Aerodynamic modelling currently relates to development of mathematical models to describe the aerodynamic forces and moments acting on the aircraft. It is a challenging part of aerodynamics that defines a comprehensive approach to using traditional methods and modern techniques to obtain relevant data. The most complicated task for the aerodynamics and flight dynamics is definition, computation and quantification of the aerodynamic description of an object. This paper presents how to determine the aerodynamic load on a gyrocopter and defines the effect on its stability and control. The first step to solution is to develop simpler approximate aerodynamic model - a model that can be used in analysis of aerodynamic load and can represent the aerodynamic properties of the gyrocopter with an acceptable degree of accuracy. Control and stability are very important parts of aircraft characteristics and therefore those characteristics were analyzed in simulation. Finally, the aerodynamic data outputs are assessed in terms of impact of aerodynamic loads on stability and control of the gyrocopter model.

Keywords: aerodynamics, stability, gyrocopter, propeller

1 Introduction

An aircraft is a device that, using aerodynamic properties, can perform a flight in the atmosphere. Considering the principle of operation, based on which the flight is performed, aircrafts can be divided into aerostats and aerodynes. In the case of an aerostat, movement relative to the centre is not necessary. It is created in accordance with the Archimedes principle, thanks to which a load-bearing force that balances the weight is created. However, the aerodynamic movement is an indispensable element without which the flight cannot take place. Gyroplane - an aircraft heavier than air (aerodyne), from the rotorcraft family, equipped by a carrying rotor and a propeller (pushing or pulling). The impeller is not driven by the engine but rotates thanks to the autorotation of the rotorcraft relative to the air resulting from the progressive movement of the propeller.

2 State of the art

Aerodynamic characteristics enormously affects the aircraft performance, stability and control. The main concerns of aircraft aerodynamics are reducing drag, reducing noise and improving lift forces on aerodynamic objects. Simulation and model development are providing effective solutions in optimizing lift to drag ratios and impact of aerodynamic loads on the stability and control.

3 Methodology

The gyroplane model is a composite structure with a central steel lattice in which the drive unit will be placed inside. Rotorcraft cabin Aduster is a completely closed, two-seater structure. The system uses the so-called “Inverted V”, which has a stationary part and a movable steering part. The four-point chassis system consists of a main shin hidden and mounted in the tail system of the rear legs of the chassis. The control system is divided according to the three axes of the aircraft (longitudinal axis, transverse axis and normal axis). The control of the rotor system, understood as inclination and tilting, is carried out using a control stick located at each of the two places in
4 Developing of the Aduster model

The aerodynamic tunnel is the basic research device for experimental aerodynamics. The most important part of each aerodynamic tunnel is the area (test chamber) in which the test object or its research model is placed. The tunnel, in addition to the chamber, consists of devices that generate a stream of air flowing around the object under test. The air acts in the same way on the object being examined, as if the object was moving and the air was still. This enables precise measurements of forces and moments, as well as flow visualizations. The tests were carried out in the wind tunnel of the Institute of Aviation in Warsaw [5]. The wind tunnel, test stand has a closed cycle with an open measuring space with a circular cross-section. Inside the open measuring space, a positioning system is installed that allows the model to be made without changing the rotor deflection, but only when the rudder is tilted [5].

The aerodynamic model was made in the 1:8 scale, and the detailed height and length dimensions were given on two views of the technical drawing (Figure 4). The windmill during the tests in the wind tunnel is devoid of propellers and rotor blades. The extension consists of a double vertical stabilizer with rudders and a horizontal stabilizer with height controls. The mast is placed so that the gondola touches the center of gravity of the aircraft. During the experiments different geometric configurations were used, which will be discussed later in the work. The aircraft and model real dimensions included in the table below were used to size forces and moments to the appropriate coefficients.

3.1 The geometrical model

Gyroplane differs from the current designs of rotorcraft companies: CelierAviation, AutoGyro, MagniGyro, ELA Aviation, because of the engine’s location and use of a pulling propulsor instead of a pusher. This project will be characterized by higher performance and less complexity of the engine-propeller system. Due to its highly aerodynamic design, the gyro Aduster is characterized by the low air resistance. The model used during the tests was provided by the ordering party. Figures 1-3 show a side view and a plan view of the gyrocopter concept [4].

The aerodyne model was made in the 1:8 scale, and the detailed height and length dimensions were given on two views of the technical drawing (Figure 4). The windmill during the tests in the wind tunnel is devoid of propellers and rotor blades. The extension consists of a double vertical stabilizer with rudders and a horizontal stabilizer with height controls. The mast is placed so that the gondola touches the center of gravity of the aircraft. During the experiments different geometric configurations were used, which will be discussed later in the work. The aircraft and model real dimensions included in the table below were used to size forces and moments to the appropriate coefficients.
5 Stability and control of the aircraft

Behavior of the aircraft after the impact of the disturbing force on it characterizes these properties of undisturbed aircraft movement, which are known as stability and control.

Table 1 Measurement of impact of weight of the “dynamic tare” model

| Alpha | Beta | Fz  | Fx  | Cx  | Cz  | Cz/Cx |
|-------|------|-----|-----|-----|-----|-------|
| -20   | -10  | -9.4265 | 4.2926 | 0.0091 | -0.0190 | -2.1960 |
| -16   | -10  | -7.0512 | 3.4726 | 0.0073 | -0.0149 | -2.0366 |
| -12   | -10  | -4.1464 | 2.9072 | 0.0061 | -0.0087 | -1.4263 |
| -8    | -10  | -1.2058 | 2.6106 | 0.0055 | -0.0025 | -0.4619 |
| -4    | -10  | 1.9721  | 2.5099 | 0.0052 | 0.0041  | 0.7857  |
| -2    | -10  | 3.5317  | 2.5703 | 0.0054 | 0.0074  | 1.3741  |
| 0     | -10  | 5.3060  | 2.6047 | 0.0054 | 0.0110  | 2.0371  |
| 2     | -10  | 6.2942  | 2.8810 | 0.0060 | 0.0131  | 2.1847  |
| 4     | -10  | 7.4409  | 3.3082 | 0.0071 | 0.0155  | 2.1896  |
| 8     | -10  | 8.2456  | 4.4648 | 0.0093 | 0.0171  | 1.8468  |
| 12    | -10  | 9.1373  | 5.4436 | 0.0113 | 0.0189  | 1.6786  |
| 16    | -10  | 10.007  | 6.4279 | 0.0133 | 0.0207  | 1.5558  |
| 20    | -10  | 11.0049 | 7.5209 | 0.0156 | 0.0229  | 1.4621  |
| -20   | 0    | -8.97146| 3.685696| 0.0091 | -0.0190 | -2.1960 |
| -16   | 0    | -6.6635| 2.923756| 0.0060 | -0.0135 | -1.98589|
| -12   | 0    | -3.75749| 2.48963| 0.0051 | -0.00775| -1.6026 |
| -8    | 0    | -0.4951| 2.212088| 0.0045 | -0.00092| -0.2032 |
| -4    | 0    | 2.878314| 2.80728 | 0.0054 | 0.0155 | 1.372372|
| -2    | 0    | 4.554367| 2.137357| 0.0048 | 0.0093 | 2.130841|
| 0     | 0    | 5.333  | 2.159 | 0.0044 | 0.012163| 2.748031|
| 2     | 0    | 7.06612| 2.241016| 0.0045 | 0.014543| 3.166471|
| 4     | 0    | 8.20449| 2.687864| 0.0055 | 0.016823| 3.05242|
| 8     | 0    | 9.11206| 3.791049| 0.0079 | 0.018726| 2.403574|
| 12    | 0    | 9.404429| 4.595181| 0.0094 | 0.019445| 2.056942|
| 16    | 0    | 9.97885| 5.176055| 0.0106 | 0.020688| 1.927887|
| 20    | 0    | 10.99508| 6.601065| 0.0124 | 0.023612| 1.81405|
| -20   | 10   | -9.28013| 4.420572| 0.0090 | -0.01904| -2.0993 |
| -16   | 10   | -7.00537| 3.527572| 0.0072 | -0.01436| -1.968589|
| -12   | 10   | -3.87517| 2.956275| 0.0060 | -0.00793| -1.31349|
| -8    | 10   | -0.79507| 2.631817| 0.0053 | -0.00163| -0.3021 |
| -4    | 10   | 2.349215| 2.458541| 0.0050 | 0.004892| 0.955532|
| -2    | 10   | 3.805268| 2.491261| 0.0051 | 0.007801| 1.527447|
| 0     | 10   | 5.824576| 2.63808 | 0.0054 | 0.013137| 2.065427|
| 2     | 10   | 7.059068| 2.852268| 0.0058 | 0.014447| 2.475107|
| 4     | 10   | 8.524265| 3.373581| 0.0090 | 0.017433| 2.529202|
| 8     | 10   | 9.406529| 4.544006| 0.0093 | 0.019288| 2.060868|
| 12    | 10   | 10.01453| 5.515316| 0.0113 | 0.020565| 1.815766|
| 16    | 10   | 10.55115| 6.463266| 0.0133 | 0.02177 | 1.632479|
| 20    | 10   | 11.67543| 7.555151| 0.0157 | 0.024071| 1.54536 |

Measuring space dimensions: D = 1.2 m, L = 1.5 m.
Dimension from the PP inlet to the axle: l = 0.443 m
Air speed: up to 40 m / s
Angle ranges: \( \alpha \in <-30; 25> \) and \( \beta \in <-25; 25> \)
Figure 5 Aerodynamic coefficients power of lift obtained during the measurements for the slip angle $\beta = 10^\circ$

Figure 6 Aerodynamic coefficients power of lift obtained during the measurements for the slip angle $\beta = 0^\circ$

Figure 7 Aerodynamic coefficients power of lift obtained during the measurements for the slip angle $\beta = -10^\circ$

Figure 8 Aerodynamic coefficients power of drag obtained during the measurements for the slip angle $\beta = 10^\circ$

Figure 9 Aerodynamic coefficients power of drag obtained during the measurements for the slip angle $\beta = 0^\circ$

Figure 10 Aerodynamic coefficients power of drag obtained during the measurements for the slip angle $\beta = -10^\circ$

Figure 11 Aerodynamic coefficients obtained during the measurements for the slip angle $\beta = 10^\circ$

Figure 12 Aerodynamic coefficients obtained during the measurements for the slip angle $\beta = 0^\circ$
When talking about stability, it is assumed that there is a balance, otherwise the notion of stability would not make sense. The static stability of an aircraft is called its ability to return independently (without the participation of the pilot) to the position of equilibrium, when the causes that break this balance cease to function. The dynamic stability, on the other hand, determines the type of movements that an airplane performs by returning to the equilibrium position (e.g. number, amplitude and time of deflections). The issues of static and dynamic stability are closely and inseparably connected, however, for the plane to be dynamically stable, it must be static [9]. The plane's stability with respect to the y axis is called longitudinal stability; it is secured by height. The stability with respect to the x and z axes, provided by the sash lift and the direction, is called the lateral and directional, respectively, but they are considered jointly as the lateral stability, since they are closely related to each other. These properties of undisturbed aircraft movement are known as stability and instability. The necessary condition for the aircraft to move is not only the balance of all the forces acting on the aircraft, but also the balance of moments relative to the three coordinate axes (x, y, z) passing through its center of gravity. The aircraft's balance should be stable, that is, the aircraft derived from the equilibrium by some external factor, such as a blast, should return to the state of balance in a sufficiently short time without the intervention of the pilot (at least when the disturbance was not too high). The concepts of stability and balance are therefore closely related [10].

6 The simulation assessment

Preparatory activities, related to assembly of the model were carried out in the following stages. The model was delivered in elements made of FDM 3D printing. The elements required matching, assembly and finishing. The activities were carried out: matching of elements and introduction of elements strengthening the internal structure and elements ensuring surface compatibility; assembly and gluing of the model; sanding and painting the external surface of the model to ensure smoothness [11].

The measurement series listed in Table 1 were implemented in the predefined positions of the model using the so-called grid of points in the space of angles. Measurement of individual measurement series was performed according to the procedure: measurement of the tare reference signal; before each measurement series, a reference signal was measured corresponding to signals in the unladen system; the measured signal is subtracted later in the measuring series from the measured signal.

Measurement of impact of the weight of the "dynamic tare" model. At each configuration, a signal measurement of forces acting on the measurement system was carried out at the changing setting of the model without aerodynamic interactions. In this measurement, impact of the weight of the model is determined at changing angles of the model's positioning. With the model placed in the measurement system in the horizontal position of the orientation of its symmetry plane, the gravity of the model mainly acts in the OY axis direction of the model, i.e. on the C measurement component. When the angle of the slide changes, gravity force affects the OX direction of the model, i.e. the X measurement component [12].

In this section, graphs of the Advent gyroplane characteristics are presented for selected angles of attack in relation to the slip angles. The research was carried out in several geometrical configurations. Values of selected aerodynamic coefficients, obtained during the measurements, are presented in the characteristics' graphs (see Figures 5-13). The characteristics in red are for the slip...
angle $\beta = 10^\circ$, the blue ones correspond to the zero-slip angle and the yellow ones are $\beta = -10^\circ$.

7 Conclusions

In this project the study about the aerodynamic characteristics of the aircraft - the Aduster gyroplane was dealt with. The purpose of the paper was to assess the impact of aerodynamic loads on the stability and control of the gyroplane model at various geometric configurations [13].

The graphs presenting $C_z = f(\alpha)$ (see Figures 5-7) are similar in shape to the characteristics in literature. There are minimal changes in the graphs under the influence of different slip angle. Characteristics of the drag coefficient as a function of the angle of attack $C_x = f(\alpha)$ is similar in shape to the characteristics in literature - there is induced resistance. In the case of angle of attack equal zero, $C_x$ is the smallest (Figure 9). For the slip angle -10$^\circ$ $C_x$ is bigger (Figure 10), and for the slip angle 10$^\circ$ $C_x$ is the largest (Figure 8), but the difference is not so big. The polar profile - Lilienthal’s Curve $C_z = f(C_x)$ is similar in shape to characteristics in the literature. On the polar airfoil one can notice a small outline of the laminar profile, which has better properties for a range of small angles of attack (low value of the lift force). For the slip angle equal zero (Figure 12) the range of $C_x$ values is the smallest, and in the case of slip angles different than zero there is a greater spread of graphs in relation to $C_z$, which indicates a higher coefficient of lift. Characteristics of airfoil attitude

Cz/Cx in the case of a zero-slip angle as a function of the angle of attack is similar in shape to the characteristics in the literature. In the case of a slip angle of 10$^\circ$, -10$^\circ$, the diagrams have a smaller spread. The characteristics of the moment coefficient as a function of the angle of attack $M_z = f(\alpha)$ indicates the zero value of the moment coefficient as a function of the angle of attack for the graph showing the negative slip angle. The graph for the value of the slip angle equal zero assumes the smallest span of values. In the case of the slip angle 10$^\circ$ the moment coefficient takes positive values (Figure 13) and in the case of the slip angle -10$^\circ$ the moment coefficient takes negative values (Figure 11).

Comparing individual graphs for given slip angles, one can notice slight differences between the angle of attack equal zero and its limit values. Having that considered and with the use of appropriate mathematical formulas, one can calculate the drag forces or the lifting force for the entire structure. The obtained result also illustrates how much one would have to increase other parameters, e.g. flight speed, to maintain the horizontal flight conditions.

Acknowledgements

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

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