimal aerodynamic design of this new type UAV. Brief, the proposed aerial vehicle may be characterized as a mixture between a Coandă UAV and a reaction engine used only for vertical take-off and landing phase.*

***Keywords***: *rocket engine, Coandă fuselage, radial nozzle, flight vehicle.*

## 1. INTRODUCTION

The widespread aerial vehicles - planes to reach a destination point using the lift force that occurs on the wing's aerodynamic profile to the flow around them to high speed airflow. Flying an airplane consists of five distinct phases - the acceleration device runway, take-off, horizontal flight, lowering, braking on the runway. Addiction current speed lift force provided in the direction of increasing development of aviation and flight gear shift planes to jet propulsion. The result does not leave much to be expected - long runways, huge airports, catastrophic accidents, rescue systems, fuel consumption is high because the airplane propeller clock functions at all five phases of flight.

Another aircraft as well spread is helicopter; the lift force is created that all the aerodynamic profile of the blades flying in formation of eddy currents. Helicopter flight includes only three phases - takeoff, horizontal flight, helicopter descent. Increase flight speed is limited by resistance propeller blades at high speeds, motorization is excluded so reactive and propellers used. Fuel consumption is much higher compared with the plane, because the helicopter propeller works extensively in all the phases of flight, there are more catastrophic accidents. There are no rescue tool systems.

A new flight system used for travel aerospace are space ships "Columbia" (USA) and "Buran" (Russia), for multiple flights, includes four main phases: STOVL (Short Take-Off, Vertical Landing) with rocket launcher, ballistic flight path, aerodynamic brake, landing on a runway by aerodynamic braking (ship "Columbia") or by reaction engines (ship "Buran"). The advantage of the flight system, called "Shuttle" means the use of rocket powered propellers, with the period of active operation of the flight path only, use of air resistance for the landing, existing rescue systems. As a disadvantage we can consider a horizontal landing on a runway long and the impossibility of a "soft" vertical landing.

Nowadays there is a wide range of unmanned aircraft that rely on an airplane or on a helicopter scheme. These devices can provide tracking moving objects, environmental monitoring, fire and flood monitoring, tracking military personnel and groups of people, including visual tracking suspects and finding missing persons. Also the use of these unmanned devices requires favorable weather conditions similar to those required for flying airplanes or helicopters (wind speed, fog, visibility and lightning). The drawback of unmanned devices is impossibility to reach in the fast tracking speed and hang in the low speed tracking. All existing devices cannot be launched from underwater position; it cannot move in water and land on water.

To overcome the drawbacks outlined above are available to interested researchers for monitoring of ecosystem a vehicle that satisfies its sustentation and propulsion through an alternative based on the Coandă effect and reaction propulsion.

## 2. UNMANNED COANDĂ AIRCRAFT WITH REACTIVE PROPULSION

Below (Fig. 1) is a schematic diagram unmanned aircraft main propulsion Coandă reactive, which contains: Coandă fuselage (1), gas generator (4) which with a radial nozzle (2) forms the central rocket engine and four side rocket engines (3).

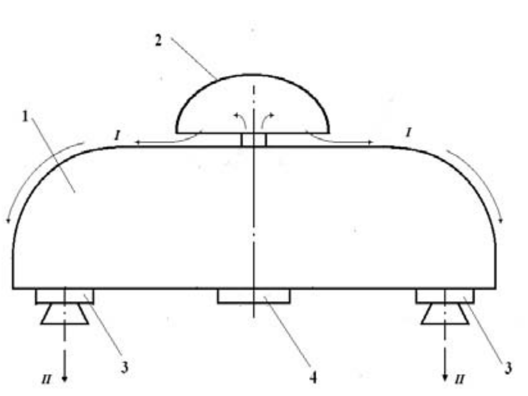

Fig. 1. Main scheme unmanned aircraft powered Coandă reactive: 1 - Coandă fuselage, 2 - radial nozzle, 3 - side rocket propellant, 4 - central rocket propellant; I - Central rocket thruster jet; II - lateral jet thruster rocket

Central rocket engine (4) produces gas that by nozzle radial (2) gets around a Coandă fuselage, causing the gas stream I. Because the supersonic Coandă jet *I*, creates a layer that significantly reduces the aerodynamic resistance of the fuselage. Supersonic jets *II* (Fig. 1) of the side rocket thrusters provide vertical take-off and guiding device on active flight path I (Fig.2). All these engines side decreases to zero speed landing providing soft landing of the last phase of flight (IV, fig. 2).

The main difference in the dynamics of the device Coandă jet flight unlike devices based on an airplane or helicopter is that movement in the horizontal direction occurs after inertial trajectory similar to ballistic missiles. The main purpose of the flight itself is done, horizontal displacement engines not started but to hang the device from the point of maximum altitude (3, fig.2) the free fall trajectory III, which may be with a different trajectory from the ballistic one.

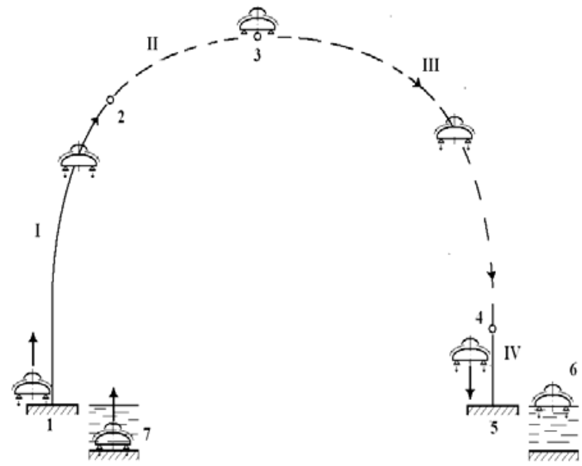

Fig. 2. Flight phases Coandă device with reactive propulsion: 1 - platform off; 2-point off the engine side; 4 - the point of maximum latitude; 5-landing platform; 6-landing on water; 7 - underwater home; I - active path; II, III - passive path; IV path braking.

Coandă jet device (Fig.1) is vertical launch and all engines starts or underwater position 7(fig. 2). Active path of the device is held up to the point 2, then engine side 3, stops. On passive path, device brakes due to aerodynamic shape and the Coandă effect. Reaching the point of landing 4, side engines are started providing a soft landing on the platform device 5, or on water surface 6 (fig. 2).

## 3. THE EXPERIMENTAL DEVICE COANDĂ JET

Experimental research conducted by most researchers [1,2 ] show that with increasing flow rate of radial nozzle, lift force developed by Coandă fuselage increased.

The Coandă device with radial convergent nozzle is shown in Fig. 3:

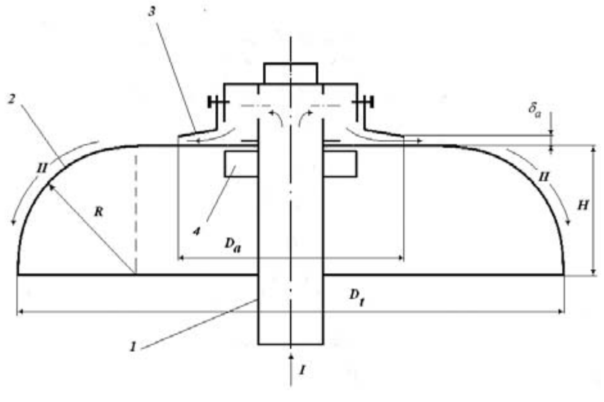

Fig.3. The Coandă device with convergent nozzle: 1-feeder; 2- Coandă fuselage; 3-convergent nozzle; 4-fixing nut; *I*-air intake; *II*-jet attachment; $D_t$, *H*-Coandă fuselage diameter and height; *R*-radius of curvature of the Coandă fuselage; $D_a$ -radial nozzles diameter; $\delta_a$- radial slot nozzle

The feeder 1 (fig. 3) is a central piece where the Coandă profile is fixed 2, with nut 4. Coandă fuselage radius *R*= 70 mm is equal to its height *H*. Nozzle 3 is screwed on top of base allowing slot nozzle size changes $\delta_a = 0.5 - 5.5$ mm. Nozzle position fix 3 is made with two diametrically located mounting screws. Compressed air tamp down by center channel base 1, and is targeted by the cross holes of the base in radial convergent nozzle 3, which accelerates and flows on being attached to the exterior profile of the plates 2, creating lift force in the axial direction.

Velocity converging gas nozzle ranges accordingly the supply pressure and the flow accordingly the slot and fixed diameter nozzle pressure.

Depending on the flow of gas in the convergent nozzle outlet section, being that subsonic (Mach number *Ma* <1) or transonic (Mach number *Ma* = 1).

In the subsonic regime speed gas flow nozzle is determined by applying Saint-Venant formula [1]:

$$\upsilon = \sqrt{\frac{2k}{k-1}\cdot\frac{P_0}{\rho_0}\left[1-\left(\frac{P_{at}}{P_0}\right)^{\frac{k-1}{k}}\right]},\ m/s \qquad (1)$$

where:

$p_0 = p + p_{atm}$ - absolute pressure supply, Pa

*p*- manometer pressure supply

$p_{atm}$- atmospheric pressure

$p_0 = \frac{p_0}{R \cdot T_0}$, kg/m$^3$ - density air supply

$R$=287 J/(kg ·K) - air gas constant

$T$=273.12+$t_0$,K - air temperature

$t_0\,^oC$ - air temperature

Air mass flow rate using the *Saint-Venant* formula for subsonic gas flow through holes and nozzles will be:

$$\dot{m} = \rho_0 \cdot \upsilon \cdot S\text{, kg/s} \tag{2}$$

where:
$S = S_a = \pi\, D_a\, \delta_a$, sectional area of exit, $D_a$, m– radial nozzles diameter; $\delta_a$, $m$– radial nozzles slot.

If the total gas pressure $p_0$ is higher than pressure of the surroundings $p_{at}$ in which flow occurs $\left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$= 1.72 time, in the convergent nozzle exit section transonic flow regime is installed with *Mach* number $M_a$ = 1,with critical thermodynamic parameters, then air mass flow is determined by the formula:

$$\dot{m} = \rho_{cr} \cdot a_{cr} \cdot S_{cr}\text{, kg/s} \tag{3}$$

where: $\rho_{cr}$ and $a_{cr}$ are the critical parameters determine by the initial parameters ($P_0$, $\rho_0$, $T_0$) and adiabatic exponent ($k$) of gas.

Critical velocity is given by:

$$\upsilon_{cr} = a_{cr} = \sqrt{\frac{P_0}{\rho_0} \cdot \frac{2k}{k+1}}\text{, m/s} \tag{4}$$

Critical air density:

$$\rho_{cr} = \rho \cdot_0 \left(\frac{2}{k+1}\right)^{\frac{1}{k-1}}\text{,m/s} \tag{5}$$

Construction model provided 5 different diameters converging nozzles, with dimensions of respectively $D_a$ = 70, 90, 130, 150 and 170 mm, with a $D_t$ = 280 mm diameter Coandă fuselage that, consecutively, ensure changes ratio $D_a/D_t$=0.25; 0.32; 0.46; 0.54 and 0.61.

## 4. RESULTS AND DISCUSSION

Experimental tests conducted in the Laboratory of Aerodynamics the Department of Fluid Mechanics, Hydraulic and Pneumatic Machines and Drives, Technical University "Gheorghe Asachi" from Iasi, aimed at measuring the static pressure on the Coandă device experimental prototype of scale achieved. Since the capacity of the laboratory compressed air supply is up to 1.5 m$^3$/min, experimental tests were performed for flow of 25 l/sec being tested several configurations of exhaust air nozzles (nozzles 70, 90, 130, 150 and 170 mm). Airflow measurement is made with a diaphragm flow meter connected to a differential manometer measuring range 0÷1500 mm $H_2O$.

The fourteen static pressure plugs are located from 10 to 10 mm, from the neighborhood feeder and ending at the bottom of the Coandă fuselage of experimental prototype, small scale developed (Fig. 4)

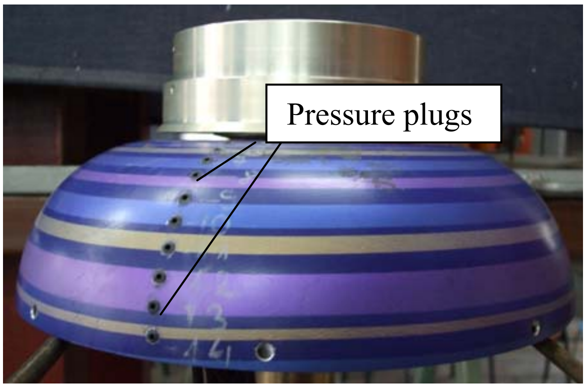

Fig. 4. Pressure plugs on the Coandă fuselage

The value of pressure drop measured on active element flow meter with diaphragm was Δp=1334 mm $H_2O$ which corresponds to a rate $Q$= 25 l/s.

In terms of fluid flow attached to the main body of experimental prototype small-scale developed, has been noticed that large diameter discs ($D_a$=150 mm and $D_a$=170 mm) ensures conditions for the separation of fluid flow in the lower housing, while for smaller diameter discs separation is achieved in the maximum curvature of the case.

In Fig. 5 is presented the static pressure distribution compared for the six nozzle diameters considered, while three slot nozzle size, $\delta_a$ =1.5; 2.5 and 5.5 mm.

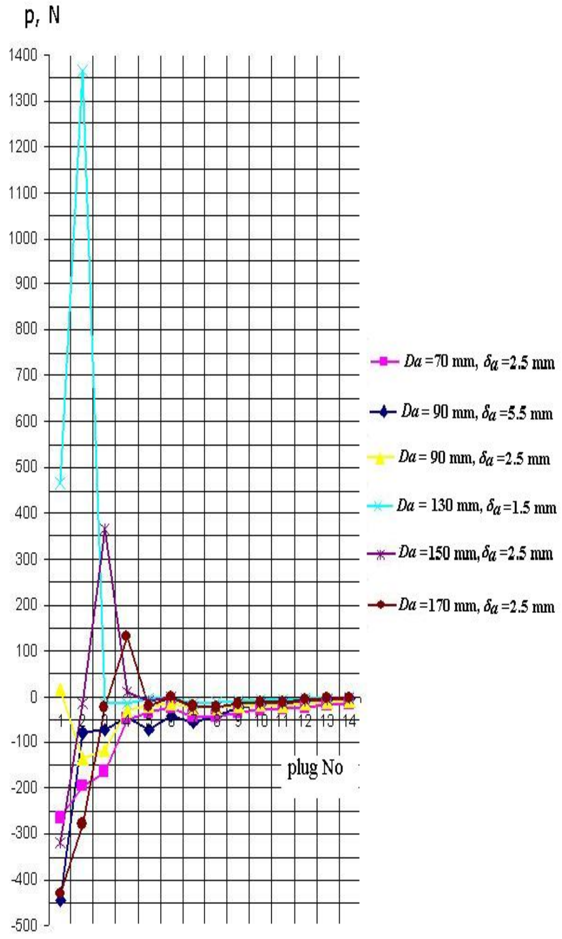

Fig. 5. Variation of static pressure on a generator of Coandă fuselage

There is a better behavior in terms of static pressure distribution, to nozzles with smaller diameters to large diameters $D_a$ = 130, 150 and 170 mm. Radial flow separation occurs on the surface of Coandă fuselage.

Below Figures 6 and 7 are graphs that dependent lift forces $R_z$ are shown determined by processing data [2], depending on nozzle diameter radial Da report to Coandă fuselage diameter $D_t$.

As shown in Figure 6, there is an optimal value for $D_a/D_t$ where aerodynamic lift force maximum and namely is.

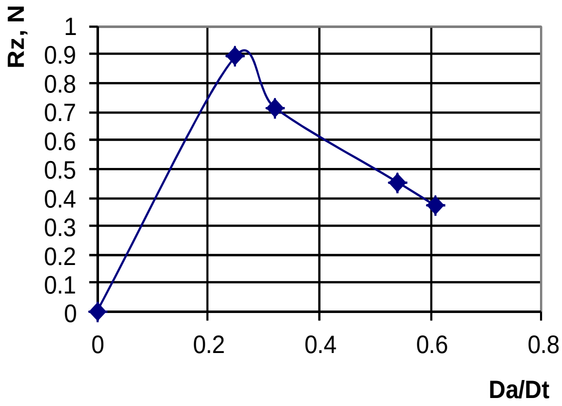

Fig.6. Aerodynamic lift force depending on the diameter ratio $D_a / D_t$ (slot nozzle $\delta_a$=2.5 mm)

With increasing flow velocity of the radial jet, also increases the aerodynamic lift force (Fig.7).

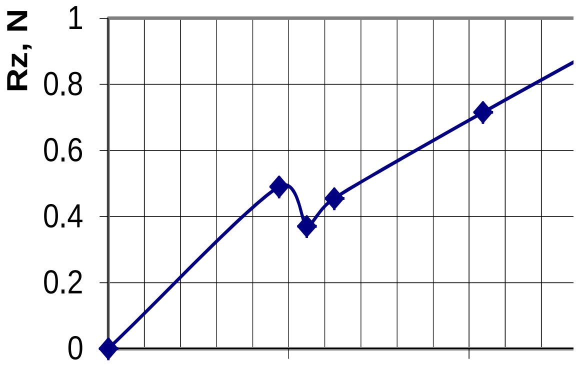

Fig.7. Aerodynamic lift force $R_z$ depending on air velocity $\upsilon$ to the exit of radial nozzle

Data processing method of least squares allowed approximation equations for the dependence of aerodynamic lift force depending on the diameter ratio $D_a/D_t$ and in speed according to radial jet flow:

$$R_Z = 19.767\left(\frac{D_a}{D_t}\right)^3 - 24.568\left(\frac{D_a}{D_t}\right)^2 + +82.655\left(\frac{D_a}{D_t}\right) + 0.0036 \tag{6}$$

$$R_Z = 0.0004\cdot\upsilon^3 - 0.0092\cdot\upsilon^2 + +0.1182\cdot\upsilon + 0.0052 \tag{7}$$

Formulas 6 and 7 allow choosing the radial nozzle geometrical parameters:

$D_a$ - radial nozzles diameter;

$\delta_a$ - radial nozzles slit.

In Tab.1 and Tab.2, are presented the experimental data collected from the dependence of aerodynamic lift force of diameter ratio $D_a/D_t$ and speed $\upsilon$.

Tab.1 Experimental data for the air velocity

| Nozzle diameter $D_a$ [mm] | Nozzle slot $\delta_a$ [mm] | Diameter ratio $D_a / D_t$ | Velocity $\upsilon$ [m/s] |
|---|---|---|---|
| 170 | 2.5 | 0.61 | 5.5 |
| 150 | 2.5 | 0.54 | 6.26 |
| 130 | 1.5 | 0.16 | 12.0 |
| 90 | 2.5 | 0.32 | 10.38 |
| 90 | 5.5 | 0.32 | 4.73 |
| 70 | 2.5 | 0.25 | 13.38 |

Tab.2 Experimental data for the lift force

| Nozzle diameter $D_a$ [mm] | Nozzle slot $\delta_a$ [mm] | Diameter ratio $D_a / D_t$ | Lift force $R_z$ [N] |
|---|---|---|---|
| 170 | 2.5 | 0.61 | 0.370 |
| 150 | 2.5 | 0.54 | 0.455 |
| 130 | 1.5 | 0.16 | 0.705 |
| 90 | 2.5 | 0.32 | 0.715 |
| 90 | 5.5 | 0.32 | 0.490 |
| 70 | 2.5 | 0.25 | 0.896 |

## CONCLUSIONS

It was proposed a new concept of flight, including in the first phase of the flight, a vertical take-off, using the propulsion forces from an on-board rocket engine.

An aerial vehicle characterized as a mixture between a Coandă UAV and a reaction engine used only for vertical take-off and landing phase it was described.

For optimizing the design of this VTOL-UAV, it was made a first experimental model at a small scale.

The aerodynamic researches have been conducted on it, in a wind tunnel.

The results of aerodynamic researches allowed determination of aerodynamic lift force depending on radial nozzles diameter, its slot and flow velocity at nozzles exit.

Nozzle diameter ratio was established to the Coandă fuselage diameter, where is the maximum aerodynamic lift force.

The numerical approximation analytical relations were obtained to calculate the aerodynamic lift force depending on the radial speed jet and geometric parameters of the aircraft.

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