AERODYNAMIC DESIGN CONSIDERATIONS OF A FLYING WING TYPE UAV

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DOI: 10.19062/2247-3173.2017.19.1.24

Abstract: *The UAV field recognizes a full conceptual, technological and applicational maturity, however, a number of national and international scientific references recommend research directions that are insufficiently explored, such as: biological inspiration through the concept of morphing, approaches of the multisystem concept, or optimizations of operating time in hostile environments. For the aerodynamic optimization stage, this paper proposed a tailless / flying wing concept design for the assessment of aerodynamic performance in the flight configuration, by means of experimental tests in a subsonic wind tunnel.*

Keywords: *Flying wing, wind tunnel, INCAS, MASIM.*

1. INTRODUCTION

The UAV field recognizes a full conceptual, technological and applicational maturity, however, a number of national and international scientific references recommend research directions that are insufficiently explored, such as: biological inspiration through the concept of morphing [1, 2, 3], approaches of the multisystem concept [4, 5, 6], or optimizations of operating time in hostile environments [5, 7].

For the aerodynamic optimization stage, this paper proposed a tailless / flying wing concept design for the assessment of aerodynamic performance in the flight configuration, by means of experimental tests in a subsonic wind tunnel [8, 11, 12], as a follow-up of several numerical evaluations [13, 14, 15].

Abbreviations

C_x	-drag coefficient	C_y	-lateral force coefficient
C_z	-lift coefficient	β	-sideslip angle
S	-area	V	-velocity
ρ	-density	K	-turbulence factor
C_m, C_n, C_r	-moment coefficients on the three axes	F_x, F_y, F_z	-aerodynamic forces on the three axes
α	-angle of incidence		

2. AERODYNAMIC TESTS CONCERNING THE PERFORMANCE OF FLYING WING UAV

2.1. Theoretical landmarks and description of the subsonic wind tunnel

The aerodynamic tunnel from INCAS is a Prandtl type, with a closed experimental chamber and octagonal cross section. This wind tunnel provides an ascending cross section channel, having four corners with 90° turning vanes, which direct the airflow from the end of the diffuser towards the collector's entrance.

[X, Y, Z] – Components of the resulting aerodynamic force:

$$C_x = \frac{2 \cdot F_x}{\rho \cdot V^2 \cdot S} \tag{1}$$

$$C_y = \frac{2 \cdot F_y}{\rho \cdot V^2 \cdot S} \tag{2}$$

$$C_z = \frac{2 \cdot F_z}{\rho \cdot V^2 \cdot S} \tag{3}$$

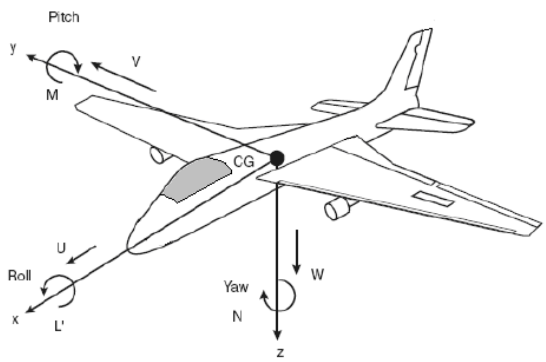


FIG. 1 Model reference system

In Fig.2 such a closed circuit wind tunnel is represented schematically. The term "closed circuit" means that the return of the airflow is done using a single lateral channel [8, 9, 10, 12, 15].

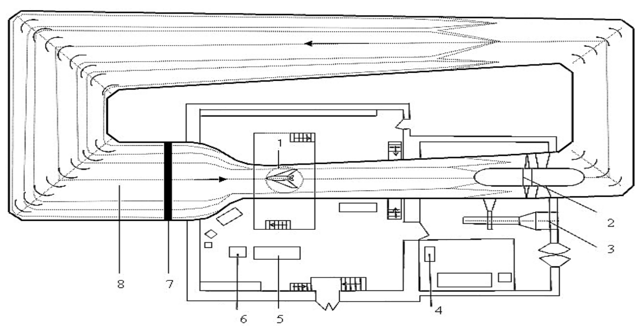


FIG. 2 Prandtl wind tunnel with closed circuit (1.operating room, 2. engine, 3.engine cooling system, 4. power supply panel, 5. control panel, 6. engine control panel, 7. section to minimize turbulence, 8. settling chamber)

In the subsonic wind tunnel from INCAS we find the technical data from Table 1, below. The venue supports testing of aircraft models of up to 1.8 m wing spans.

Table 1. Subsonic wind tunnel technical data

No.	Component	Description
1.	Experimental chamber	2.0 m height x 2.5 m width
2.	Compression ratio	10:1
3.	Experimental chamber dimensions	2 x 2.5 x 6.0 m
4.	Maximum wind speed	110 m/s
5.	Turbulence coefficient	0.2 % (Dryden, at Reynolds No. = 385.000)
6.	Turbulence factor	K = 1.11
7.	Working pressure	atmospheric pressure
8.	Measurement system	external balance, 6 components, of pyramidal type
9.	Accuracy	0.02 % full scale, all axes
10.	Resolution	0.002 % full scale, all axes
11.	Incidence angle	-25....+45 deg. - 1...5 deg/sec
12.	Yaw angle	+/- 180 deg.- 0.5...6 deg/sec

2.3 Experimental setup

The MASIM model was mounted on the three elements of the external balance. The latter is used to measure aerodynamic loads on the model, inside the test section, as seen in Fig. 3.

FIG. 3 Model mounted on the balance inside the subsonic wind tunnel

The balance is located outside the subsonic aerodynamic tunnel and it measures three forces and three moments. It is also used to position the model at different pitch and yaw angles. The position angles are measured with absolute encoders. For all measurements, the incidence varied with one degree step. To determine the aerodynamic parameters of the model, four sets of measurements were taken. The model was positioned on the balance and was considered to be at zero degrees, when the indicator on the control desk measured +7.37 degrees [12].

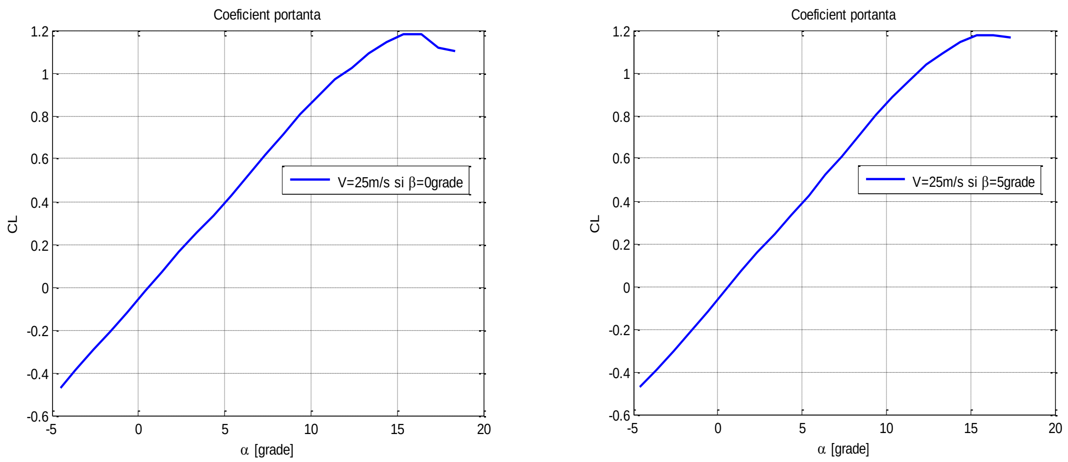
The first experiment was performed at an incidence angle ranging from -4.53 to 18.37 degrees and yaw angle was constant at 0 degrees. For the next two experiments, the angle of incidence varied from -4.62 to 17.37 degrees, while the yaw angle was constant at -5° and +5° at a time, respectively. For these first three tests, the wind speed inside the experimental chamber was 25 m/s.

The last experiment was performed at a constant yaw angle of 0°, while the incidence angle varied from -2.67 to 17.33 degrees. In this case, the wind speed inside the experimental room was 30 m/s.

2.4 Experimental results

The experimental tests generated a series of results, the most relevant being presented in Fig. 4 (a, b, c, d). The final data is obtained following numerical transformations of the balance measurement units by means of some specific coefficients.

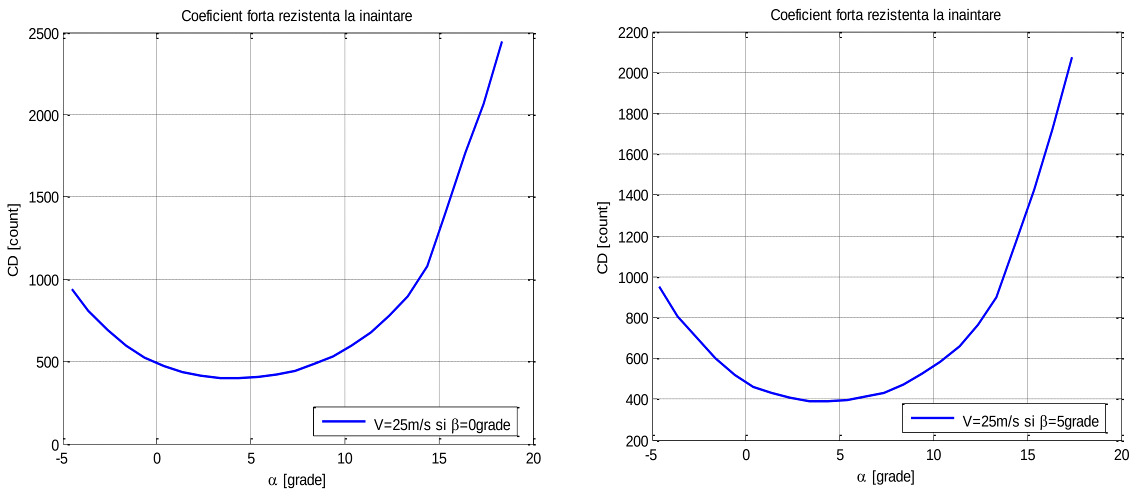
For the speed of 25 m/s, according to Fig.4 we observed a maximum value of the lift coefficient, C_z,at an incidence of 16° for a sideslip angle $\beta=0^o$,and of 15° for $\beta=5^o$.



(a) (b)

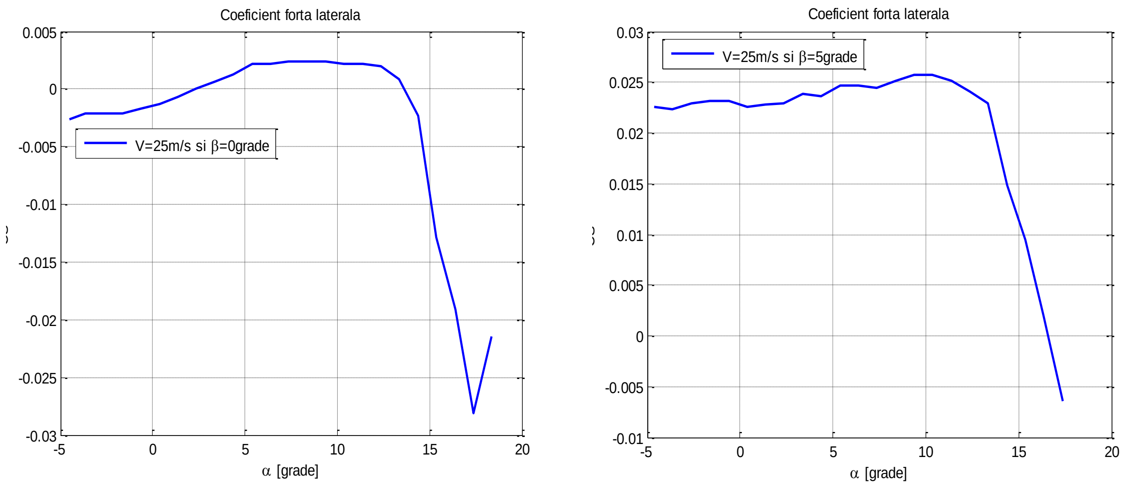
FIG. 4 Lift coefficient, C_z

Drag has a minimum corresponding coefficient, C_D,at 5° incidence (see Fig. 5), and the coefficient of the lateral force F_y grows in absolute value, proportionally (towards -0.03) with flight incidence, but also with the sideslip angle β (0,005 for $\beta=0^o$ vs 0,025 for $\beta=5^o$), according to the graph in Fig. 6.



(a) (b)

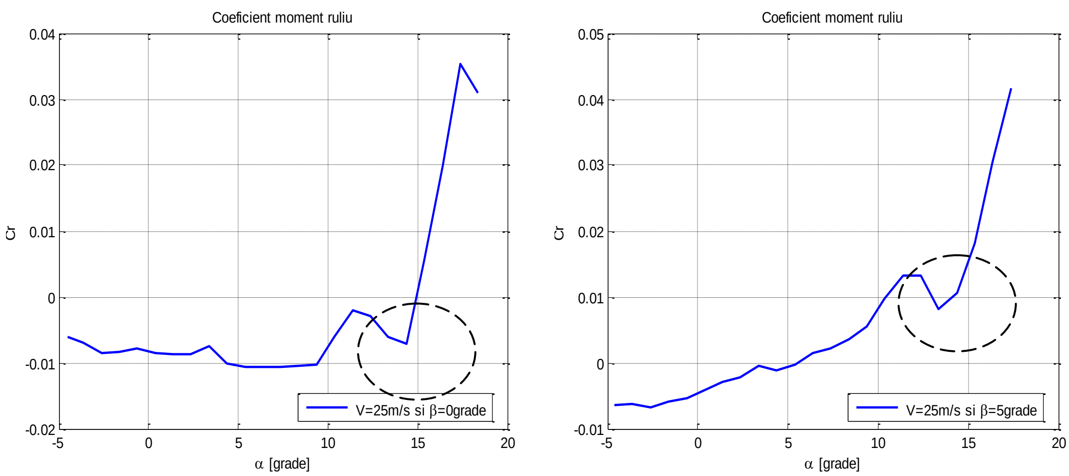
FIG. 5 Drag coefficient, C_D



(a) (b)

FIG. 6 Coefficient of the side force F_y

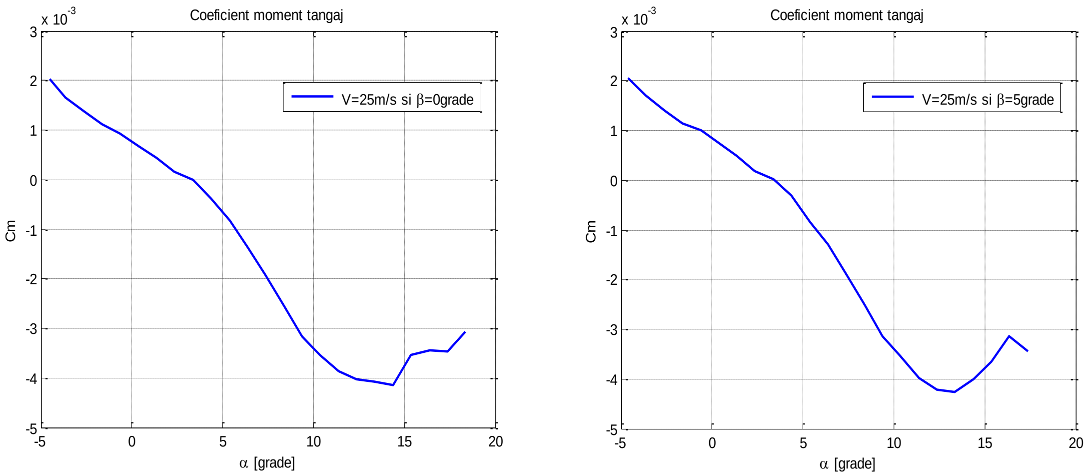
The roll coefficient C_r, grows significantly after the incidence of 15° (see Fig.7), having value differences within the incidence range of 0°-10°.



(a) (b)

FIG. 7 Rolling moment coefficient

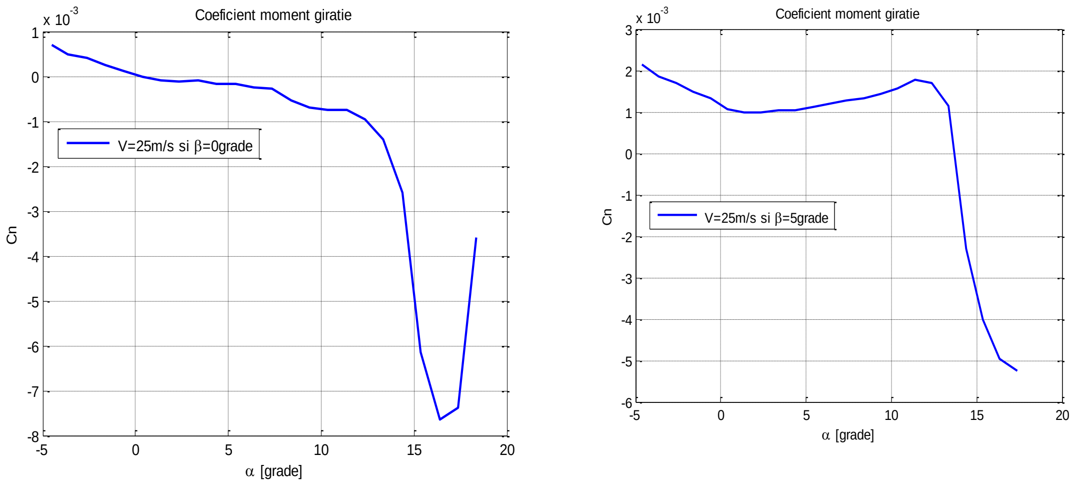
The pitching moment, C_m, versus incidence, for a speed of 25 m/s is highlighted in Fig. 8, with a null C_m, for incidence values around 3° (Fig. 8), for both sideslip angles, β.



(a) (b)

FIG. 8 Pitching moment coefficient

The yawing moment coefficient, C_n, varies significantly after the incidence of 13°, as seen in Fig. 9, having variations in the incidence range of 0°-10°.



(a) (b)

FIG. 9 Yawing moment coefficient

The values of the aerodynamic coefficients are shown in Table 2.

Table 2. Aerodynamic coefficients (left β=0°, right β=5°).

V	Incidenta	Beta	CL	CD	Cm	CS	Cn	Cr
25	7.37	0	0.616138107	0.044525949	-0.0019	0.002147	-0.00033	-0.01079
25	-4.53	0	-0.468694598	0.094089505	0.002028	-0.00258	0.000701	-0.00606
25	-3.62	0	-0.389114161	0.080926724	0.001656	-0.00215	0.000495	-0.00691
25	-2.62	0	-0.292934124	0.068901468	0.001366	-0.00215	0.000413	-0.00842
25	-1.63	0	-0.210424345	0.059476267	0.001118	-0.00215	0.000248	-0.00836
25	-0.63	0	-0.116197202	0.052001108	0.000931	-0.00172	0.000124	-0.00782
25	0.37	0	-0.018552494	0.046963501	0.000683	-0.00129	0	-0.00855
25	1.37	0	0.069815966	0.043388425	0.000435	-0.00064	-8.3E-05	-0.00867
25	2.37	0	0.167460674	0.040950873	0.000166	0	-0.00012	-0.00861
25	3.37	0	0.254852688	0.039488341	0	0.000644	-8.3E-05	-0.00752
25	4.37	0	0.335409572	0.039650845	-0.00037	0.001288	-0.00017	-0.01
25	5.37	0	0.429148491	0.040625866	-0.00083	0.002147	-0.00017	-0.01061
25	6.37	0	0.52142274	0.041925893	-0.00137	0.002147	-0.00025	-0.01061
25	7.37	0	0.617602777	0.044038438	-0.00192	0.002361	-0.00029	-0.01067
25	8.37	0	0.715735709	0.048751039	-0.00255	0.002361	-0.00054	-0.01042
25	9.37	0	0.808498181	0.053301136	-0.00317	0.002361	-0.0007	-0.01018
25	10.37	0	0.887590395	0.059313764	-0.00354	0.002147	-0.00074	-0.006
25	11.37	0	0.972541291	0.067276434	-0.00387	0.002147	-0.00074	-0.00206
25	12.37	0	1.025757656	0.077514152	-0.00404	0.001932	-0.00095	-0.00291
25	13.37	0	1.091179611	0.089539408	-0.00408	0.000859	-0.0014	-0.00606
25	14.37	0	1.146348871	0.107739796	-0.00414	-0.00236	-0.0026	-0.00715
25	15.38	0	1.182477412	0.140565495	-0.00354	-0.01288	-0.00615	0.005455
25	16.38	0	1.180036295	0.176641264	-0.00344	-0.0191	-0.00763	0.01988
25	17.38	0	1.119008352	0.206866908	-0.00346	-0.02812	-0.00738	0.035335
25	18.37	0	1.104361646	0.244242704	-0.00306	-0.02147	-0.00359	0.030971
25	7.37	0	0.607350083	0.043875935	-0.00186	0.001073	-0.00029	-0.01109

V	Incidenta	Beta	CL	CD	Cm	CS	Cn	Cr
25	7.37	5	0.610768	0.043713	-0.0019	0.024471	0.00132	0.002485
25	-4.63	5	-0.47065	0.094902	0.002049	0.022539	0.002145	-0.00636
25	-3.63	5	-0.39107	0.080764	0.001697	0.022324	0.001856	-0.00618
25	-2.63	5	-0.30465	0.070201	0.001387	0.022968	0.001691	-0.00679
25	-1.63	5	-0.21384	0.059801	0.001138	0.023183	0.001485	-0.00588
25	-0.62	5	-0.11717	0.052164	0.000993	0.023183	0.00132	-0.00533
25	0.37	5	-0.02539	0.046151	0.000745	0.022539	0.001073	-0.00406
25	1.37	5	0.070304	0.043063	0.000497	0.022754	0.00099	-0.00297
25	2.37	5	0.158673	0.040951	0.000186	0.022968	0.00099	-0.00212
25	3.37	5	0.244112	0.039163	2.07E-05	0.023827	0.001031	-0.00042
25	4.37	5	0.334433	0.039001	-0.00031	0.023612	0.001031	-0.00121
25	5.37	5	0.426219	0.039651	-0.00085	0.024686	0.001114	-0.00018
25	6.37	5	0.523376	0.041113	-0.0013	0.024686	0.001196	0.001576
25	7.37	5	0.609303	0.043388	-0.00188	0.024471	0.001279	0.002182
25	8.37	5	0.707436	0.047451	-0.0025	0.025115	0.00132	0.003515
25	9.37	5	0.801175	0.052489	-0.00315	0.025759	0.001444	0.005515
25	10.37	5	0.888567	0.058339	-0.00354	0.025759	0.001568	0.009819
25	11.37	5	0.963753	0.066139	-0.00397	0.025115	0.001774	0.013273
25	12.37	5	1.039428	0.076539	-0.00422	0.024042	0.001691	0.013213
25	13.37	5	1.090691	0.089864	-0.00426	0.022968	0.001155	0.008122
25	14.37	5	1.146837	0.116515	-0.00399	0.014811	-0.00231	0.010607
25	15.37	5	1.177595	0.142353	-0.00366	0.009445	-0.004	0.018183
25	16.37	5	1.174178	0.172254	-0.00315	0.001932	-0.00495	0.030486
25	17.37	5	1.166854	0.207192	-0.00344	-0.00644	-0.00524	0.041638
25	7.37	5	0.606862	0.043063	-0.00184	0.024686	0.001361	0.002

3. CONCLUSIONS

The experimental steps for the proposed lifting surface were limited procedurally and financially, which led to the strict selection of initial test conditions with minimal implications for the level of confidence of the results. However, some obtained data contain numerical deviations that can be seen in the graphs in Fig.7 regarding the curves of the rolling moment coefficient, C_r, in the incidence range 10°÷15°.

Although experimental results depend on a number of parameters from the test chamber (ex. test chamber geometry, airflow quality) [8], tests in the aerodynamic tunnels along with CFD (Computational Fluid Dynamics)simulations can confirm the expectations of the chosen configurations or indicate complete or partial geometric optimization processes.

The paper presents the tests results performed under the MASIM project framework in the INCAS (National Institute for Aerospace Research “Elie Carafoli”) subsonic wind testing facility. The aim of the tests was to obtain the main aerodynamic coefficients for the an flying wing – a memeber of a formation flying system.

ACKNOWLEDGMENT

This work is supported bytheExecutive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI) under MASIM project (PN-II-PT-PCCA-2013-4-1349).

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