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EXPERIMENTAL RESEARCH OF REACTION FORCE PRODUCED BY COANDA NOZZLE

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ABSTRACT

The paper presents research results of gas dynamics of Coanda nozzle, that is a key element of drones with jet propulsion. The jet propulsion Coanda drones allow you to quickly monitor the large areas in emergency situations: forest fires, earthquakes, meteor attacks and so on. The aim of this work consists in establishing of the geometric and gas dynamic parameters at which the reaction force produced by Coanda nozzle is maximal.

KEYWORDS: jet propulsion drone, Coanda nozzle, reaction force, Mach number

1. INTRODUCTION

Due to the increasing gravity of natural disasters such as big meteorite fall as it was in Russia at the beginning of 2013 in Cheleabinsk region, also to their rapidly growing proportions, emergency response forces have to identify new technologies that will enable them to fulfill their missions. In order to realize good interventions and to properly protect rescue crews [1, 2], it is necessary to collect rapidly data from large area surfaces. Only an aerial platform, which is able to cover rapidly the whole area of interest, to collect the necessary information using the onboard sensors, and to relay that information to the forces engaged in action accomplished all requirements.

The classic drones of airplane type [3, 4] use air acceleration around airfoil wings to create the aerodynamic force. The drag acts against the airplane motion, limiting the airplane speed. From this reason, these vehicles are not fast enough to arrive to disaster location.

The classic drones of helicopter type use several rotating wings to generate the aerodynamic force. Unfortunately, the main component of this force creates the lift force and only a small component gives the trust force. Moreover, aerodynamic force magnitude is limited by rotating wingspan due to the high relative speed at rotating wing tip, which causes the boundary layer detachment that induces an additional resistance to motion. Therefore, helicopters are slower than airplanes. Furthermore, airplanes need long runways to take off and to land on. Unfortunately, the runways are usually at long distances from the disaster place.

Nowadays, there are used only conventional drones, which are not able to monitor rapidly the damaged environment. Because these drones are generally in the aeromodel size, they depend on the weather conditions and cannot be always used. Increase of their size is not a valid solution because this would generate fuel consumption augmentation.

For these reasons, the most convenient aerial platforms are the jet propulsion drones. To overcome the drawbacks outlined above, a vehicle based on the Coanda effect and jet propulsion [5] is the best choice for interested researchers to monitor the destroyed ecosystems. The flight path of these aerial vehicles include four main phases: take off with rocket launcher, ballistic flight path, aerodynamic brake and landing with a parachute. Furthermore, these aerial vehicles are independent on whether and can be launched from long distances to disaster place because they are fast.

The main aim was to make the drones based on the Coanda effect, which can monitor rapidly the environment in critical conditions. To design this type of drones, it is necessary to investigate the influence of geometric and gas dynamic parameters on reaction force that appears on Coanda airfoil when one uses the rocket engine. Unfortunately, the transonic jet flow produced by rocket engine is not studied for Coanda nozzle.

2. EXPERIMENTAL SET UP AND PROCEDURE

The Coanda nozzle, which allows obtaining a subsonic and transonic flow, is shown in Fig. 1 from [5].

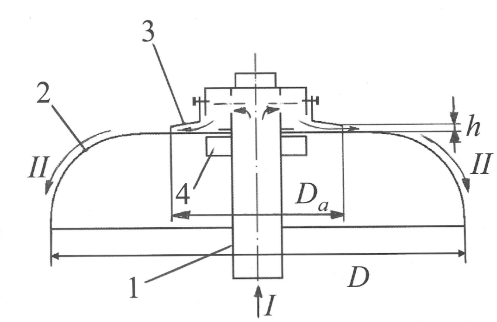

Fig. 1. Coanda nozzle: 1-air supply pipe; 2- Coanda airfoil; 3-radial nozzle; 4-binding nut; *I*-compressed air; *II*-radial jet; D – Coanda airfoil diameter; D_a – radial nozzle diameter; h – slot size

The air supply pipe 1 is the main piece on which the Coanda airfoil 2 is fixed, with nut 4. Curvature radius of Coanda airfoil is 70 mm and it is equal to its width. Radial nozzle 3 is conic and for it is screwed on top of main piece 1 allowing slot size h changes between 0.65 – 2.0 mm. Compressed air enters through air supply pipe 1, and it is directed by the cross holes in radial conic nozzle 3, which accelerates the flow. The radial jet attached to the exterior profile of the Coanda airfoil 2 creates the reaction force in the axial direction. The jet velocity depends on slot size and supply pressure. Depending on these critical parameters, the flow jet regime is subsonic or transonic.

The Coanda nozzle model (Fig. 2) has 5 radial nozzle with diameters D_a = 70, 90, 130, 150 and 170 mm, Coanda airfoil diameter D = 280 mm, which ensures the diameter ratio D_a/D = 0.25; 0.32; 0.46; 0.54 and 0.61. board.

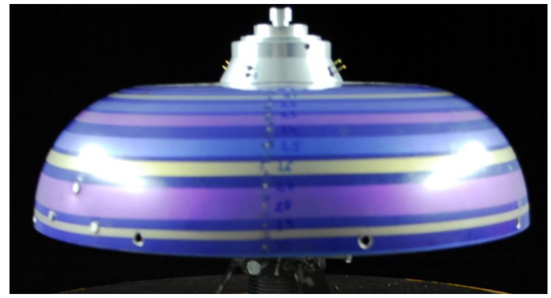

Fig. 2. Coanda nozzle view

The test rig (Fig. 3) consists in supporting frame of drone model, air supply system, measurement annular system of reaction force and aerodynamic balance TEM Engineering Limited (England). The accuracy of this balance is ±0.001 %.

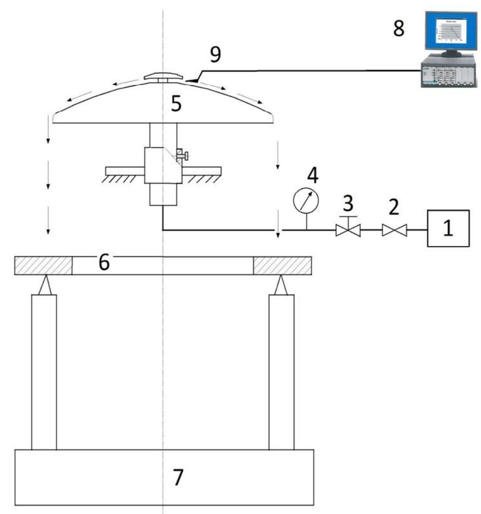

Fig. 3. Test rig for reaction force measurements:1 – compressor;2 – valve; 3 – expansion valve; 4 – manometer; 5 – Coanda nozzle; 6 – ring; 7 – aerodynamic balance; 8 - Streamline Pro Anemometer System; 9 - conical film probe 55R42

Compressed air (10 bar) from compressor 1 passes through valve 2 and arrives in expansion valve 3 where the pressure decreases up to 3 bar. The Coanda nozzle 5 is connected to air supply system and it creates reaction force. To measure the jet velocity, it uses the system Streamline Pro Anemometer System 8 equipped with conical film probe 9. The compressor UP5-15-10 is used. Compressor discharge pressure is up to 10 bar, flow rate is 2.3 m^3/min and nominal power is 15 kW.

The Coanda nozzle placed in INCAS low speed wind tunnel during the reaction force measurements is shown in Fig. 4.

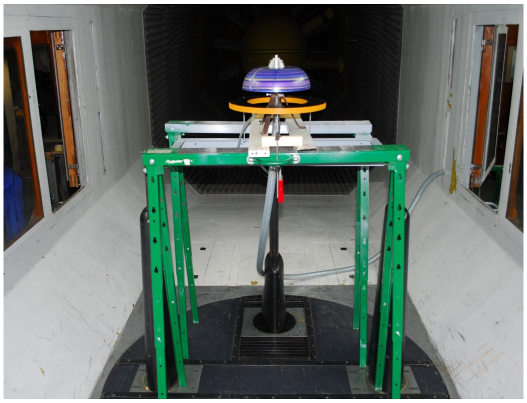

Fig. 4. Coanda nozzle placed on a balance of INCAS low speed wind tunnel

In order to measure the velocities at the radial nozzle exit, we used Streamline Pro Anemometer System made by Dantec Dynamics. In this experiment, we used conical film probe 55R42 as shown in Fig. 5.

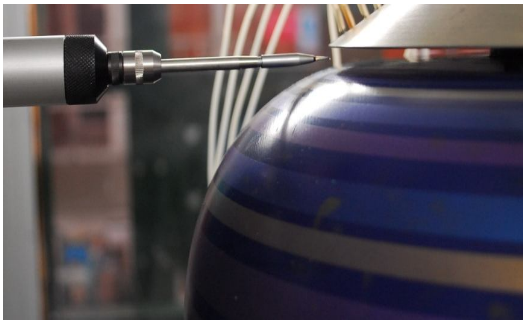

Fig. 5. Probe 55R42 during the velocity measurements

The sensor of this probe is placed as a ring (diameter approx. 0.6 mm) around a cone on the tip of a 1.5 mm quartz rod. Sensor dimension is 1.4x0.2 mm. As the sensor is placed downstream from the very tip of the probe, velocity fluctuations are damped through the boundary layer. The bandwidth is thus lower than the one of wedge-shaped film probes. The conical probe is less sensitive to contamination than a fiber or a wedge probe, and it should be preferred to the wedge types whenever possible. Velocity range is from 0.05 m/s to 400 m/s with accuracy of ±0.02 m/s.

The principal aim of measurements was to determine the radial nozzle exit diameter and slot size at which the reaction force is maximal. For subsonic to transonic jet flow, the variation of supplied pressure is used.

The reaction force was considered the force which jet produced by Coanda nozzle pushes on the ring tied with aerodynamic balance. The outer diameter of this ring is 400 mm, its width is 75 mm and its thickness is 18 mm. The distance between Coanda airfoil and ring is 48 mm.

The authors pursued the variation of studied parameters in function of jet velocity at drone nozzle exit.

3. RESULTS AND DISCUSSIONS

The results regarding the influence of jet velocity on reaction force at different diameters of radial nozzle are presented in Figs 6 ÷ 11.

As shown in Fig. 6, the reaction force increases as long as the jet velocity augments. Moreover, the reaction force is small and the flow regime is low subsonic (M < 0.45).

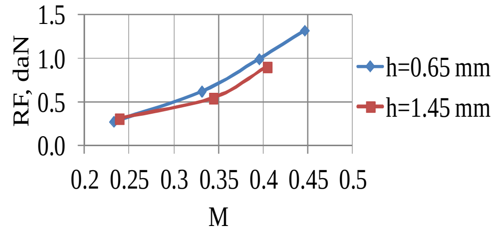

Fig. 6. Reaction force (daN) in function of jet velocity and slot size (h) of radial nozzle at its diameter ratio D_a/D = 0.61 (subsonic regime)

As seen in Figs 7, 8 and 9, the reaction force increases as long as Mach number goes up.

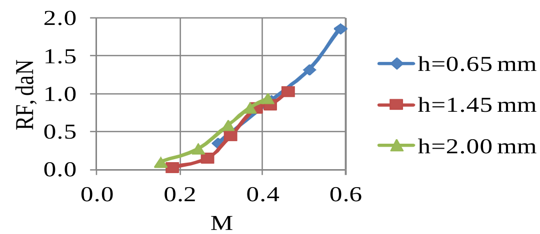

Fig. 7. Reaction force (daN) in function of jet velocity and slot size (h) of radial nozzle at its diameter ratio D_a/D = 0.54 (subsonic regime)

The slot size of radial nozzle influences weakly the reaction force for large diameter ratio ($D_a/D \geq 0.46$), see Fig. 8.

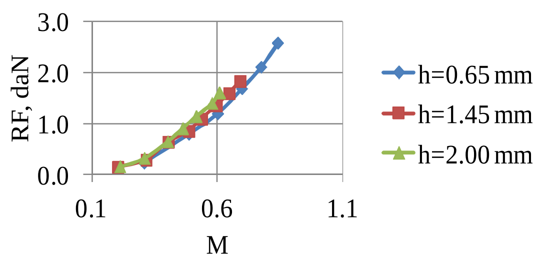

Fig. 8. Reaction force (daN) in function of jet velocity and slot size (h) of radial nozzle at its diameter ratio D_a/D = 0.46 (subsonic regime)

As long as the diameter ratio decreases, the slot influence is bigger (Figs 9 and 10).

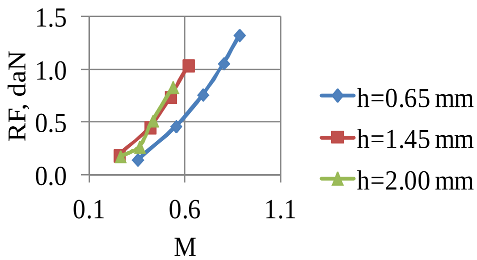

Fig. 9. Reaction force (daN) in function of jet velocity and slot size (*h*) of radial nozzle at its diameter ratio D_a/D = 0.32 (subsonic and transonic regimes)

The maximal reaction force values (L = 2.4÷2.6 daN) are in transonic regime ($M \approx 1$) as seen in Fig. 10.

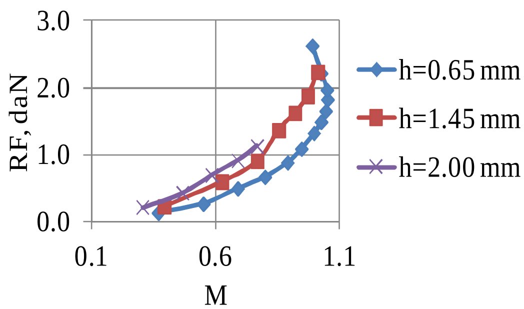

Fig. 10. Reaction force (daN) in function of jet velocity and slot size (*h*) of radial nozzle at its diameter ratio D_a/D = 0.25 (transonic regime)

The results regarding diameter ratio influence show that the high reaction force values are obtained at D_a/D = 0.25 and transonic flows (Fig. 11).

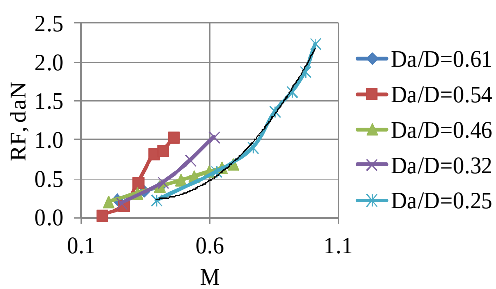

Fig. 11. Reaction force (daN) in function of Mach number and diameter ratios at slot size h = 1.45 mm

Approximation of the reaction force curve in function of Mach number, at diameter ratio of 0.25 through the least root square method is given by

$$RF = 4.88 \cdot M^2 - 3.73 \cdot M + 0.95;\ R^2 = 0.994\ ; \quad (1)$$

where RF is the reaction force, daN; M is the Mach number and R^2 is the squared approximation error.

4. CONCLUSIONS

The Coanda drone with jet propulsion is very good to monitor the environment that is destroyed or damaged by natural phenomena such as meteor falls, volcano eruptions and tsunami. This type of drone allows the situation analysis in very short time, in extreme weather conditions when the drones of airplane are not able to fly. The influence of geometric and gas dynamic parameters on reaction force of Coanda drone was studied and were established the following conclusions:

- reaction force depends on flow velocity in radial nozzle exit and its value is maximal at transonic flow regime;
- optimal value of radial nozzle diameter at which the reaction force achieves its maximal value is a quarter of airfoil Coanda diameter;
- dependence of reaction force in function of radial jet Mach number is a quadratic function.

The present results allow building a drone that is able to operate in different media (gases, plasma, and liquid).

5. ACKNOWLEDGEMENT

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