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WIND TUNNEL TESTS OF AIRCRAFT AERODYNAMIC CHARACTERISTICS AT OVERCRITICAL ANGLES OF ATTACK

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Abstract

During air shows or competition aerobatics pilots perform aerobatic flying. Most aerobatic figures are combination of a few basic manoeuvres like loops, rolls, spins, and hammerheads. During such manoeuvres, aerobatic aircrafts often fly in the range of overcritical angles of attack. The flight in the range of higher than critical angles of attack is accompanied by a flow separation. This phenomenon is connected with significant changes of the aircrafts aerodynamic characteristics, as well as may be accompanied by strong vibrations. For these reasons, the knowledge of the aircraft overcritical aerodynamic characteristics is required for its proper design.

In wind tunnels models of aircraft are usually tested in the range up to α = 20°-25°, while aircraft performing aerobatic flying usually achieve considerably higher angles of attack. To obtain the aircraft aerodynamic characteristics in the whole used angles of attack range, a special wind tunnel stand was designed and manufactured in the Institute of Aviation enabling the wind tunnel tests in range, α = 0°-360°.

The paper presents the wind tunnel tests results of aerobatic aircraft "Harnaś 3" model, for a set of chosen model configurations. The studies included both balance measurements of the model basic aerodynamic characteristic, as well as flow visualization tests. Investigation were carried out for the range of angles of attack α = -90°-90° and the range of slideslipe angles β = -90°-90°. Wind tunnel tests are very rarely carried out in such a wide angles of attack range.

The experimental tests were performed in the Institute of Aviation's low speed wind tunnel T-1 (1.5 meter diameter test section). For the tests, the model of aerobatic aircraft (manufactured in a 1:10 scale) was situated both vertically and horizontally in the wind tunnel test section. Wind tunnel tests were performed at Mach number $M \approx 0.1$ ($V \cong 34$ m/s), which corresponds to the Reynolds number $Re = 0.22*10^6$.

Keywords: *applied aerodynamics, aerodynamic characteristics, aerobatic aircraft*

1. Introduction

The flight in the range of high angles is accompanied by a flow separation on the lift and control surfaces. Experimental and numerical investigation has shown that aerodynamic characteristics of airplanes at high angles of attack and high sideslip angles are extremely nonlinear, as compared to the small angles of attack. Flow separation causes that condition of flow becomes unsteady and significant changes of the aircrafts aerodynamic characteristics results in a change of aircraft performance. For these reasons, this area of research is called high angle of attack aerodynamics [6, 8]. The knowledge of the aerodynamic characteristics in the full operating range is essential to determine the aircraft dynamics during its aerobatic flight.

The problems associated with the phenomena occurring during the aircraft's flight at high angles of attack were presented at a series of scientific conferences [2, 5]. It was generally found that high angle of attack aerodynamics is inherently associated with:

- separated flows, and thus nonlinear aerodynamics,
- heavily dependent on wind tunnel testing,
- is connected with flight simulation to ensure good handling qualities.

Due to the importance of the wind tunnel testing of models aerodynamic characteristics at the higher angles of attack, a lot of space in literature was devoted to measurement techniques. It concerned such problems as, support interference in a high angle of attack testing [5], or wind tunnel corrections for high angle of attack models [4]. Most combat aircraft, characterized by a high manoeuvrability were tested at the range of high angle of attack [1, 3]. In a similar way space, vehicles were tested [7].

In particular, it is important to know the high angle of attack characteristics of aerobatic aircraft. Aerobatic aircrafts have been created for performing flying manoeuvres that are not used in normal flight. Most aerobatic manoeuvres are based on rolling i.e. rotation of the aircraft about its longitudinal axis or based on pitching, i.e. rotation of the aircraft about its lateral axis. During such manoeuvres, an aerobatic aircrafts often fly in the range of high angle of attack and high sideslip angle.

The paper presents the wind tunnel tests results of aerobatic aircraft "Harnaś 3" model, for a set of chosen model configurations. The studies included both balance measurements of the model basic aerodynamic characteristics, as well as a flow visualization tests. Due to the usage of a rear sting investigation were carried out for the range of angles of attack α = -90°-90° and the range of slideslipe angles β = -90°-90°.

2. Experimental arrangement

2.1 Wind Tunnel

The experimental tests described in this paper were performed in the Low Speed Wind Tunnel T-1 in the Institute of Aviation (IoA). The T-1 wind tunnel is a closed-circuit continuous-flow wind tunnel with a 1.5 m diameter of the open test section, Fig. 1. The controlled range of freestream velocity is 15-40 m/s. The wind tunnel driving system consists of four-bladed fan powered by a 55 HP AC motor.

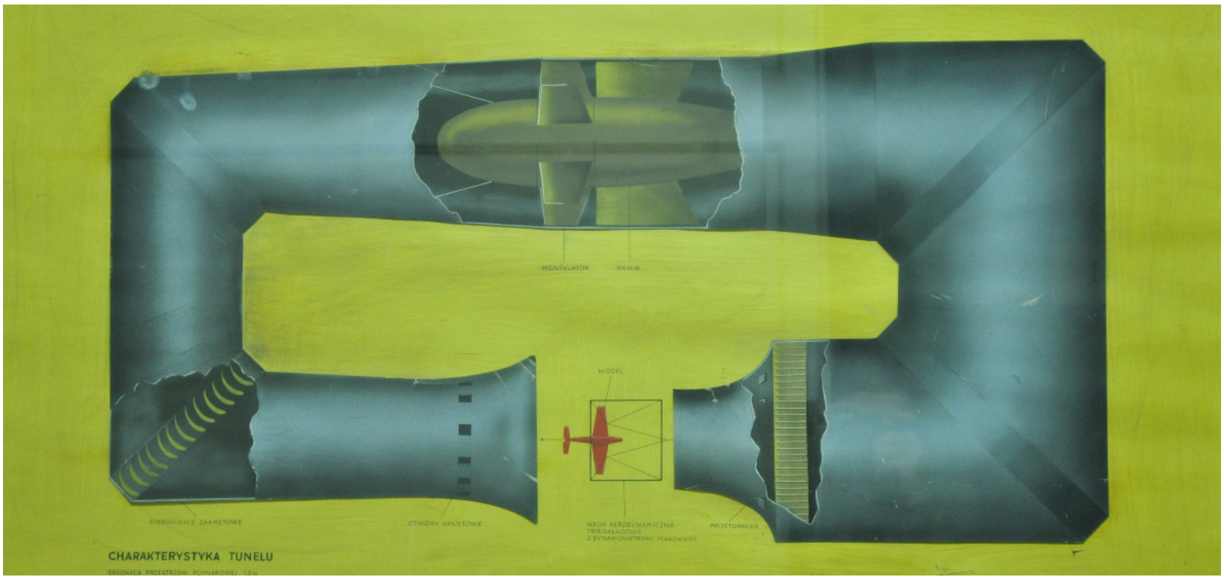

Fig. 1. Low Speed Wind Tunnel T-1

2.2. Tested model

The object of the study was a model of aerobatic aircraft "Harnaś 3" manufactured in the 1:10 scale. It was a biplane, equipped with movable control surfaces, like elevator, rudder, ailerons (at each wing) and additionally flaps on the vertical wing support. The model of 0.8 m span and 0.79 length was completely made of composite, except internal aerodynamic balance fixing. The model of aircraft „Harnaś 3" in T-1 (Ø=1.5 m) IoA wind tunnel is presented in Fig. 2.

Fig. 2. The model of aircraft „Harnaś 3" in T-1 IoA wind tunnel

2.3. Measuring technique

The tested model of aircraft "Harnaś 3" was placed in the middle of the wind tunnel test section and fixed to specially manufactured model support. The support was designed in such way that it allows to test models in a full range of angle of attack (α), sideslipe angle (β) and rolling angle (φ), i.e. α = 0°-360°, β = 0°-360° and φ = 0°-360°. The model positions for rolling angles φ = 0°, 90° and 270° are presented in Fig. 3-5.

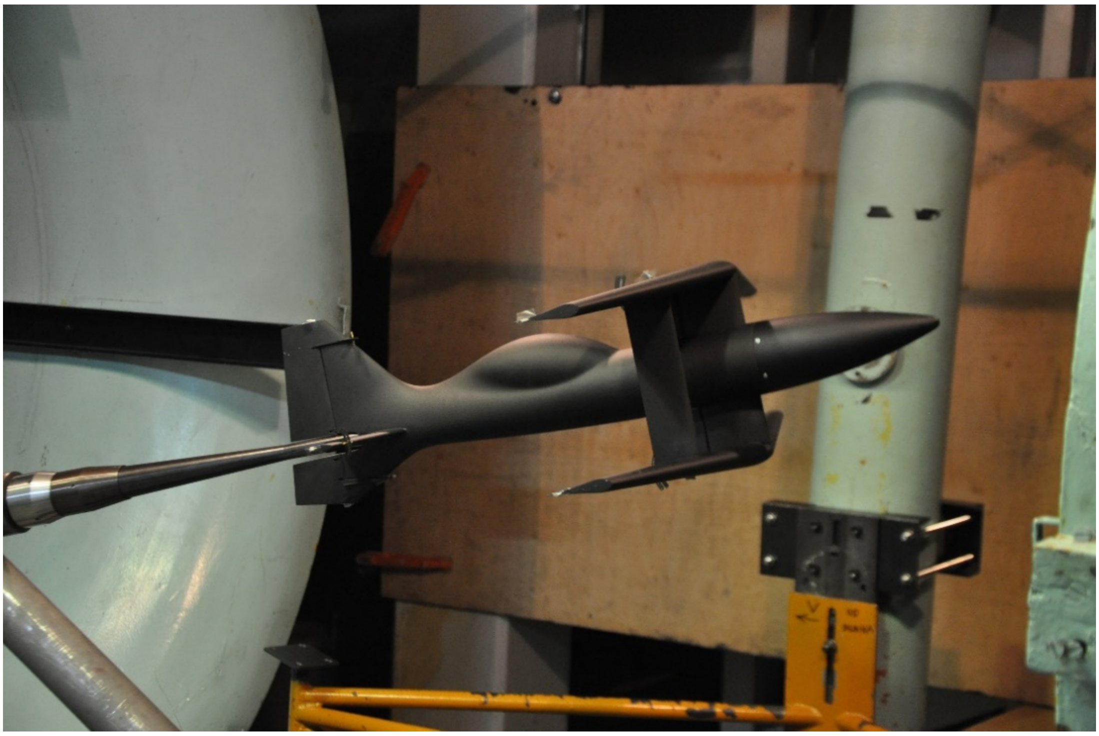

Fig. 3. The model of aircraft „Harnaś 3" in T-1 IoA wind tunnel at rolling angle $\varphi = 0°$

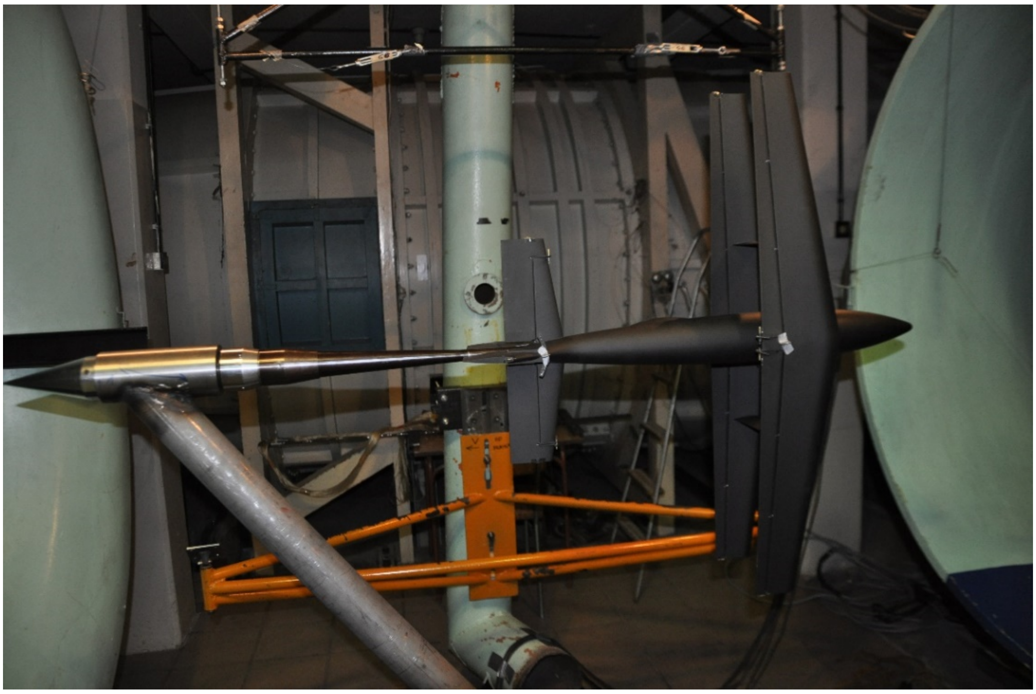

Fig. 4. The model of aircraft „Harnaś 3" in T-1 IoA wind tunnel at rolling angle $\varphi = 90°$

Fig. 5. The model of aircraft „Harnaś 3" in T-1 IoA wind tunnel at rolling angle $\varphi = 270°$

Measurements of aerodynamic characteristics were performed using 6-component internal balance Rollab I-646-2. The multiple repeated tests showed that characteristics are determined with the following accuracy: lift coefficient ± 0.01, drag coefficient ± 0.002 and pitching moment coefficient ± 0.001.

Model geometrical data taken to the coefficient calculations. Wing surface, S = 0.156 m^2. Middle aerodynamic chord MAC = 0.1011 m (for pitching and yawing moments). Model span b = 0.8 m (for rolling moment). The centre of the coordinate system was situated at 34.09% MAC. The used coordinate system is presented in Fig. 6.

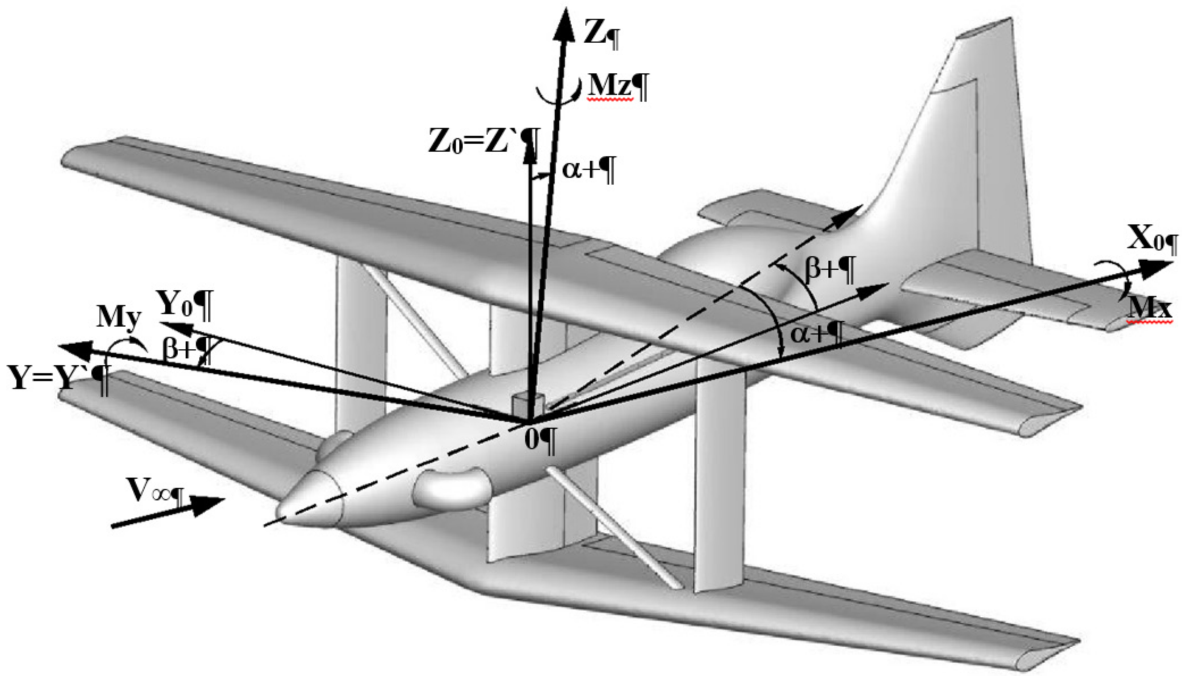

Fig. 6. The used coordinate system

3. Wind tunnel tests results

In Fig. 7-9 the aerodynamic characteristics of the model of aerobatic aircraft “Harnaś 3”, i.e. lift (C_L), drag (C_D) and pitching moment (C_{my}) coefficients in its basic configuration (with not deflected control surfaces) versus angle of attack at the range α = -90°-90° and V_∞ = 34 m/s are presented.

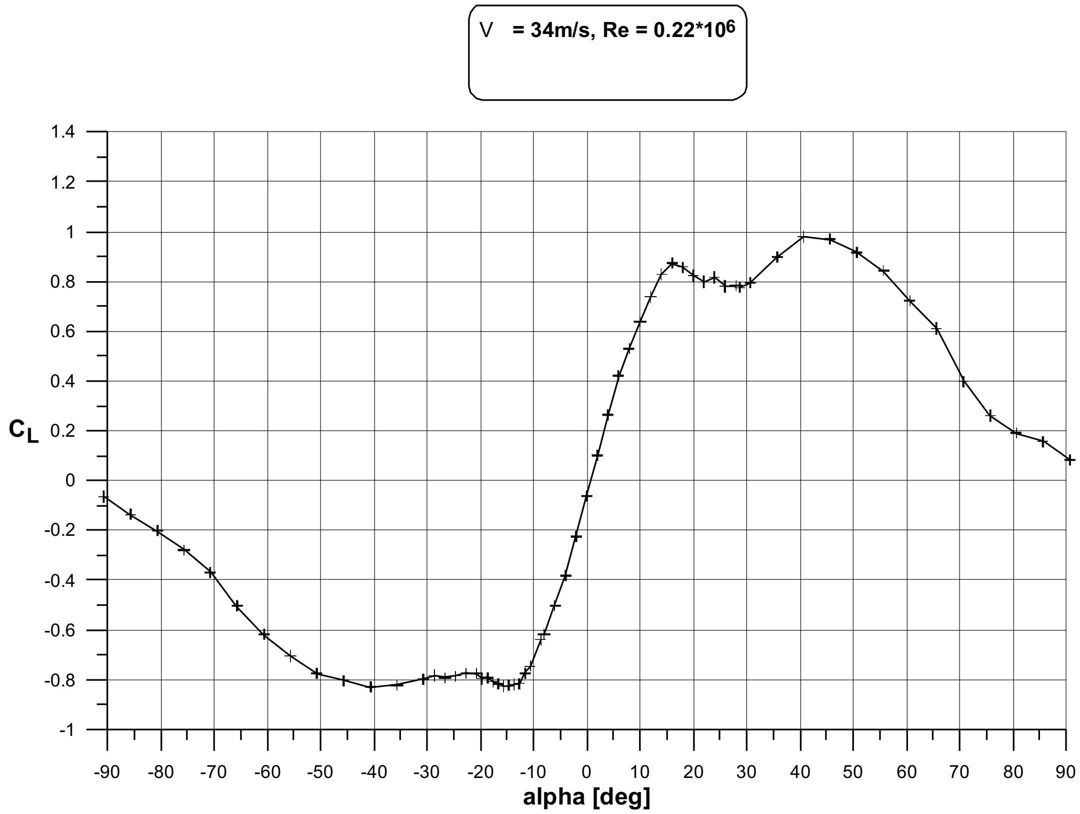

Fig. 7. Lift coefficient versus angle of attack

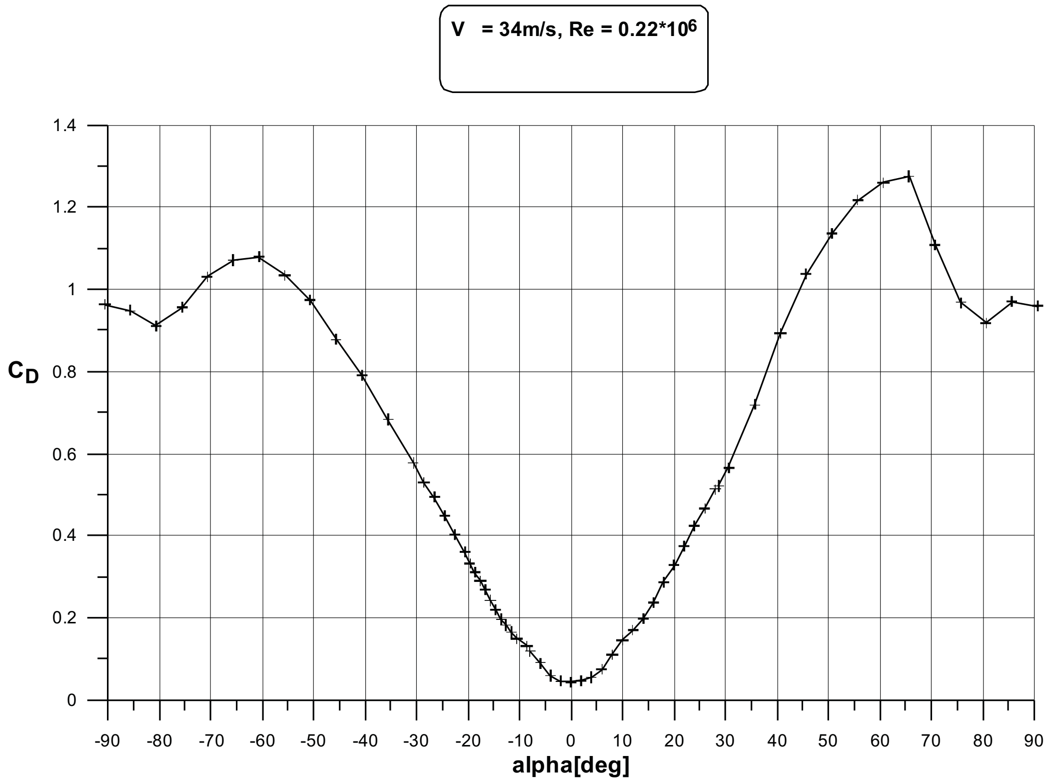

Fig. 8. Drag coefficient versus angle of attack

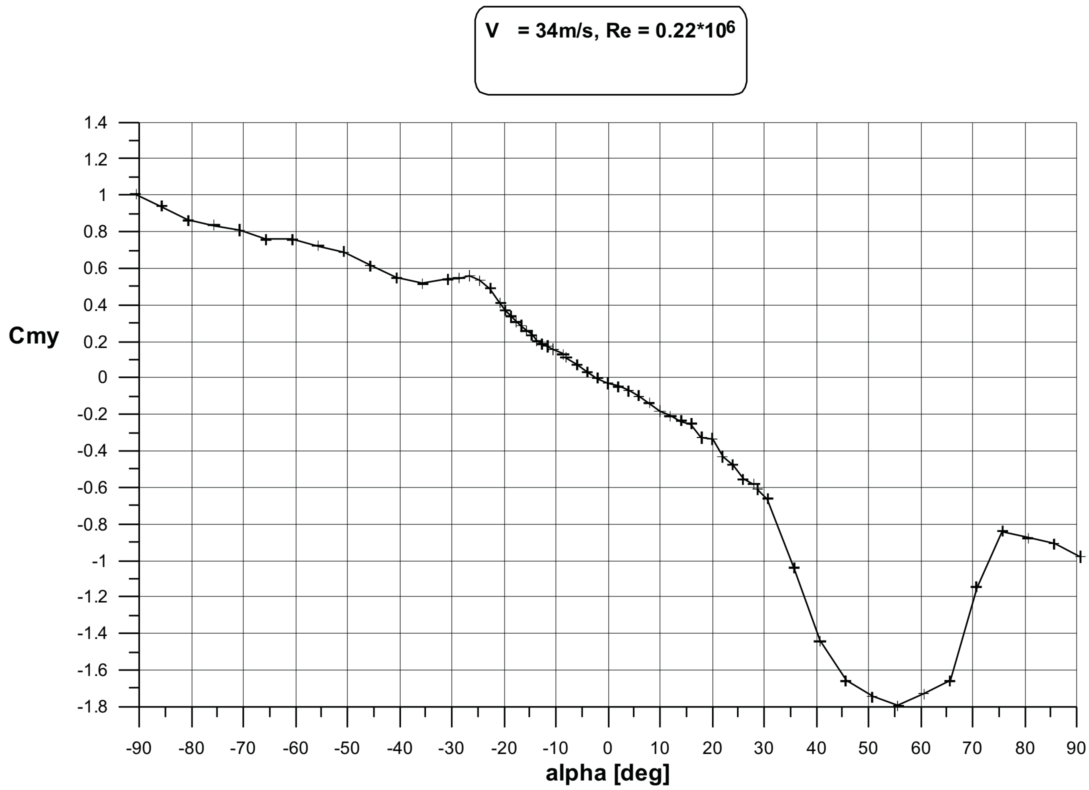

Fig. 9. Pitching moment coefficient versus angle of attack

In Fig. 10-12, the samples of flow visualization test on upper wings surfaces for higher angles of attack, i.e. α = 15°, 30°, and 50° are presented. The tests were performed using fibre, known as “monofilament”, characterized by an increased content of optical brightener. During tests the fibre was exposed to UV light which caused its luminescence in a visible range.

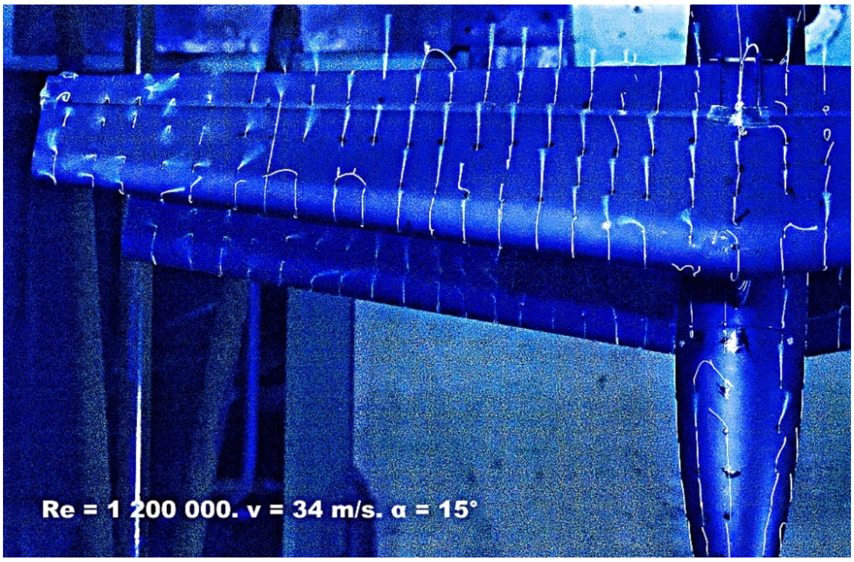

Fig. 10. Flow visualization at α = 15°

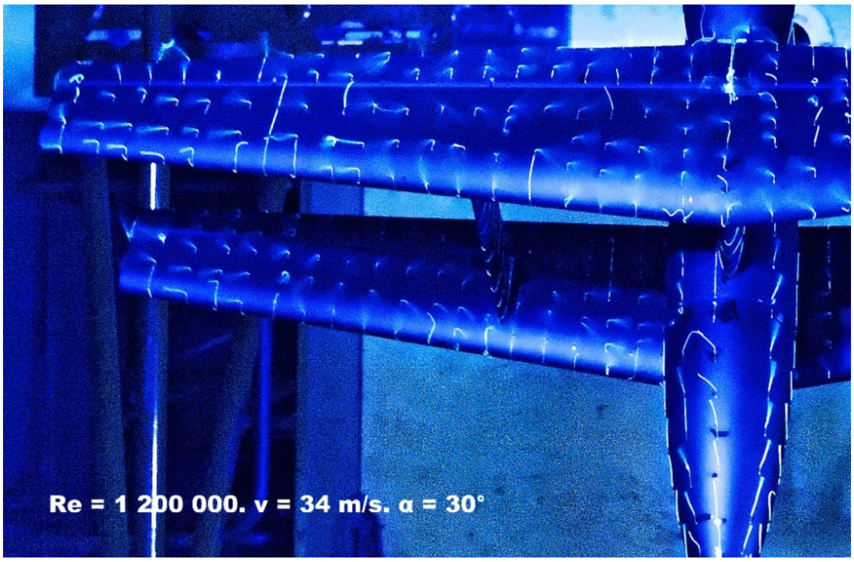

Fig. 11. Flow visualization at α = 30°

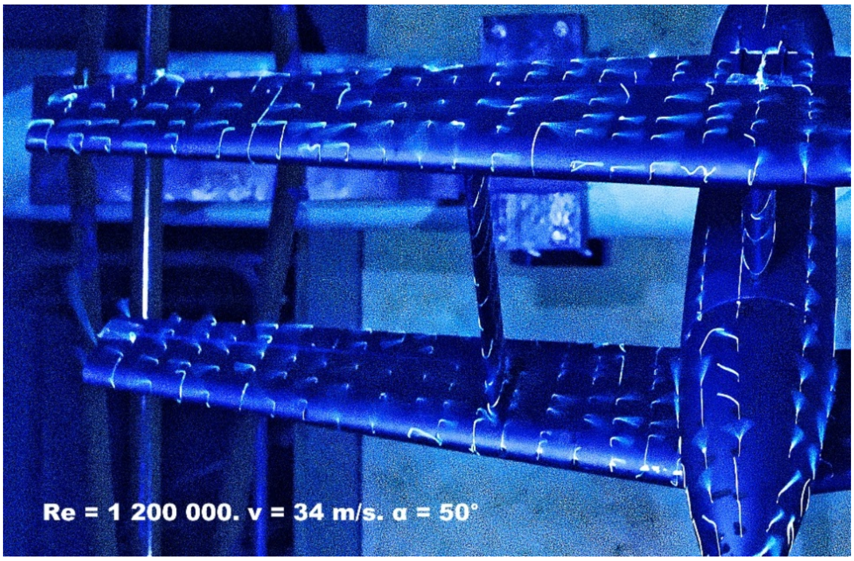

Fig. 12. Flow visualization at α = 50°

3. Conclusions

The wind tunnel tests of aircraft model "Harnaś 3" at a range of high angles of attack showed that it is characterized by the following aerodynamic features:

1. At the zero of sideslip angle, the range of aircraft model angles of attack, characterized by the absence of flow separation and linearity of the $C_L = f(\alpha)$ characteristic, is α = -7°-7° (Fig. 7). In the range of angles of attack α = -10°-7° and α = 7°-12° the $C_L = f(\alpha)$ characteristic becomes slightly curved which indicates the beginning of flow separation on the wing surface. The aerodynamic stall associated with the full flow separation on the aircraft wing is relatively "mild" at both negative and positive angles of attack. As a result, the lift decrease at overcritical angles of attack is small. In a wide range of angles of attack, i.e. for α = -10° – -50° and α = 10°-50° the value of lift force remains at a high level, close to its maximum value, i.e. $C_{lmax} \approx 0.8$-0.9. This shows that the flow separation development on the wings, with the angle of attack increase is relatively slow (Fig. 10-12).
2. The minimum of the aircraft model drag coefficient is relatively small, $C_{Dmin} = 0.045$ (Fig. 8).
3. the model aircraft "Harnaś 3" is statically stable in the longitudinal direction over a wide range of angles of attack, i.e. α = -90°-55° (except the range α = -27°-35°). In the range of overcritical angle of attack, a significant asymmetry of the pitching moment values at the positive and negative angles of attack is observed.

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