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ASPECTS REGARDING CONCEPT, DESIGN, DEVELOPMENT AND USE OF A COANDĂ EFFECT UNMANNED AERIAL VEHICLE

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ABSTRACT

This scientific paper presents certain aspects regarding the stages of concept, design, development and use of a Coandă unmanned aerial vehicle. The study is based on MEDIAS project case study, a Lightweight UAV (LUAV) developed at "Dunărea de Jos" University of Galati.

KEYWORDS: UAV, Coandă effect, CFD, Fluent, MEDIAS

1. INTRODUCTION

This paper describes the concept, design and development stages and the potential missions for a Coandă Unmanned Aerial Vehicle (UAV). The paper is a study case based on an aerial vehicle named MEDIAS, which was designed and built as an ecological one, under the frame of the Romanian national research projects contest, financed by Program 4 PN II - *Partnerships in priority areas*, 2008 edition, in the Field 3 - Environment.

The work conducted in the frame of this national grant between 2008 and 2011, allowed the researchers to design, develop and test several experimental models related to the solution initially anticipated. The models differed in execution technology solutions, as well in the materials used to manufacture each of them. However, each of these experimental models allowed us to conduct a series of experiments that helped us to determine some aerodynamic parameters for this type of air vehicle.

2. MEDIAS - A NONPOLLUTING UAV, MEANT TO MONITOR ENVIRONMENTAL PARAMETERS

As far as the UAV with the above mentioned destination is concerned, there are a number of special design restrictions resulting from the limited field of activity where it has to be used.

The environmental monitoring project described in this paper mainly focused on interaction with the environment. The authors carefully considered the environmentally - friendly dimension of the aerial vehicle. Consequently, the design specifications required that the vehicle should have the lowest possible impact on the environment. For an UAV meant to monitor the parameters of the natural environment, the main restriction is to be non-polluting, in order to alter not, in any way, the environmental parameters which have to be measured.

2.1. ENGINE AND PROPULSION

This first design feature is at the same time a design restriction implying solutions which involve particular aerial vehicle propulsion. In short, the design task is to have nonpolluting propulsion. Our solution was an electric engine driving a propeller.

2.2. SPEED AND AUTONOMY

Other secondary UAV characteristics connected to the task of performing scientific research missions are:

1. They do not need a high cruise speed;

this is due to the fact that the vehicle carrying mobile sensors should also be able to keep the same aerial position for a long time in order to perform certain tasks of monitoring natural environmental parameters;

2. Since it has been assumed that the cruise speed would be low, the duration of the mission / the autonomy should be - on the contrary – higher, amounting to several hours (up to 24 hours or more);

3. As the mission autonomy should be relatively high for a small LUAV (less than 150 kg) – “Light UAV-category”, this implies that the propulsion system must be highly efficient. At the same time, the fuel tank and/or the onboard power source should provide increased autonomy.

Considering these characteristics, we searched for solutions to increase the efficiency of the propulsion. As a first solution, we adopted a ducted propeller due to its superior efficiency when comparing with a usual propeller.

Afterwards, we vertically redirected the exhausted air currents in order to add some reactive force to the sustentation. For our design theme, Coandă effect seemed to be a suitable solution, because it was able to vertically redirect the exhausted jets from the propeller duct, adding more air masses from the vicinity of the vehicle in the same process. All these additional effects were achieved only by reusing the energy of the air entrained by the propeller.

2.3. SIZE/DIMENSIONS OF THE VEHICLE AND PAYLOAD

As far as the dimensions and weight of the vehicle are concerned, there are more constraints. First, we intend to carry a payload of at least 2-3 kg, but we also have to keep the overall size under a minimal value (taking into consideration the on-field deploying demands).

2.4. FINAL DESIGN

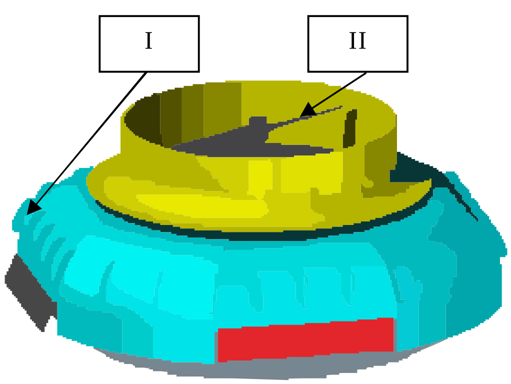

Fig. 1 Specific contribution of each device component to the propulsion & sustentation of MEDIAS-LUAV

MEDIAS research project finally proposed a Vertical Take-Off and Landing (VTOL) UAV, with a hybrid design. Due to the restrictions imposed for this aerial vehicle, the solution which was finally chosen is characterized by the fact that the UAV shall use Coandă effect (I) and an electrically driven propeller (II).

The specific contribution of each device to the propulsion and sustentation of MEDIAS aerial vehicle is shown in the Fig. 1.

Alongside these features, optional conversion and use of solar energy will compete at improving and increasing the UAV’s mission autonomy.

3. METHODS USED FOR THE DESIGN OF THE AERIAL VEHICLE

In the design and conception stages, as in the development one, the contribution of Iasi (P1) and Bacau (P2) academic consortium partners proved to be extremely important for the shape of the fuselage of MEDIAS, our Coandă environmentally friendly aerial vehicle.

With the help of our academic consortium colleagues, we were able to analyze the dynamic of the working fluid, simultaneously, both from the point of view of the numerical modelling and of the experimental proof. This double approach, the computational, and through experimental research, allowed us to verify, using two complementary methods, both the physical principles of the basis of the chosen solution for the experimental model, and the design method.

For the analysis of the flow around the MEDIAS vehicle and for optimizing the shape of the fuselage, we used a virtual 3D model for simulating the air flow, as an input element for a CFD program. In this specific case we used FLUENT v 6.2, known as one of the most accurate and powerful CFD programmes. The virtual 3D model and the FLUENT analysis were achieved by our colleagues of the Department of Power Engineering and Electrical Engineering of the “Vasile Alecsandri” University of Bacău (Partner P2).

At the same time, in order to verify the obtained data in order to design and manufacture the experimental model, we materialized the designed fuselage vehicle by a scale model in order to obtain quantitative information about the phenomenon of air flow around the experimental model.

In the same time, the scale model was studied in the wind tunnel at Iaşi, respectively at the Department of Fluid Mechanics, Machines and Hidro-pneumatical Actuators of the “Gh. Asachi” Technical University of Iasi (Partner P1). The study has enabled us to complete the knowledge obtained through the CFD analysis of the Coandă effect, acquiring the real flow values obtained by measuring the actual status of flow parameters of working fluid (air) around the fuselage of the vehicle. The main measured parameters were the static pressure (the air flow over the upper part of the fuselage has as known effect the decrease of the static pressure providing a required sustentation), as well as the actual lifting force developed through the studied Coandă effect.

During the researches, essential for the design and implementation of experimental model designed by the researchers of Mechanical Engineering Faculty of Brăila, from the "Dunărea de Jos" University of Galaţi, we could compare two sets of values: the first generated by numerical modeling and simulation on the virtual 3D model, using FLUENT, and the other obtained by measuring the flow parameters of the working fluid determined experimentally on the scale model tested in the wind tunnel.

3.1. SIMULATION OF AIR FLOW AROUND THE FUSELAGE BY CFD ANALYSIS

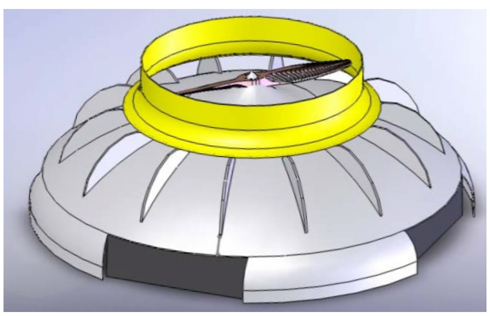

Fig. 2 - The 3D virtual model of the MEDIAS experimental model, created with SolidWorks - isometric view

For the air flow simulation, we created our virtual 3D model, using SolidWorks, thus we were able to estimate very accurately the geometric dimensions of the vehicle and also we had the premises to substantially reduce the time necessary to design the shape of the fuselage, including the body parts and the assembly, as well to test different nozzle propeller shapes, before choosing a proper one.

Further, we used this virtual 3D model for the simulation of fluid flow around the fuselage by CFD analysis. As software for this analysis we have chosen to use FLUENT, known as one of the most accurate and powerful CFD programmes.

As an input parameter, we chose the air jet diameter created by the propeller ensemble (powered propeller and nozzles) and we studied how the flow parameters were influenced by modifying the input. During the analysis we used five different diameters (330 mm, 350 mm, 400 mm, 450 mm and 500 mm) for the air jet, keeping constant - as a consequence - the unitary air flow over the border of the virtual frontier that materializes the propeller disc. The exemplifying diagrams presented are those obtained for the 500 mm air jet diameter.

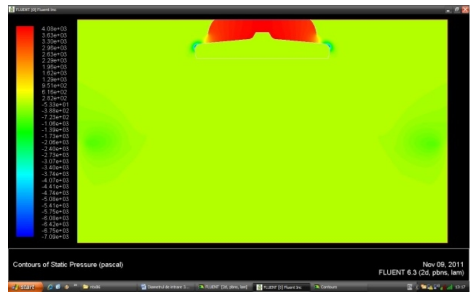

Fig. 3 - Static pressure diagram

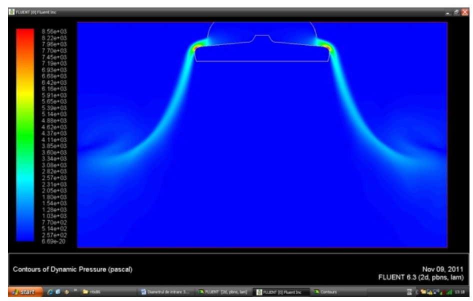

Fig. 4 - Dynamic pressure diagram

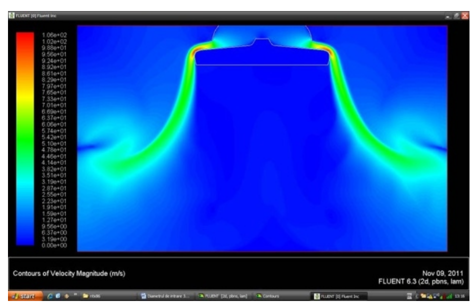

Fig. 5 – Velocity magnitude diagram

In order to have a field of flow that one may compare, including from the point of view of air flow detaching phenomenon and emergence of turbulence at the detachment off the fuselage, we managed to keep the same input speed in the model (v = 10 m/s).

3.2. EXPERIMENTAL WORKBENCH, TESTS AND METHODOLOGY

Theoretical and experimental tests carried out with the designed models had different types of nozzles and variable diameters, so we could adjust the circular outlet aperture of the air, in order to analyze the influence of the Coandă effect forces needed for the take-off and the sustentation of the aerial vehicle.

The experimental workbench consists of a source of compressed air, the tested device, related piping system, measuring apparatus and an experimental data acquisition and analyzing system.

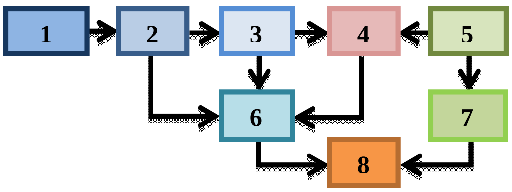

Fig. 6 - Experimental workbench components: 1-compressed air supply, 2-air flow measuring apparatus, 3-pressure measuring apparatus (digital manometer), 4 - tested device, 5-sustentation force measuring apparatus (dynamometer), 6-manometers set, 7-dynamometer, 8-computer

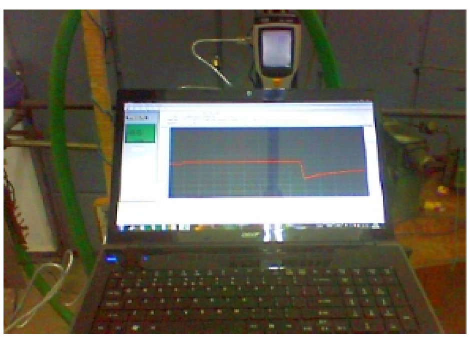

Fig. 7 - Digital manometer and portable experimental data acquisition system

Since the capacity of the compressed air supply in the lab was of maximum 1.5 m^3/min, experimental tests have been carried out for the nominal flow of 25 l/sec, in various configurations of jet-nozzle outlets (Laval nozzles and 70, 90, 130, 150, 170 mm nozzles). The air flow measurement in the experimental tests was made with a diaphragm flow meter connected to a differential pressure gauge having a measurement range of 0-1500 mm H_2O.

The fourteen intakes for measuring the static pressure are located at each every 10 mm starting from the close vicinity of the central air distributor and ending at the lower edge of the main body of the experimental scale model.

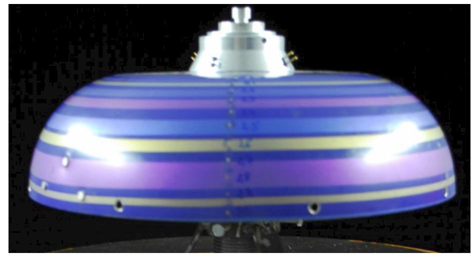

Fig. 8 - Experimental scale model main body with jet-nozzle outlet and 14 intakes for measuring the static pressure

4. DEVELOPMENT STAGE

Three MEDIAS-LUAV experimental models were almost simultaneously developed using similar conception and design outlines, but by different teams, in different locations (Bacău, Brașov and Brăila).

Fig. 9 - Experimental model MEDIAS-01

Fig. 10 - Experimental model MEDIAS-02

This helped us to check some initial presumptions and also to learn from the well-known trial and error method, acquiring a valuable know-how, which we will value in the development of the prototype.

Fig. 11 - Fuselage, propeller & propeller duct, before assembling them. (MEDIAS-02)

Table 1 presents the construction and outfitting comparative characteristics for all three experimental models.

Table 1 Construction and outfitting characteristics

Internal designation	*MEDIAS-01*	*MEDIAS-02*	*MEDIAS-03*
Workshop location	Bacău	Brașov	Brăila
Fuselage material	Balsa wood	Fiberglass	Balsa wood
Propeller duct material	Fiberglass	Fiberglass	Balsa wood
Diam. of the fuselage: mm	600	600	900
Radial nozzle diameter: mm	240	380	480
Circular gap height (variants): mm	10; 20; 30	40	18; 24; 30; 36; 42; 48; 56
Propeller Diameter: inch	9	14	18
Propeller pitch: inch	5	8	6
Maximum thrust of the propeller: g	1200	3500	4600
Electrical engine weight: g	97	195	377
LiPo batteries total weight: g	300	560	650
The maximum power of the engine: W	840	840	810
Nominal voltage of power supply of the engine: V	20	38	35
Nominal intensity of the supplied current: A	25	43	45
Total mass (equipped vehicle, w/o additional payload): g	950	3450	2440
Gain of upward force (Maximum thrust – total weight): g	250	50	2160

Because the gain of upward force was very small, mainly due to the high weight of its fiberglass body, the experimental model MEDIAS-02 was not able to float, at all.

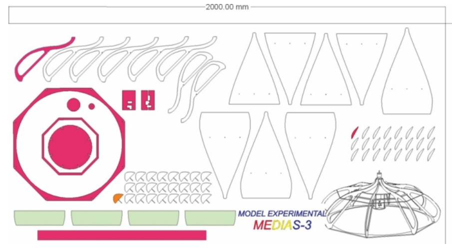

Fig. 12 - Nesting drawing of the experimental model MEDIAS-03

Fig. 13 – Balsa wood body frame, anti-torque flaps, body control flaps, propeller duct, propeller and electrical engine. (MEDIAS-03)

Fig. 14 – The arrangement of the actuators used in the anti-torque flaps and body control flaps. (MEDIAS-03)

5. MISSIONS TO BE CARRIED OUT BY A COANDĂ UAV

The first tasks for the experimental model within the project will be either photo- or video- recordings, with scientific purpose or real time monitoring of the nature reserves and of the areas found within the range of the remote control.

Fig. 15 - General view of the MEDIAS-03

Besides the measurement of environmental parameters, the MEDIAS-LUAV described here will be able to carry out a large variety of missions such as:

a. Wildlife inventory and species conservation, especially in wetlands or mountains,
b. Forestry or fishery inspection,
c. Forest and crop disease management, fire detection and firefighting management,
d. Monitoring of natural disasters (water flows, avalanches, oil spill tracking)
e. Cartography and GIS data collection for areas accessible only by air, water, etc.

6. CONCLUSIONS

1. First, by delaying - as much as possible - the detachment moment of the fluid current from the lower end of the fuselage and redirecting it along the vertical direction, we obtain an augmentation of the thrust force.

2. Therefore, the reaction force obtained by the detachment of the air jets has a favorable effect increasing the propulsion efficiency, working in the same direction with the thrust force provided by the propeller, thus increasing the overall efficiency of the propeller propulsion.

3. Also, according to the experimental observations, even if the static pressures has comparable values between the upper and lower faces of the fuselage, the air jets leaving the small circular gap may develop significant lifting forces, benefiting from a larger area of flow exposure for the upper fuselage face.

4. As a consequence of the previous conclusion, we may recommend for further research and development, to replace the propeller, that usually has a large diameter, but a small number of blades, (2 ... 3), with a turbine, correctly dimensioned as speed and flow, to favor the developing of Coandă effect.

This recommendation is based on the fact that turbines - commonly - have a higher number of blades, but a few times smaller diameter. As a result, the effective load-bearing surface of the Coandă vehicle increases (while the central propulsion area decreases) and, therefore, increase the sustentation capabilities of the Coandă vehicle.

ACKNOWLEDGEMENT

The project, named MEDIAS, has taken part in the Romanian national project contest financed by PROGRAM 4 PN II „*Parteneriate în domeniile prioritare*" (translator's note: "*Partnerships in priority areas*"), 2008 edition, and has become one of the winners in the Field 3. "*Environment*", for the Research Direction 3.3 "*Ecological protection and reconstruction of critical areas and conservation of protected areas*", at Research Theme 3.3.2 "*Monitoring systems for the biological and ecological diversity dynamics at structural and functional level*".

REFERENCES

[1] **Constantinescu, S. G., Bălan, G.**, „*Experimental research of reaction force produced by Coandă nozzle*", The Annals of „Dunărea de Jos" University of Galaţi, Fascicle XIV Mechanical Engineering, ISSN 1224-5615, pp. 29-32, 2013

[2] **Florescu, D., Florescu, I., Nedelcu, I.**, „*The simulations regarding the air flow parameters on the outer shell of a warm air current vehicle*", The 12th International Conference of Scientific Papers, „*Scientific Research and Education in the Air Force-AFASES 2010*", ISBN 978-973-8415-76-8, pp. 646-649, 27-29 mai, 2010, „Henri Coandă" Air Force Academy, Braşov, Romania.

[3] **Florescu, I., Florescu, D., Nedelcu, I** „*Theoretical and experimental studies for auto sustainable device using Coandă effect*", ", The Annals of „Dunărea de Jos" University of Galaţi, Fascicle XIV Mechanical Engineering, ISSN 1224-5615, pp. 55-58, 2011.

[4] **Nedelcuţ, F.**, „*Current Aspects of Using Unmanned Aerial Vehicles in Environmental Monitoring*", 1818, Journal of Environmental Protection and Ecology (JEPE), ISSN 1311-5065, Vol. 12, No. 4, 2011, pp. 1818-1824.

[5] **Nedelcuţ, F., Bălan, G., Ciobanu, B., Florescu, I.** „*Specifications for an UAV for scientific research in the field of monotoring environmental parameters*, AIRTEC – International Aerospace Supply Fair, November, 2009, Frankfurt/Main, Germany.

[6] ******* – „*Raport tehnico-ştiinţific – Vehicul cu auto-sustentaţie pentru supravegherea aeriană a mediului natural*" – PNCDI II-P4, Contract 32-123, Et. IV, 2011