A RESEARCH ON THE STATIC STABILITY OF THE MAVS USING VIRTUAL TUNNELS

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Abstract: *This report discusses the using of a free software to determine the aerodynamic coefficients of a developed MAV. The coefficients obtained, as well as the aerodynamic forces and moments, have been investigated for their applicability in the balancing and static stability of this type of aircraft. The results of the work are used to synthesize a suitable autopilot.*

Keywords*: MINI UNMANNED AIR VEHICLES (MAVs), AERODYNAMIC COEFFICIENTS, BALANCING, STATIC STABILITY, FREE SOFTWARE, AUTOPILOT*

1. Introduction

In the development of MAVs, it is necessary to select an appropriate control system to perform the tasks which are to be carried out by this type of aircrafts.

The synthesis of such kind of control system is directly related to the properties and characteristics of the MAVs. In this case, it is necessary to study in advance the object which is to be controlled in order to introduce characteristics close to the real ones in the algorithms of the MAVs flight-navigation complex.

A big challenge for the designers of the control system is the handling of non-standard airfoils, for which it is not known what the flying characteristics of the MAVs will be.

In order to reduce this uncertainty in the present work, the characteristics of static stability in the vertical and horizontal flying planes of non-standard airfoils for MAVs flying wing type were investigated.

For achieving this goal, it is necessary to observe the conditions of longitudinal and lateral equilibrium, to obtain the balancing diagrams and hence to determine the static stability of the longitudinal and lateral direction.

2. Stability research of a prototype of the developed MAV

For the development MAV, the equilibrium conditions in the longitudinal and lateral channels were first found, and then balancing diagrams were researched. Static stability in the vertical plane at glide angle has been established at $\beta = 0^o$ and at balancing deflecting angle $\delta_б$ as well as in the horizontal plane at a balancing angle of attack $\alpha = \alpha_б^o$. For the purpose of the study, velocity was selected in the longitudinal direction $V_x = 3$ m/s.

The software product to be used as a virtual aerodynamic tunnel is XFLR5 [1, 2]. This product has its advantages and disadvantages. Its biggest advantage is that it is free and many developers prefer to work with it to study the characteristics of MAVs.

2.1. Stability research of a prototipe of the developed MAV in longitudinal direction

The general case of longitudinal equilibrium of the MAVs is given by the expressions:

$$(1)\quad \begin{cases} \sum F_x = P\cos(\alpha_p) - X_a - G\sin(\theta) = 0 \\ \sum F_z = P\sin(\alpha_p) + Z_a - G\cos(\theta) = 0 \\ \sum M_y = 0 \end{cases}$$

where the force indexes are aligned with the XFLR5 coordinate system designations [4, 5, 6] and α_p is the angle of mounting of the engine.

Equilibrium of the Forces by:

- the tangent to the trajectory is provided by the engine operating modes;
- the normal to the trajectory is ensured by the choice of the angle of attack.

In the longitudinal movement for balancing of the MAVs the pitching moment is determinative. The coefficient of this moment is given by the expression [3]:

$$(2)\quad m_y = m_{y0} + c_a\left(\bar{X}_T - \bar{X}_F\right) + m_{y}^{\bar{\omega}_z}\bar{\omega}_z + m_y^{\delta_б}\delta_б = 0$$

It can be seen from (2) that for equilibration of the longitudinal moment four methods of balancing the MAVs in the vertical channel are used:

1. to use self-stabilizing airfoils for wing construction (first member of (2));
2. to move the masses in the MAVs so that it gets balanced (second member of (2));
3. to change the V-shape of the wing (third member of (2));
4. to change the angle of the elevator from zero to the balancing $\delta_б$ (fourth member of the(2)).

The first method is inapplicable to this study because the airfoils were obtained when making a MAV from readymade templates. The second method produces a result within the range $\pm 4^o$ at negative attack angles, which is not acceptable.

The variation of the V-shape of the wing within the frame $\pm 10^o$ yields a result similar to the method described above.

For the purposes of the study, the result gives the last one that is the fourth method. In this balancing test is used only the elevator of MAV.

Figure 1 shows the longitudinal motion picture in the vertical plane in the environment of the XFLR5.

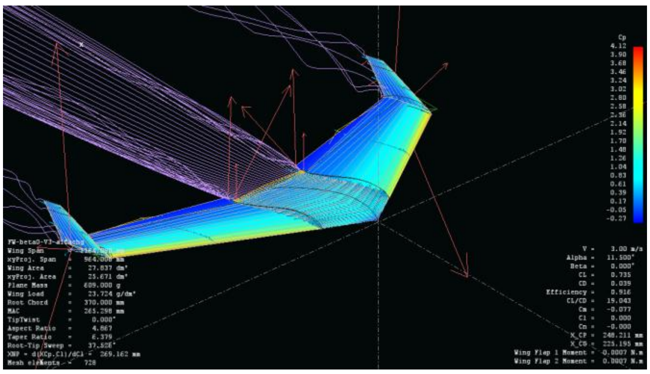

Fig. 1. *Stability research of the developed MAV in longitudinal direction.*

For the purpose of the survey, the angle of attack changes in the range $\alpha=(-20\div60)^o$. The results obtained for the pitching moment coefficient $c_m=f(\alpha)$ and the lift force coefficient $c_L=f(c_m)$ are shown in Figure 2.

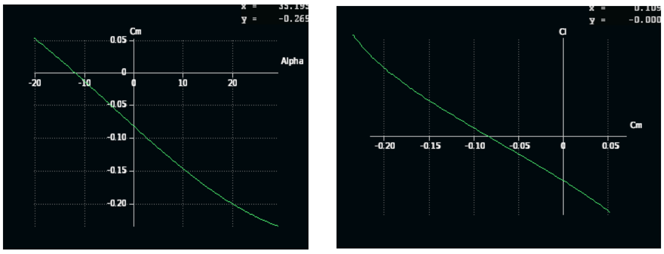

Fig. 2. *Coefficients of the pitching moment and lift force.*

From this figure (Figure 2) it can be seen that when $c_m = 0$ the angle of attack and the coefficient of lifting force are negative. This means that the model can not fly even though it is statically stable. In other words, it must be balanced in the vertical plane.

Another parameter which monitors the balance of the MAV in the longitudinal movement is the position of the center of pressures on the X axis (Figure 3).

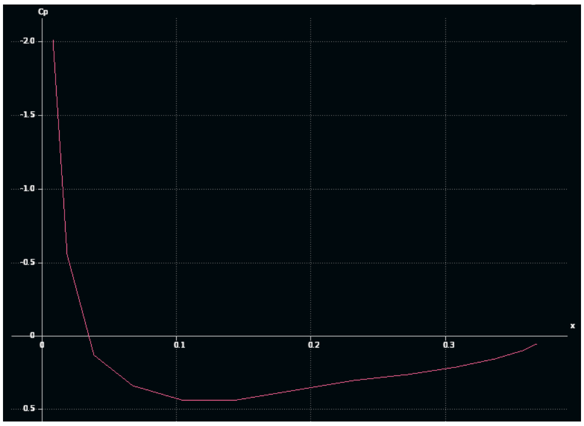

Fig. 3 *The position of the center of the pressures on axis X.*

Figure 4 shows the dependence of the coefficient of the pitching moment from the angle of attack after balancing deflection of the elevator.

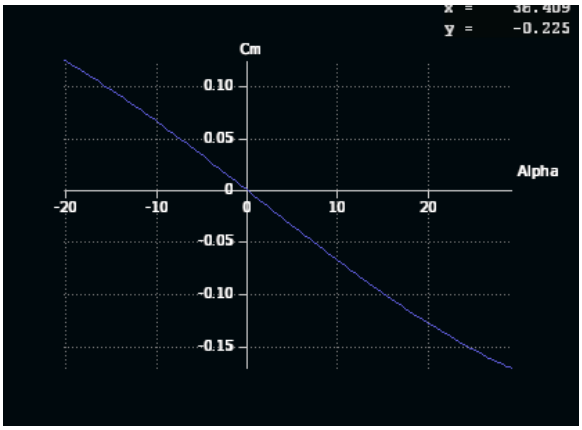

Fig. 4 *Coefficient of the pitching moment in a function of the angle of attack*

The results shown in Figure 4 are obtained at a balancing angle $\delta_б=-7{,}3^o$, which for the XFLR5 product means an upward deflection of the elevator. For the balancing angle of the attack is obtained $\alpha_б=(2{,}85\,10^{3})^o$ which is close to the computational error.

After balancing of the MAV on the pitch movement, it is checked for the lifting force coefficient (Figure5).

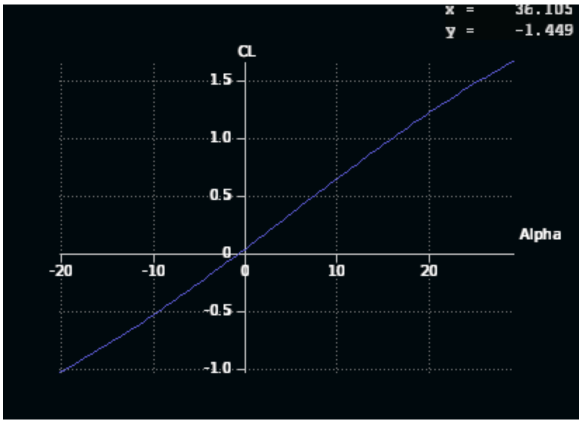

Fig. 5 *Coefficient of the lifting force in a function of the angle of attack.*

For the balancing angle of the attack, the coefficient of the lifting force is $c_L > 0$, which means that the balanced in the vertical plane MAV can fly.

The picture of the position of the center of pressure on the X axis (Figure 6) is now different from Figure 3.

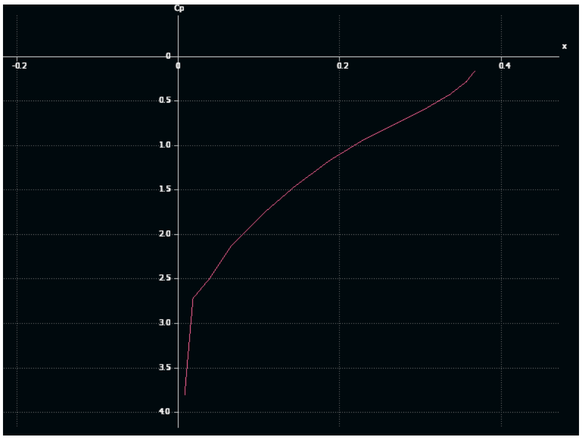

Fig. 6 *The position of the center of the pressure on axis X after balancing*

In Fig. 7, it is shown the change of the application point of the pressure center in the direction of the axis X in function of the angle of attack.

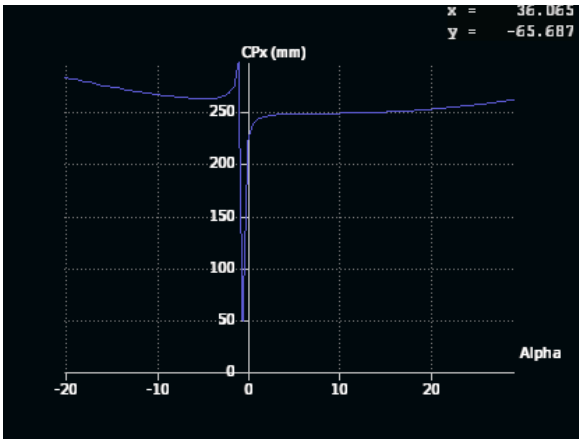

Fig. 7 *Changing position of the point of the pressure in X-direction*

From this graph (Figure 7) it becomes clear that there is no singularity at the angle of attack because the pressure point remains on the X axis and the pitch reference point coincides with the point of application of the pressures.

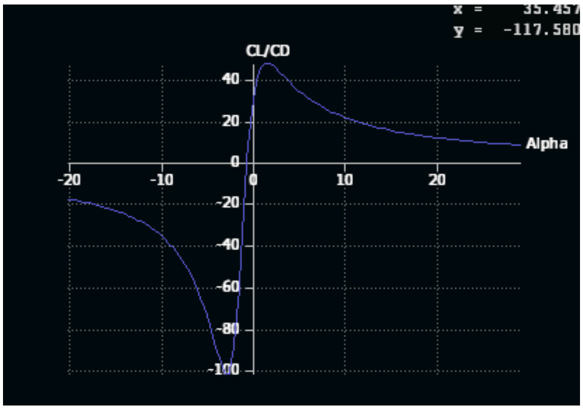

Fig. 8 *The quality of the wing in a function of the angle of attack*

The quality of the wing for this type of MAVs at angles of attack close to the balancing one approaches its best (Figure 8).

For MAVs operating at low Reynolds numbers with comparatively small variations in flight velocity, the balancing diagrams give a single value for the deflection angle of the elevator. Then, for the static stability of these aircrafts to the angle of attack, it is judged by Figure 4 and Figure 5. Based on these figures it can be concluded that the aerodynamic focus is behind the center of the gravity, which creates an additional pitching moment, striving to reduce the angle of attack - or the plane is statically stable to the angle of attack.

As the speed increases, the lift force of the investigated aircraft also increases. From there, the plane has a tendency to increase the angle of the trajectory slope and hence decrease its speed. At the expense of this trend, there is an extra pitching moment that seeks to counter the rise in the lift power. It follows that the aircraft is statically stable in speed.

2.2. Stability research of a prototype of the developed MAV in latitudinal direction

The conditions for static stability in the lateral channel are given by the equations [3]:

$$
(3)\quad \begin{bmatrix} \sum F_z = Y_a - G\cos(\vartheta)\cos(\gamma) = 0 \\ \sum M_x = N_x^{\beta}\beta + N_x^{\delta}\delta_e = 0 \\ \sum M_z = N_z^{\beta}\beta + N_z^{\delta}\delta_e = 0 \end{bmatrix},
$$

which conform to the designations accepted in product XFLR5 [4, 5].

The exploration in the environment of the XFLR5 of the MAVs in the horizontal plane of the lateral movement is shown in Figure 9.

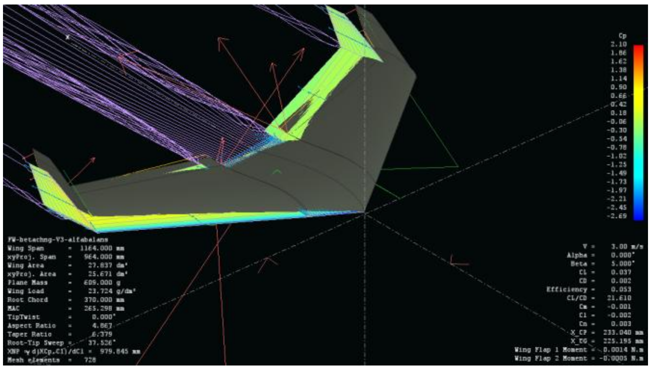

Fig. 9 *Stability research of the developed MAV in lateral direction.*

Consideration type MAVs are balanced in lateral movement only with ailerons. Then for the coefficients of the heading and lateral moment are gotton the following expression:

$$
(4)\quad \begin{bmatrix} m_x^{\beta}\beta + m_x^{\delta}\delta_e = 0 \\ m_z^{\beta}\beta = 0 \end{bmatrix}
$$

When performing a flight with sliding angle, an aerodynamic force are appeared and applaed to the lateral aerodynamic focus. In Figure 10 it is shown the dependence of the lateral force on the sliding angle.

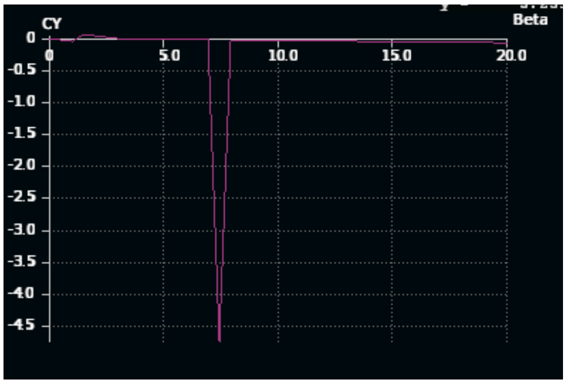

Fig. 10 *Coefficient of the lateral force in a function of the angle of sideslip.*

From Figure 10 it can be seen that, within the limits of the small sliding angles, the lateral force attempts to damping the fluctuation of the nose of the aircraft, but, as the sliding angle rises, this tendency is lost.

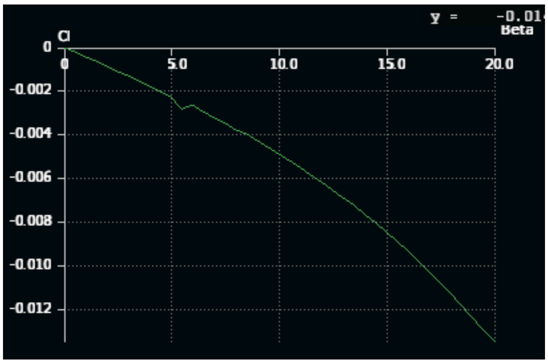

Fig. 11 *Coefficient of the moment of rolling as function of the angle of sideslip.*

As a result of the lateral force, a thrust moment is appeared. Its coefficient is shown in Figure 11 and a lateral torque has a coefficient shown in Figure 12.

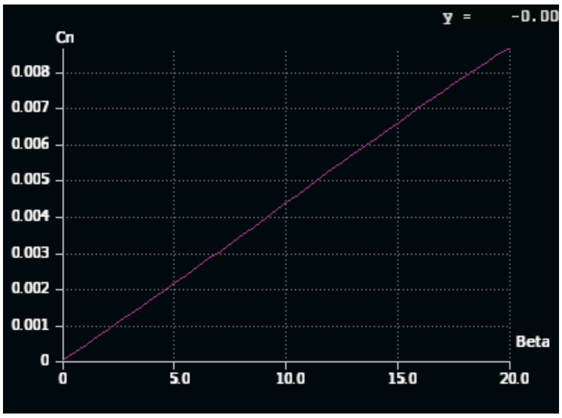

Fig. 12 *Coefficient of the moment of heading as function of the angle of sideslip.*

The rolling moment seeks to roll the plane and heading moment has tendency to remove the sliding.

The displacement of the lateral center of pressure relative to the sliding angle is shown in Figure13.

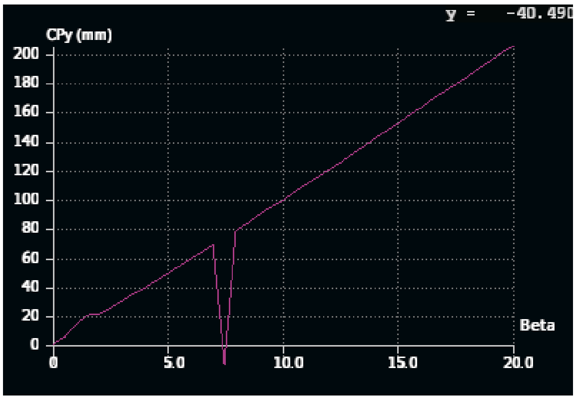

Fig. 13 *Changing position of the point of the pressure in Y-direction*

For static heading stability it is judged from the results in Figure 11. It becomes clear that the center of gravity of the MAV lies in the front of the side aerodynamic focus, which is why the coefficient of the heading moment is negative. Therefore, this MAV is static stable in the heading.

Lateral static stability is established with results shown in Figure 13. In this figure it can be seen that the investigated MAV is statically unstable laterally.

3. Conclusions and results

1. MAV in longitudinal and lateral motion was investigated.

2. In the longitudinal movement MAV is statically stable in velocity and angle of attack.

3. In the lateral movement, studied MAV is statically stable in heading, but it is statically unstable laterally.

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