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Experimental Determination of the Effect of Floats on Aerodynamic Characteristics of the "OSA" Aircraft in Asymmetric Flow

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Abstract. This study provides the results of experimental tests of the effect of floats on the aerodynamic characteristics of the "OSA" plane in an asymmetric flow. The tests were carried out in a low-speed wind tunnel owned by Institute of Aviation Technology, Faculty of Mechatronics, Armament and Aerospace (FMAA), Military University of Technology (MUT, Warsaw, Poland). The model of "OSA" was tested at dynamic pressure q = 500 Pa within the range of slip angles β = -28°÷28°. The tests were carried out for the plane model in the so-called "plain" configuration, i.e. at non-deflected control surfaces and wing mechanisation elements. The model was tested in two variants – with floats and without floats. The effect of deflection of the flaps, ailerons and rudder on the aerodynamic characteristics of the test model was also examined. The obtained values of drag coefficient, lateral force coefficient and yawing moment coefficient are presented in the form of tables and graphs.

The tests showed that the floats had a significant impact on the curves of the characteristics. They result in a considerable increase of the value of the drag coefficient and in a deterioration of weathercock stability.
Keywords: mechanical engineering, aerodynamic characteristics, wind tunnel, plane model flow

1. INTRODUCTION

Planes equipped with floats are called hydroplanes. Their design allows them to take off and land on the surface of the water. Two main types of hydroplanes can be distinguished [12]:

- flying boats;
- seaplanes.

In flying boats, their main float gear is the fuselage having direct contact with the water surface. In these planes, smaller floats are usually mounted at the tips of the wings to stabilise the fuselage on the water. The design of seaplanes is similar to the design of a conventional plane, but their float gear is substituted with separate floats. Usually two floats are used. In these designs, the fuselage is located high above the water surface [12].

In the case of hydroplanes, an important design-related issue to be solved is to design the floats in a proper manner. They transfer very high loads, particularly during landing [5], [7], [11]. The literature contains many examples of useful data concerning the engineering design of hydroplanes [5], floats [13], and information on proper installation of the floats and their inspection before take-off [12]. It is difficult, however, to find details on the direct impact of the floats on the aerodynamic characteristics of the planes, in particular on comparison of the aerodynamic characteristics of the planes with floats and without floats. This is why this article is provided with a comparison of the aerodynamic characteristics of the "OSA" with and without floats.

This study also contains the results of experimental tests of the impact of floats on the aerodynamic characteristics of the "OSA" in asymmetric flow, being the continuation of the tests the results of which are published in [9]. The experimental aerodynamic tests were carried out in the Aerodynamics Laboratory of Institute of Aviation Technology MUT in a low-speed wind tunnel with a test section diameter D = 1.1 m, provided with a type IAW aerodynamic balance by prof. Witoszyński

The plane's motion under the influence of lateral force P_y, yawing moment N and rolling moment L is called lateral motion, and stability and manoeuvrability in this motion are lateral stability and lateral manoeuvrability, respectively. The term "lateral motion" includes the plane's displacement towards axis Oy (lateral displacement) and its rotation around axes Ox and Oz [1]. Designations of control surface deflections and force and moment directions are presented in Figure 1.

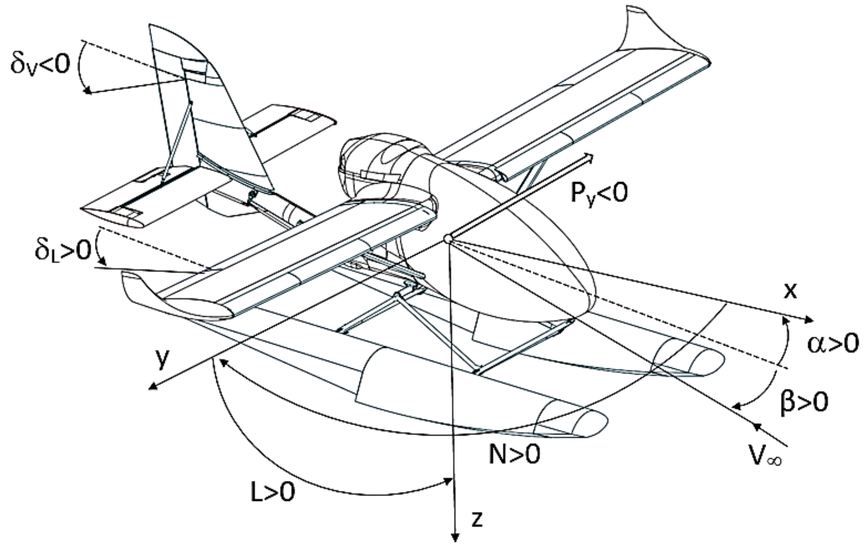

Fig. 1. Designations of control surface deflections and force and moment directions.

The "OSA" is a light plane (with a take-off mass up to 750 kg) built as part of the execution of a scientific and research project entitled: "*Development of design and construction of a demonstrator of an ultra-light plane as a network-centric element of the intelligence and command support system*". Under this task, a STOL plane demonstrator was designed and constructed. The main guidelines for the engineering design were highly specialised tasks established for the new product by potential recipients, namely the Police, the Territorial Defence Troops and other services that may use this plane for patrolling and monitoring. The designed plane should be characterised by:

- excellent visibility from the cockpit;
- high manoeuvrability;
- low stalling speed;
- short take-off run and landing run;
- possibility of using grass airfields;
- low fuel consumption.

The results of the tests of aerodynamic characteristics of this plane can be found for instance in [3] and [4]. The engineering design process description for a plane with floats can be found e.g. in [6].

When designing the "OSA", a traditional wheel undercarriage with a controlled front wheel was provided. To increase its usage capabilities, it was decided to equip the plane with floats and test their impact on its aerodynamic characteristics during asymmetric flight.

For this purpose, a 1:10 scale model of the plane was constructed in the Aircraft Construction and Operation Department of Institute of Aviation Technology FMAA MUT using state-of-the-art numerical surface shaping and mapping techniques. A photograph of the plane with floats, suspended in the tunnel's test section for asymmetric flow testing, is presented in Photo no. 1.

Photo 1. The "OSA" with floats installed, suspended in the wind tunnel test section.

The methodology and the programme of performing the aerodynamic characteristics calculations were developed on the basis of [2], [8] and [10].

The plane model was suspended in the wind tunnel test section, so that the axis of yawing moment of the aerodynamic balance crossed the point corresponding to the plane's centre of mass x_Q = 180 mm from the plane model's nose, and the model's longitudinal axis coincided with the balance's axis of drag force. The test model was equipped with 0.534 m long and 0.083 m wide floats. The surface area of projection of the floats to a horizontal plane was 0.037 m^2, and to a vertical plane – 0.025 m^2. The centre of mass of actual floats would be located at 40% of their length.

The tests were carried out for the model in the so-called "plain" configuration, i.e. with non-deflected control surfaces and wing mechanisation elements. Additionally, the impact of the floats on the aerodynamic characteristics of the model with flaps deflected at an angle of $\delta_{fl} = 21^o$ and $\delta_{fl} = 44^o$, with ailerons deflected at an angle of $\delta_a = +5^o\ -5^o$, $\delta_a = +10^o\ -10^o$, $\delta_a = +15^o\ -20^o$ (angle of deflection of right, left aileron, respectively), and at the rudder deflected at an angle of $\delta_V = 10^o$, $\delta_V = 20^o$, $\delta_V = 28^o$.

Positive angles of deflection of the control surfaces were assumed as angles causing negative moments, i.e. positive deflection of the ailerons: right aileron down, left aileron up, whereas positive deflection of the rudder is when the rudder is deflected to the left (Fig. 1).

The results of the tests were presented in the form of graphs illustrating the curves of the basic aerodynamic characteristics, such as:

a) $C_d = f(\beta)$ – drag coefficient as a function of slip angle β;

b) $C_y = f(\beta)$ – lateral force coefficient as a function of slip angle β;

c) $C_n = f(\beta)$ – yawing moment coefficient as a function of slip angle β.

The tests of the "OSA" were carried out at dynamic pressure q = 500 Pa ($V \approx$ 30 m/s), which corresponded to Reynolds number $Re \approx$ 210000 within the slip angle range β = -28°÷28° with an increment of 2°. Aerodynamic coefficients for asymmetric flow were referred to the surface area of the model's wing S = 0.108 m^2 and its wingspan L = 0.9 m. The value of the yawing moment coefficient was determined for a point corresponding to the plane's centre of mass – x_Q = 180 mm from the plane model's nose. The plane model's length with floats was 0.634 m. Aerodynamic characteristics obtained from the experimental tests were converted using the corrections described in [2] and using the ratio of the model's span to the diameter of the L/D stream, which amounted to 0.82.

2. IMPACT OF FLOATS ON AERODYNAMIC CHARACTERISTICS OF THE MODEL IN "PLAIN" CONFIGURATION WITH DEFLECTED FLAPS

The tests of the impact of floats on the aerodynamic characteristics in asymmetric flow for the "OSA" in the "plain" configuration and at two flap deflection angles were carried out for the conditions specified in section 1. Measurements of the forces acting on the model were carried out using two strain gauges enabling for measurements with an accuracy of ±0.01 N. The value of dynamic pressure was read from a pressure transmitter with an accuracy of ±1 Pa.

Drag coefficient $C_d = f(\beta, \delta_{fl})$

The impact of the floats on the curves of the drag coefficient characteristics for the plane model in the plain configuration ($\delta_{fl} = 0^o$) and in two flap deflections $\delta_{fl} = 21^o$ and $\delta_{fl} = 44^o$ is presented in Figure 2. Important numerical data concerning the curves of the characteristics are provided in Table 1.

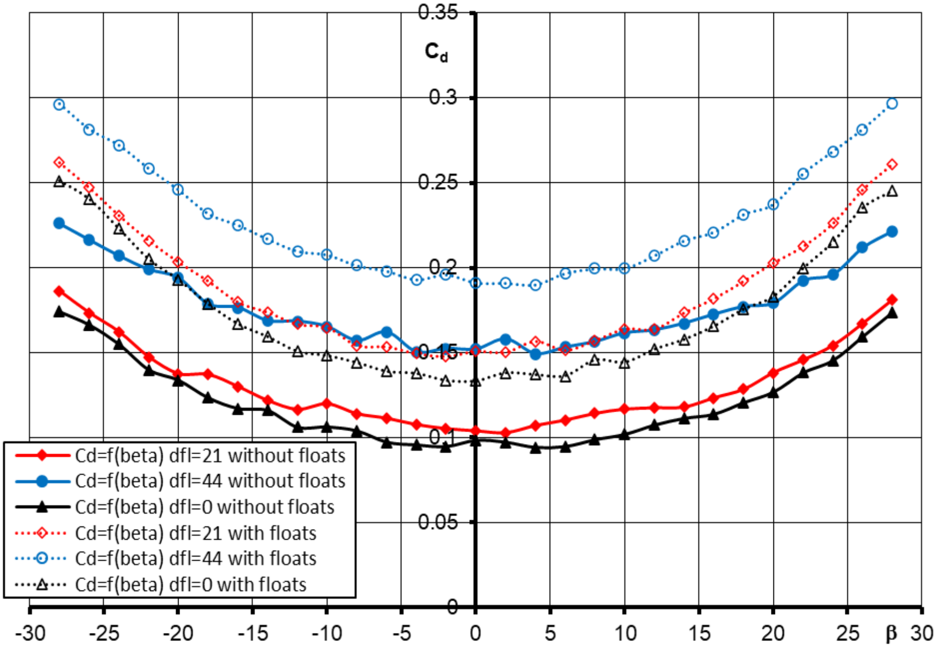

Fig. 2. Characteristics C_d = f(β) for different flap deflection angles

Table 1. Important numerical data

	model without floats			model with floats		
δ_{fl} °	0	21	44	0	21	44
β^o ($C_{d\ min}$)	-2	2	4	0	-2	4
$C_{d\ min}$	0.09	0.10	0.15	0.13	0.15	0.19
$C_d(\beta = -28^o)$	0.17	0.19	0.23	0.25	0.26	0.30
$C_d(\beta = 28^o)$	0.17	0.18	0.22	0.25	0.26	0.30

where:

β^o ($C_{d\ min}$) – value of slip angle corresponding to the minimum value of drag coefficient.

The curves of drag coefficient C_d as a function of slip angle β are parabolic in the entire range of angles under consideration. It can also be claimed that the characteristics are symmetric with respect to the axis of ordinates – axis C_d. Based on the above characteristics, it can be stated that the presence of floats has a large impact on the value of the drag coefficient. Irrespective of the flap deflection angle, the presence of floats results in an increase of the minimum value of drag coefficient by a fixed value amounting to approximately 0.04.

With the increase of the slip angle, the increase of the drag coefficient caused by the presence of floats is higher and amounts to approximately 0.08 for slip angles $\beta = \pm 28^0$, irrespective of the value of the flap deflection angle.

Lateral force coefficient C_y = f(β, δ_{fl})

The impact of the floats on the curves of the lateral force coefficient characteristics for the plane model in the plain configuration ($\delta_{fl} = 0^o$) and at two flap deflections $\delta_{fl} = 21^o$ and $\delta_{fl} = 44^o$ is presented in Figure 3. Important numerical data concerning the curves of the characteristics are provided in Table 2.

The curves of lateral force coefficients C_y as a function of the slip angle β are approximately linear in the entire range of angles under consideration, and their inclination is negative ($\frac{\partial C_y}{\partial \beta} < 0$). Based on the presented characteristics, it can be clearly seen that the presence of floats results in an increase of derivative $\frac{\partial C_y}{\partial \beta}$ (slope of the characteristics of the lateral force coefficients). It can also be concluded that in both cases, the model with floats and the model without floats, only the deflection of the flaps at an angle of $\delta_{fl} = 44^o$ has a significant impact on the curve of lateral force coefficients as a function of slip angle. It can also be claimed that the presented characteristics are symmetric with respect to the origin of the coordinate system.

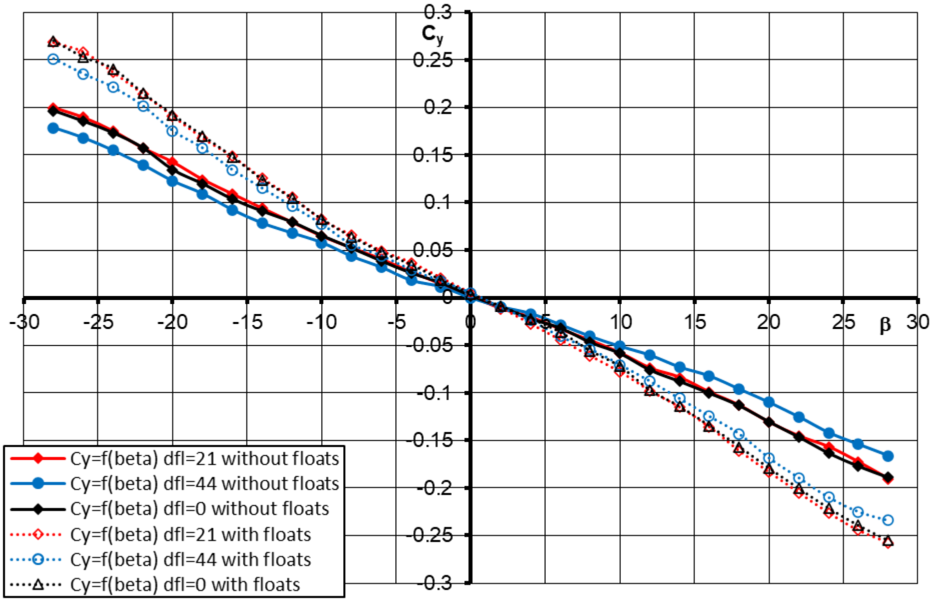

Fig. 3. Characteristics C_y = f(β) for different flap deflection angles.

Table 2. Important numerical data

	model without floats			model with floats		
$\delta_{fl}{}^{o}$	0	21	44	0	21	44
$C_y(\beta = -28^o)$	0.20	0.20	0.18	0.27	0.27	0.25
$C_y(\beta = 0^o)$	0.00	0.00	0.00	0.00	0.00	0.00
$C_y(\beta = 28^o)$	-0.19	-0.19	-0.23	-0.26	-0.26	-0.23

Yawing moment coefficient $C_n = f(\beta, \delta_{fl})$

The curves of yawing moment coefficient characteristics for the "OSA" model in the plain configuration ($\delta_{fl} = 0^o$) and at two flap deflections $\delta_{fl} = 21^o$ and $\delta_{fl} = 44^o$ are presented in Figure 4.

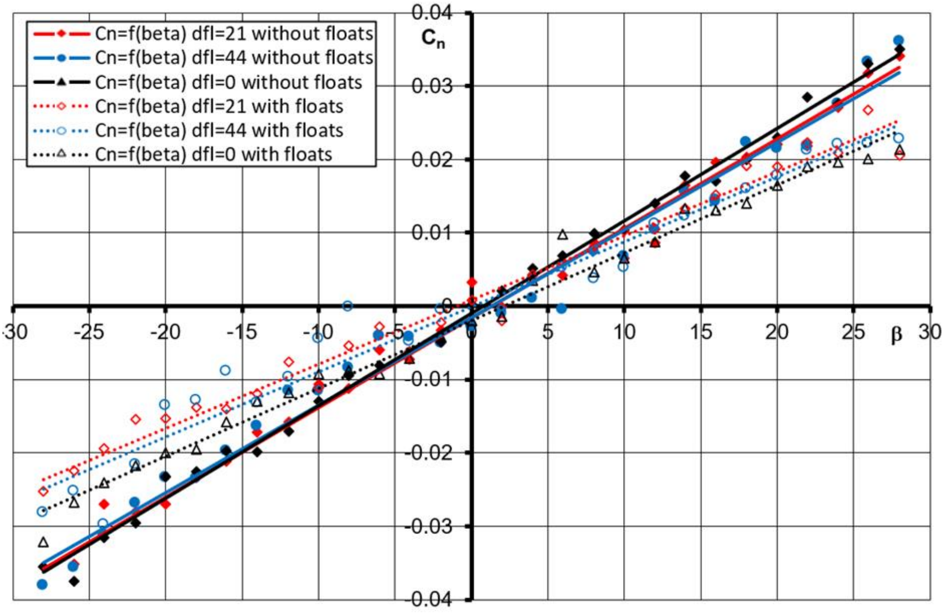

Fig. 4. Characteristics $C_n = f(\beta)$ for different flap deflection angles.

Table 3. Important numerical data

	model without floats			model with floats		
$\delta_{fl}{}^{o}$	0	21	44	0	21	44
$C_n(\beta = -28^o)$	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03
$C_n(\beta = 0^o)$	0.00	0.00	0.00	0.00	0.00	0.00
$C_n(\beta = 28^o)$	0.04	0.03	0.04	0.02	0.02	0.02

Important numerical data concerning the curves of the characteristics are provided in Table 3.

Based on the obtained characteristics, it can be claimed that both the model with floats and the model without floats have weathercock stability in the entire slip angle range under consideration. This is indicated by the sign of the derivative $\frac{\partial C_n}{\partial \beta} = f(\delta_{fl})$ – it is positive for the entire range of slip angles under consideration ($\frac{\partial C_n}{\partial \beta} > 0$). At the same, it can be seen that the floats cause a slight decrease of the value of the derivative $\frac{\partial C_n}{\partial \beta} = f(\delta_{fl})$, which in turn results in a deterioration of weathercock stability. Analysing the characteristics presented in Figure 4, it can also be claimed that the impact of the flap deflection on the curve of the yawing moment coefficient is small.

3. IMPACT OF FLOATS ON AERODYNAMIC CHARACTERISTICS OF THE MODEL IN THE "PLAIN" CONFIGURATION WITH DEFLECTED AILERONS

The impact of the floats on the aerodynamic characteristics in asymmetric flow with deflected ailerons was tested at dynamic pressure q = 500 Pa ($V \approx 30$ m/s), which corresponded to Reynolds number $Re \approx 210000$ within the slip angle range β = -28°÷28° with an increment of 2°. The ailerons were deflected at the following angles: δ_a = +5°; -5°, δ_a = +10°; -10°, δ_a = +15°; -20° (angle of deflection of left, right aileron, respectively). Positive angles of deflection of ailerons were assumed as angles causing a negative yawing moment, i.e. right aileron down, left aileron up.

Drag coefficient $C_d = f(\beta, \delta_a)$

The impact of the floats on the curves of the drag coefficient characteristics for the plane model in the plain configuration (δ_a = 0°) and at fixed aileron deflections is presented in Figure 5. Important numerical data concerning the curves of the characteristics are provided in Table 4.

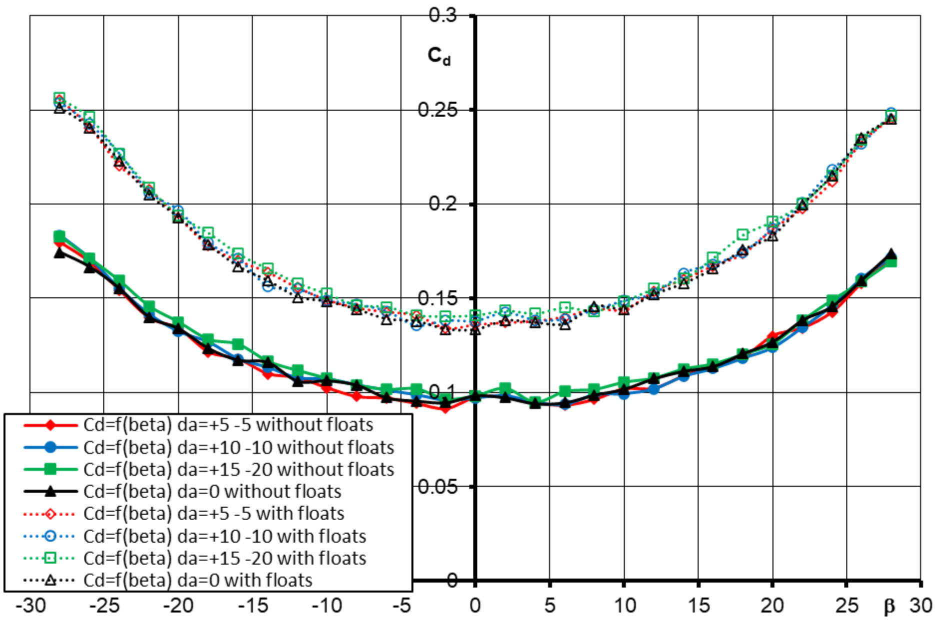

Fig. 5. Characteristics $C_d = f(\beta)$ for different aileron deflection angles.

Table 4. Important numerical data

	model without floats				model with floats			
$\delta_a{}^o$	0	+5 -5	+10 -10	+15 -20	0	+5 -5	+10 -10	+15 -20
β^o ($C_{d\ min}$)	-2	-2	6	4	0	-2	-4	-2
$C_{d\ min}$	0.09	0.09	0.09	0.09	0.13	0.13	0.14	0.14
$C_d(\beta = -28^o)$	0.17	0.18	0.18	0.18	0.26	0.26	0.26	0.25
$C_d(\beta = 28^o)$	0.17	0.17	0.17	0.17	0.25	0.25	0.25	0.25

where:

β^o ($C_{d\ min}$) – value of the slip angle corresponding to the minimum value of the drag coefficient.

The curves of drag coefficient $C_d = (\beta, \delta_a)$ are parabolic in the entire range of slip angles under consideration. Based on the presented characteristics, it can be claimed that aileron deflection has a slight impact on the increase of the plane's drag coefficient in both configurations. In this case, it can also be stated that irrespective of the aileron deflection angle, the presence of floats results in an increase of the minimum value of the drag coefficient by a fixed value amounting to approximately 0.04. With the increase of the slip angle, the increase of the drag coefficient caused by the presence of the floats is higher and amounts to approximately 0.08 for slip angles $\beta = \pm 28^0$, irrespective of the value of the aileron deflection angle.

Lateral force coefficient $C_y = f(\beta, \delta_a)$

The impact of the floats on the curves of the lateral force coefficient characteristics for the plane model in the plain configuration ($\delta_a = 0^o$) and at fixed aileron deflections are presented in Figure 6, while important numerical data concerning the curves of the characteristics are provided in Table 5.

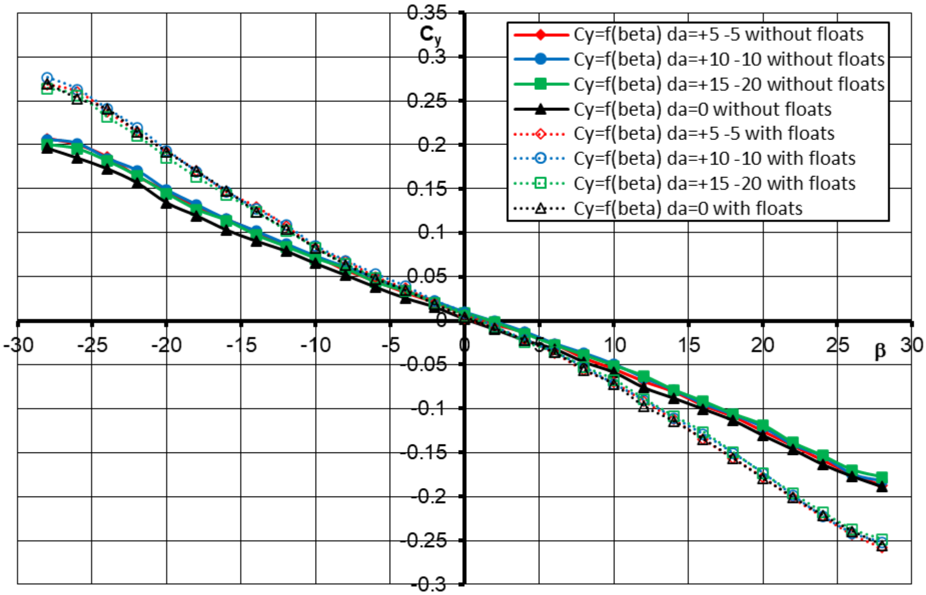

Fig. 6. Characteristics $C_y = f(\beta)$ for different aileron deflection angles

Table 5. Important numerical data

	model without floats				model with floats			
δ_a^o	0	+5 -5	+10 -10	+15 -20	0	+5 -5	+10 -10	+15 -20
$C_y(\beta = -28^o)$	0.20	0.20	0.18	0.20	0.27	0.27	0.28	0.26
$C_y(\beta = 0^o)$	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
$C_y(\beta = 28^o)$	-0.19	-0.19	-0.18	-0.18	-0.26	-0.26	-0.25	-0.25

Based on the presented characteristics of the lateral force coefficient as a function of the slip angle for different aileron deflection angles, it can be stated the aileron deflection has negligible impact on the value of the lateral force coefficient in both plane model configurations. In this case, it can also be claimed that the characteristics are symmetric with respect to the origin of the coordinate system.

Yawing moment coefficient C_n = f(β, δ_a)

Characteristics of the yawing moment of the "OSA" model in the "plain" configuration and at fixed aileron deflections are presented in Figure 7. Important numerical data concerning the curves of the characteristics are provided in Table 6.

Based on the presented characteristics, it is stated that aileron deflection causes a decrease in the value of the yawing moment coefficient, which is particularly visible for the range of high slip angles β<-10 and β> 10. Changes in the values of C_n at aileron deflection are more visible in the model with floats. For the model with floats, aileron deflection causes an increase in the value of the derivative $\frac{\partial C_n}{\partial \beta} = f(\delta_a)$ with respect to the value of the derivative $\frac{\partial C_n}{\partial \beta} = f(\delta_a)$ for the plain configuration.

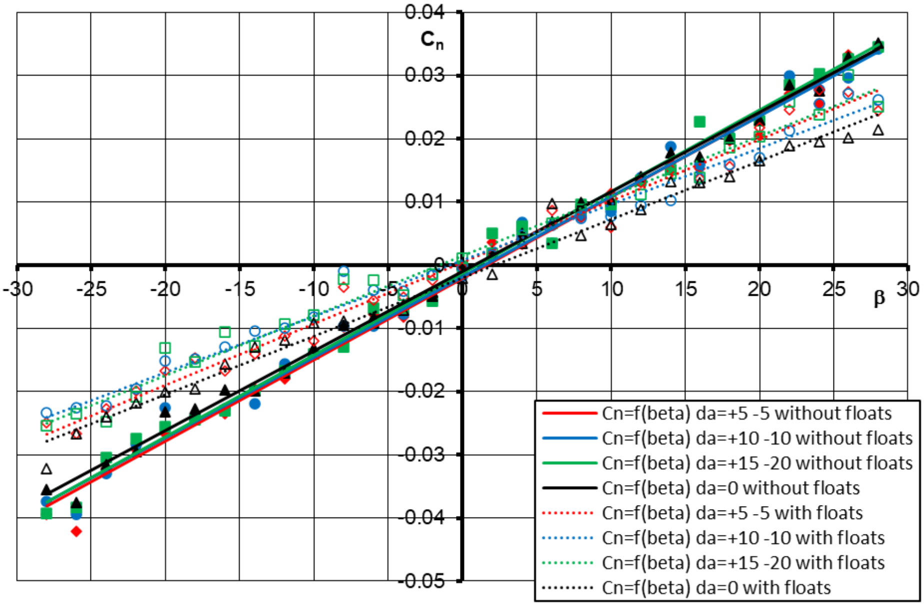

Fig. 7. Characteristics C_n = f(β) for different aileron deflection angles

Table 6. Important numerical data

	model without floats				model with floats			
δ_a°	0	+5 -5	+10 -10	+15 -20	0	+5 -5	+10 -10	+15 -20
$C_n(\beta = -28°)$	-0.04	-0.04	-0.04	-0.04	-0.03	-0.02	-0.02	-0.03
$C_n(\beta = 0°)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$C_n(\beta = 28°)$	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.03

4. IMPACT OF FLOATS ON THE AERODYNAMIC CHARACTERISTICS OF THE MODEL IN "PLAIN" CONFIGURATION WITH DEFLECTED RUDDER

The test of the impact of the floats on the aerodynamic characteristics in asymmetric flow with a deflected rudder were carried out at dynamic pressure q = 500 Pa ($V \approx$ 30 m/s), which corresponded to Reynolds number $Re \approx$ 210000 within the slip angle range β = -28°÷28° with an increment of 2°. The rudder was deflected at the following angles: $\delta_V = 10^o$, $\delta_V = 20^o$, $\delta_V = 28^o$. A positive angle of deflection of the rudder was assumed as an angle causing a negative yawing moment, i.e. the rudder is deflected to the left.

Drag coefficient C_d = f(β, δ_V)

The impact of the floats on the curves of the drag coefficient characteristics for the plane model in the plain configuration ($\delta_V = 0^o$) and at fixed rudder deflections is presented in Figure 8. Important numerical data concerning the curves of the characteristics are provided in Table 7.

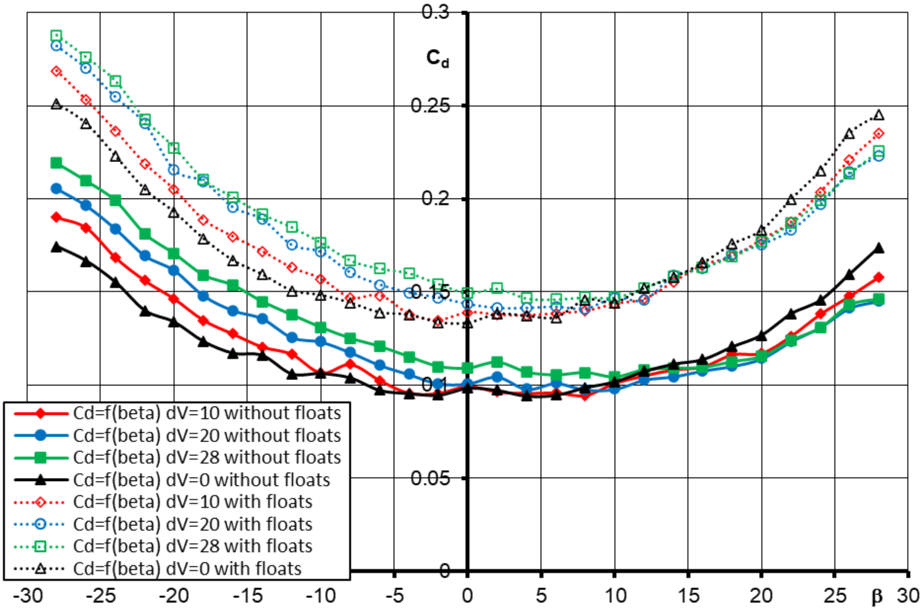

Fig. 8. Characteristics C_d = f(β) for different rudder deflection angles

Based on the presented characteristics, it is clearly seen that the rudder's deflection has a significant impact on the value of the drag coefficient, which is particularly visible within the range of negative slip angles. If the slip angle value $\beta = 10^o$ is exceeded, the values of the drag coefficients at the deflected rudder begin to be lower with respect to the "plain" configuration for both "OSA" models – with and without floats.

It can also be noted that the rudder's deflection has large impact on the asymmetric character of the characteristics. In this case, it can also be stated that irrespective of the rudder deflection angle, the presence of the floats results in an increase of the minimum value of the drag coefficient by a fixed value amounting to approximately 0.04. With the increase of the slip angle, the increase of the drag coefficient caused by the presence of the floats is higher and amounts to approximately 0.08 for slip angles $\beta = \pm 28^0$, irrespective of the value of the aileron deflection angle

Table 7. Important numerical data

	model without floats				model with floats			
$\delta_V{}^o$	0	10	20	28	0	10	20	28
β^o ($C_{d\ min}$)	-2	8	10	10	0	-2	8	10
$C_{d\ min}$	0.09	0.09	0.10	0.10	0.13	0.13	0.14	0.15
$C_d(\beta = -28^o)$	0.17	0.19	0.21	0.22	0.26	0.27	0.28	0.29
$C_d(\beta = 28^o)$	0.17	0.16	0.15	0.15	0.25	0.24	0.22	0.23

where:

β^o ($C_{d\ min}$) – value of the slip angle corresponding to the minimum value of the drag coefficient.

Lateral force coefficient $C_y = f(\beta, \delta_V)$

The impact of the floats on the curves of the lateral force coefficient characteristics for the plane model in the plain configuration ($\delta_V = 0^o$) and at fixed rudder deflection angles is presented in Figure 9. Important numerical data concerning the curves of the characteristics are provided in Table 8.

Based on the presented curves $C_y = f(\beta, \delta_V)$**,** it can be clearly seen that the rudder's deflection causes shifting of the characteristics towards higher values of the lateral force coefficient – "up". For a slip angle of $\beta = 0^o$, the rudder's deflection at an angle of $\delta_V = 28^o$ caused an increase in the value of the lateral force coefficient by 0.07 with respect to the "plain" configuration for both models – with and without floats

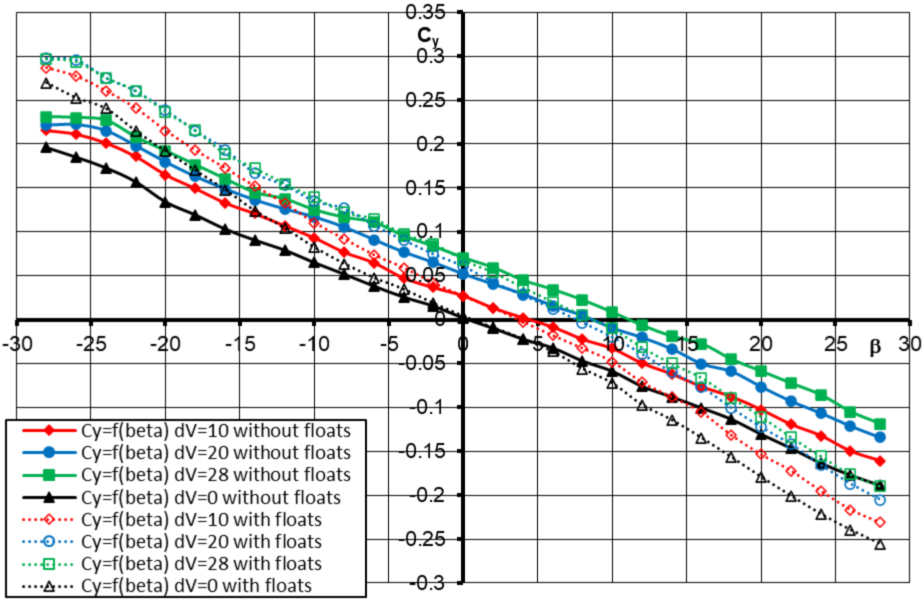

Fig. 9. Characteristics C_y = f(β) for different rudder deflection angles

Table 8. Important numerical data

	model without floats				model with floats			
δ_V°	0	10	20	28	0	10	20	28
$C_y(\beta = -28°)$	0.20	0.22	0.22	0.23	0.27	0.29	0.30	0.30
$C_y(\beta = 0°)$	0.00	0.03	0.05	0.07	0.00	0.03	0.06	0.07
$C_y(\beta = 28°)$	-0.19	-0.16	-0.13	-0.12	-0.26	-0.23	-0.21	-0.19

Yawing moment coefficient C_n = f(β, δ_V)

The impact of the floats on the curves of the yawing moment coefficient characteristics for the plane model in the plain configuration (δ_V = 0°) and at fixed rudder deflection angles is presented in Figure 10. Important numerical data concerning the curves of the characteristics are provided in Table 9.

Based on the presented curves C_n = f(β, δ_V), it can be clearly seen that the rudder's deflection to positive values causes shifting of the characteristics towards lower values of the yawing moment coefficient – down. For a slip angle of β = 0°, the rudder's deflection at an angle of δ_V = 28° caused a decrease in the value of the yawing moment coefficient by 0.03 with respect to the "plain" configuration for the model without floats.

What is more, the presence of the floats caused a slight decrease in the value of the derivative $\frac{\partial C_n}{\partial \beta} = f(\delta_{fl})$ irrespective of the rudder's angle of deflection, which results in a deterioration of weathercock stability.

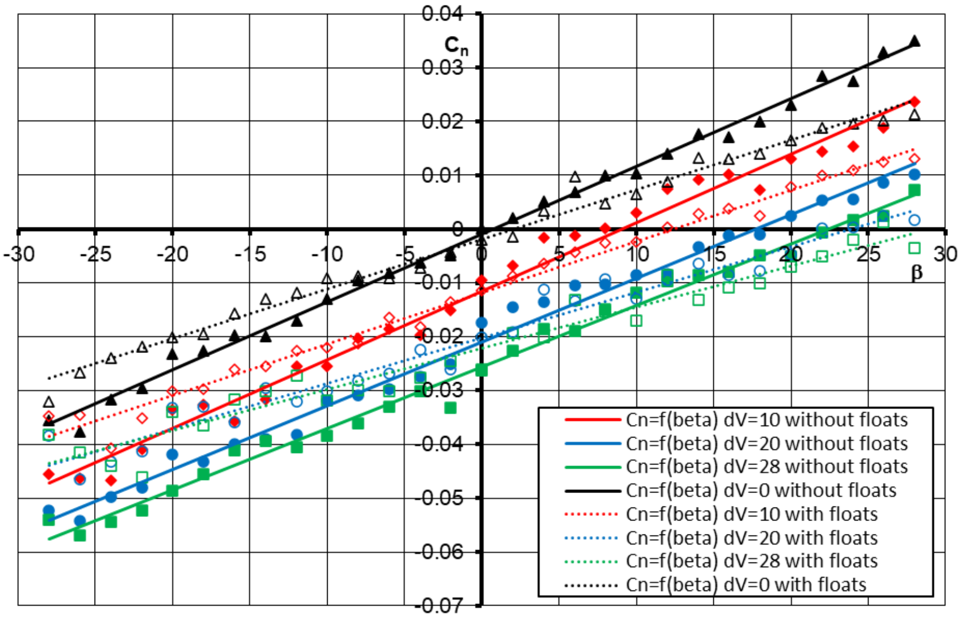

Fig. 10. Characteristics C_n = f(β) for different rudder deflection angles

Table 9. Important numerical data

	model without floats				model with floats			
δ_V°	0	10	20	28	0	10	20	28
$C_n(\beta = -28°)$	-0.04	-0.05	-0.05	-0.05	-0.03	-0.03	-0.04	-0.04
$C_n(\beta = 0°)$	0.00	-0.01	-0.02	-0.03	0.00	-0.01	-0.02	-0.03
$C_n(\beta = 28°)$	0.04	0.02	0.01	0.01	0.02	0.01	0.00	0.00

5. CONCLUSIONS

In this article, the results of experimental tests of the aerodynamic characteristics of the "OSA" model in two configurations – with and without floats – are presented. The tests showed a significant impact of the presence of floats on the curves of the characteristics.

The test results provided in this study constitute a complete set of experimental aerodynamic characteristics for the tested "OSA" model which can be obtained in the wind tunnel owned by Institute of Aviation Technology FMAA MUT.

The use of floats causes a significant increase in the value of the drag coefficient. Irrespective of the flap, aileron, or rudder deflection angle, the presence of floats resulted in an increase of the minimum value of the drag coefficient by a fixed value amounting to approximately 0.04. With the increase of the slip angle, the increase of the drag coefficient caused by the presence of floats was higher and amounted to approximately 0.08 for slip angles $\beta = \pm 28^0$, irrespective of the value of the aileron deflection angle.

What is more, the floats resulted in a deterioration of weathercock stability, which is presented by the curves $C_n = f(\beta)$ – if the floats are present, a slight decrease in the value of the derivative $\frac{\partial C_n}{\partial \beta}$ occurs.

The obtained results of the experimental tests of aerodynamic characteristics in symmetric flow presented in [9] and in asymmetric flow will constitute a basis for further analytical calculations of the characteristics of the real plane, and for numerical analyses of the plane which are required to test the dynamics of its motion.

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