ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1217285

LOW SPEED WIND TUNNEL TEST OF THE JET TRAINER MODEL AT HIGH ANGLES OF ATTACK

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Abstract

The article discusses the results of the wind tunnel test of the model of the highly manoeuvrable jet trainer, in the wide range of angles of attack. The main objective of this work was to modify the geometry in order to achieve the assumed properties (stability, control and dynamic behaviour in terms of high angles of attack), and possibly reliable verification of characteristics. In order to control the geometry of subsequent variants of aerodynamic models during the test, the full parametric representation of the CAD geometry was used (applying Siemens NX system) and the modular construction of the models. This enables to change the various components (e.g. the front part of the fuselage, the air inlets, wings, tail, strakes etc.). The wind tunnel models were produced using 3D printers, based on the FDM (Fused Deposition Modelling) method. This allows for relatively fast model prototyping while maintaining full control of geometry and very low cost. Studies were conducted using several models differing in geometry as well (in order to determine the effect of blockage) model scale implementation. Studies carried out in a low speed wind tunnel using an internal balance mounted on bent sting (to enable measurement at high angles of attack). The measurements were carried out in the range of angles of attack -2° to 56° and slip angles +/- 20°, with different deflections of leading edge flaps, trailing edge flaps, elevator, rudder and ailerons. The static aerodynamic characteristics of final version of the model indicates the correct properties in the entire range of flight conditions: the ability to ensure a longitudinal balance with appropriate longitudinal moments necessary to control (reduce the angle of attack), the correct dynamic characteristics at high angles of attack (no pro-spin trend) and the ability to lateral and directional control. Some interesting novelty that will be presented in the paper is a preliminary evaluation of the dynamic properties of the aircraft at high angles of attack, carried out on the model in the tunnel, providing three degrees of freedom (rotation about all three axes).

Keywords: *aerodynamics, aerodynamic project, high angles of attack aerodynamics, manoeuvrability*

1. Introduction

The present paper is a continuation of previous work on the initial stage of conceptual design of a light, highly manoeuvrable jet trainer. The previously presented results of the research indicated the correct aerodynamic characteristics of the final version of the wind tunnel model throughout the assumed range of angles of attack. This was achieved by manual modifications of the external model geometry, covering mainly the change in shape of the strakes, the fuselage nose, the side surface of the air intakes, planform, location, and the setting angle of the vertical tail, under-fuselage aft plates and additional vertical elements on the strakes, that make vortex core break down more symmetrical – improving lateral characteristics. Modifications to the geometry of the model were carried out using plastic mass by manually shaping it. This way of the geometry modifications allowed the flexibility, but unfortunately, it did not provide proper geometry documentation. Only the final geometry of the model was subjected to try to define in the CAD system (NX Unigraphics) based on manual measurements of the model geometry. Unfortunately, aerodynamic model reproduced in such a way was not satisfactory. Sensitivity to geometrical changes in aerodynamic characteristics was relatively large.

The main objective of the present study was such modification of the model geometry that allows achieving the assumed aerodynamic characteristics (stability, controllability and the dynamic behaviour) at the assumed range of angles of attack, and a reliable documentation of the geometry. In order to control the geometry of the model during the wind tunnel test the fully parametric representation of geometry was applied using a system Siemens NX (Unigraphics). Additionally a modular structure of the aerodynamic model was utilized that allows the replacement of individual components (e.g. the front part of the fuselage, the air inlets, wings, tail, etc.).

For the manufacturing of aerodynamic models the 3D printing technique, based on the method of deposition of melted material (FDM: Fused Deposition Modelling) was used. This allowed for a relatively quick change of geometry while retaining its full shape control and low manufacturing cost. Also for model, design the NX system was used – Fig. 1. The final version of the model geometry, taking into account changes in individual components is shown in Fig. 2.

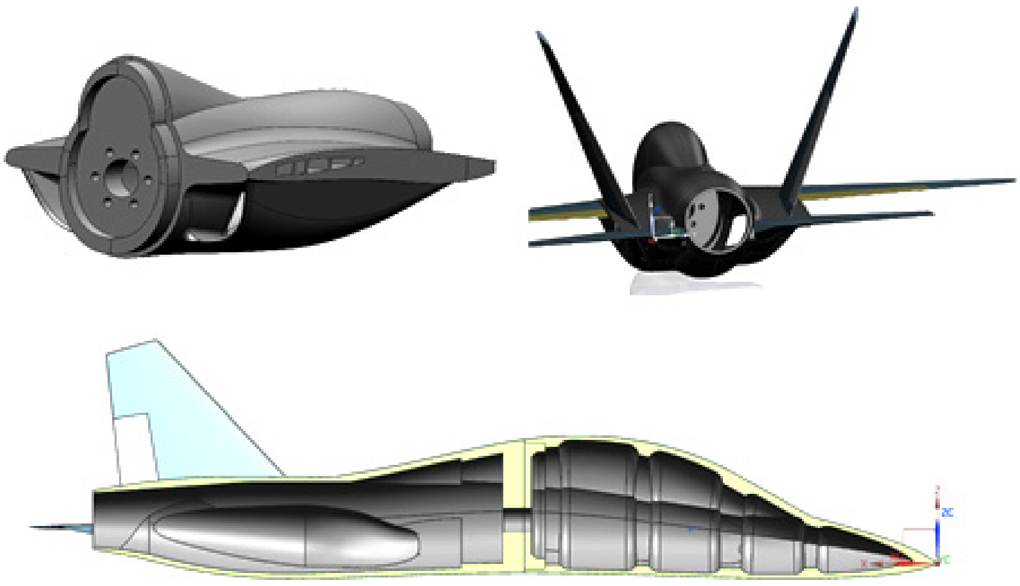


Fig. 1. The aerodynamic model components designed using NX CAD system

2. Aerodynamic problems of high angles of attack

Problems of high angles of attack were shortly presented in the previous paper and related literature [1-6]. The main objectives of the present work were (same as before): provide required controllability and proper dynamic behaviour in the entire range of flight conditions and secure possibility to trim the plane in the entire range of angles of attack and centre of gravity position. The proper location of the aircraft characteristics in the integrated Bihrle-Weizmann chart [1] was the most important issue that secure no departure, pro-spin tendencies and ailerons reversal.

3. Wind tunnel test

Wind tunnel tests were carried out in a low speed wind tunnel at Warsaw University of Technology. The tunnel has a closed circuit and open space test section. Diameter of the test section is 1.16 [m]. To determine the aerodynamic forces and moments, a 6-component internal aerodynamic balance was used. Support system allows testing models in the wide range of angles of attack (-2º – 56º) and sideslip (+/-20º). Classical wind tunnel corrections were applied [7]. Because the basic model size was relatively large (also met wind tunnel test technique requirements) two models of final geometry were tested, the first one having 6% size compared with the full size plane and second one having 4.5% size. Final results for both models were very

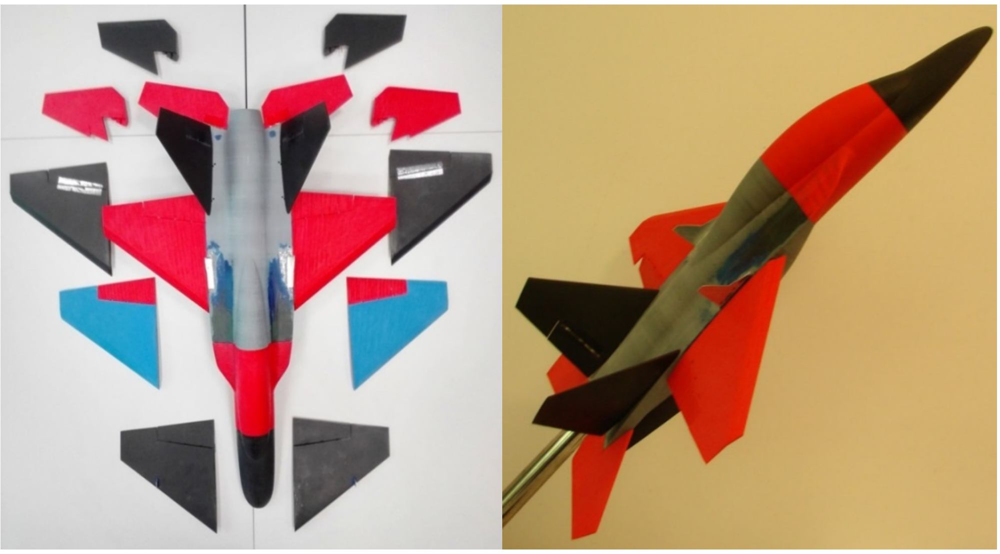


Fig. 2. The aerodynamic model made using 3-D printing technology

similar at large angles of attack, except small range of angles of attack 22º – -25º, where small kink in lift coefficient occurred for the smaller model. Additionally results of the smaller model were more symmetrical in respect to sideslip. Typical Reynolds number based on mean chord was about $2.1 \cdot 10^5$ for the 6% model and $1.6 \cdot 10^5$ for the 4.5% model. The measurements covered different variants of the controls deflection, including the combination of aileron (from symmetrical deflection +/-10º through the differential +10º /-20º to upward only 0º / 30º), rudder +/-25º and elevator -40º – +20º. All together 6 models were tested with additional modifications of model components. Aerodynamic derivatives were calculated using finite differences. In the case of sideslip derivatives, they were calculated using different changes of (symmetrical +/-) sideslips: +/-2º, +/-5º, +/-10º and +/- 20º. In addition, $\boldsymbol{Cn_{\beta dyn}}$ and ***LCDP*** were calculated using different finite differences.

4. Results

The wind tunnel test results of the lift coefficients for 6% and 4.5% scale models with leading edge flaps deflection 30º and different elevator deflections are presented in the Fig. 3. Characteristics of both models differ only in the range of angles of attack about 22º – -25º. The maximum lift coefficient for zero horizontal tail deflection reaches approx. 1.6 – 1.65, and the angle of attack at the maximum lift (the critical angle) is approx. 40º.

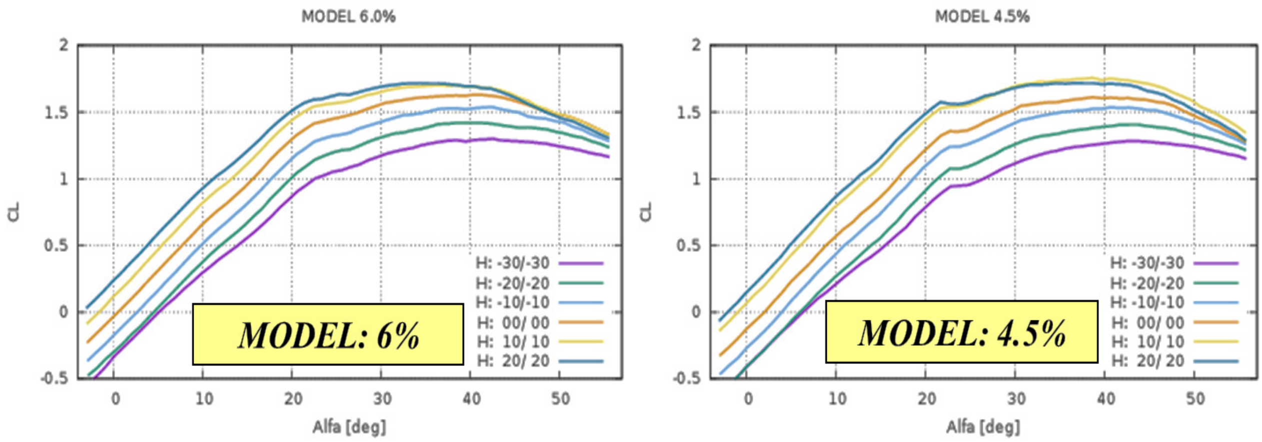


Fig. 3. Lift coefficient characteristics for the final geometry and two-model size

Graphs in Fig. 4 show the longitudinal moment coefficient for the 4.5% model for the two locations of the centre of gravity, corresponding for 15% change of the static margin, which corresponds to the maximum anticipated range of the plane balancing. As can be seen it is possible to balance the airplane up to angle of attack about 50º while maintaining an adequate margin of negative moment coefficient to safety (the possibility of reducing the angle of attack).

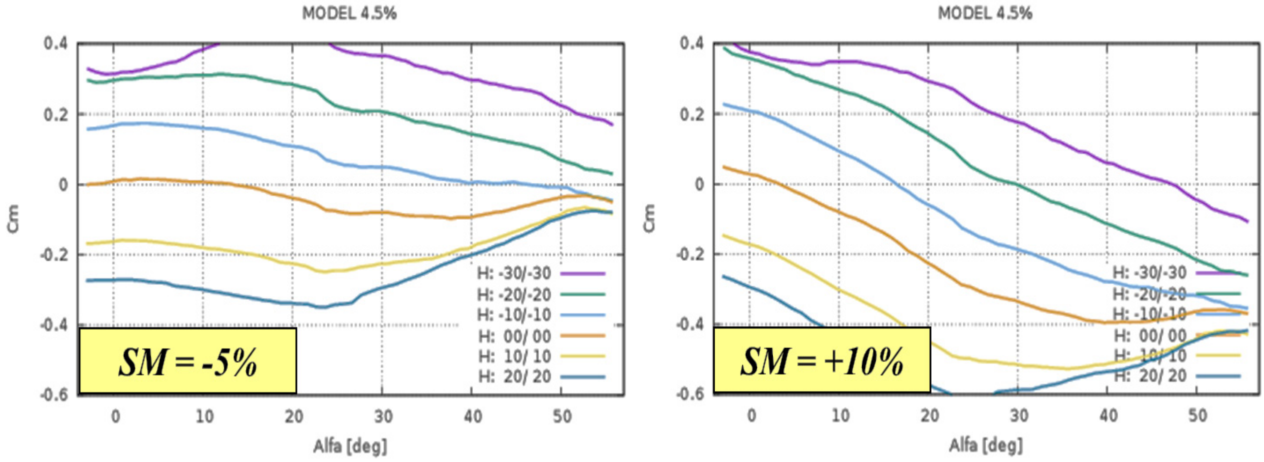


Fig. 4. Pitching moment coefficient characteristics for the final geometry and two values of static margin

The most efficient way for lateral control at high angles of attack is one sided upward flaperon deflection. In this case, flaperon on one wing only is deflected up; the second is in neutral position. Deflection of the second flaperon down causes limited effect regards roll moment, but produces adverse directional moment. In the case of one-sided deflection, (upward) directional moment is favourable even at high angles of attack. Efficiency of the flaperons depends slightly on the horizontal tail deflection: for negative deflections, efficiency is smaller and directional moment less favourable – Fig. 5.

Much more interesting are characteristics of the rudder effectiveness and influence of horizontal tail – Fig. 6. In the range of angles of attack up to 23º rudder is more effective for zero elevator deflection. Its effectiveness, however, falls to near zero at 50º angle of attack in this case, additionally producing adverse rolling moment. In the case of elevator deflection -20º the effectiveness of the rudder is slightly smaller at low angles of attack compared to the previous case, however, it maintains very high efficiency, even at very high angles of attack and, what is specific. It generates nearly no adverse rolling moment in this case!

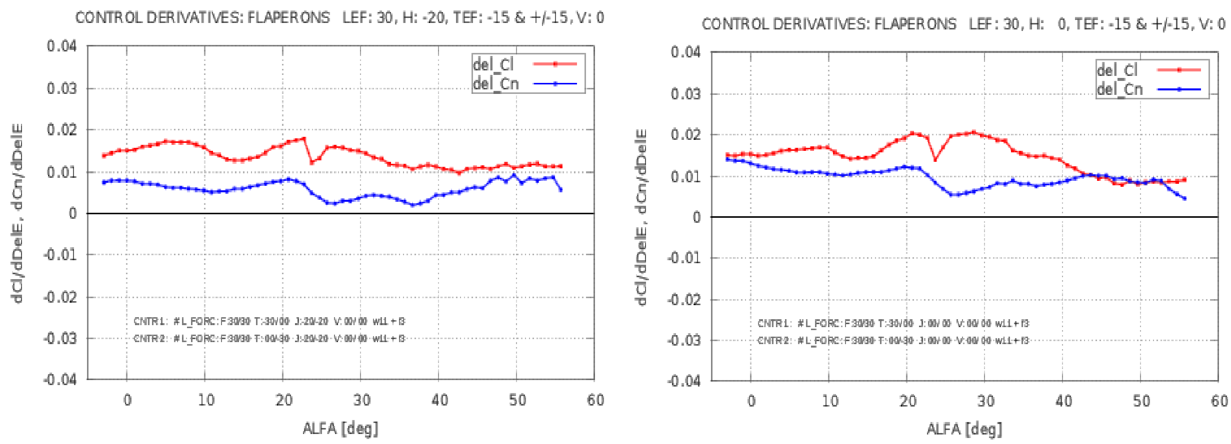


Fig. 5. Rolling and yawing moment changes due to one-sided flaperon deflection (-30º), horizontal tail deflection -20º (left) and 0º (right)

The most interesting are the parameters $\boldsymbol{Cn_{\beta\_dyn}}$ and ***LCDP*** plotted on the integrated Bihrle-Weizmann chart. The characteristics of both derivatives (directional and lateral moments) due to yaw angle at high angles of attack are nonlinear. They were determined using finite differences: $Cl_\beta = (Cl(\beta) - Cl(-\beta)) / (2\beta)$ and similarly Cn_β. All charts were calculated with ARI factor set to 0.3. Depending on the angle of sideslip (+/-)β derivatives have slightly different values, which change the layout of Bihrle-Weizmann chart. All charts present $\boldsymbol{Cn_{\beta\_dyn}}$ and LCDP values for angles of attack in the range -2º – +56º.

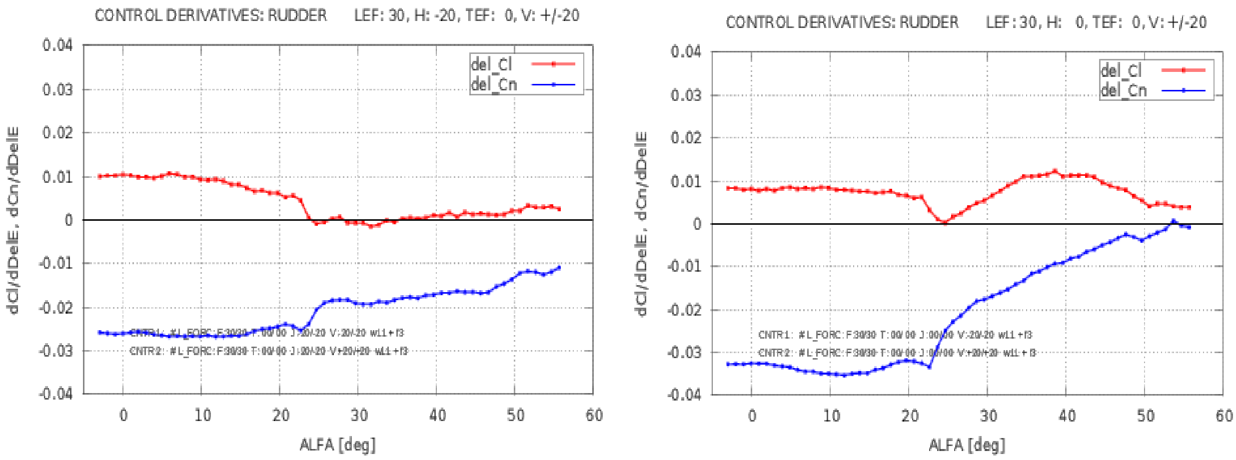


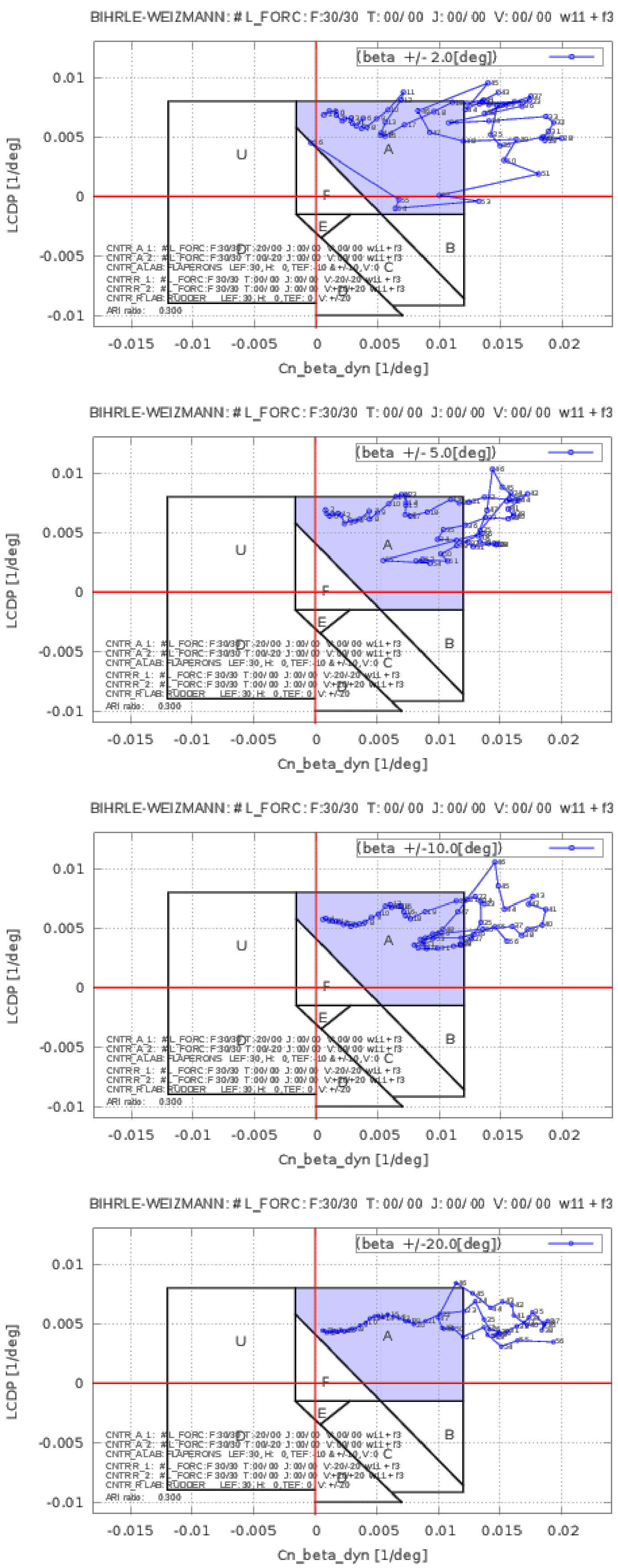
Fig. 6. Yawing and rolling moment changes due to rudder deflection 20º, horizontal tail -20º (left) and 0º (right)

In general, better characteristics (stronger tendency to reduce the departure) are at higher angles of sideslip, which seems to be advantageous. The subsequent figures show the diagrams determined for derivatives calculated using the slidslips respectively +/-2º (a) +/-5º (b) +/-10º (c), and +/-20º (d). Fig. 7 shows graphs for horizontal tail angle equal 0º, which corresponds to the trim conditions with rear location of the centre of gravity. Fig. 8 shows the diagrams for the case of horizontal tail angle -20º, which correlates with the forward position of the centre of gravity at higher angles of attack. Generally, it should be noted that the Bihrle-Weizmann chart characteristics are favourable over the tested range of flight conditions and the aircraft becomes particularly resistant to departure at higher sideslips.

The final and slightly original attempt to determine the dynamic properties of the aircraft at high angles of attack was to test a remote-controlled model in the wind tunnel (model had three degrees of freedom: the ability to rotate relative all three axes) – Fig. 9. Completed studies have confirmed the correct behaviour of the aircraft in the considered range of angles of attack.

4. Summary

The paper presents low speed wind tunnel test results of the aircraft model designed to operate at high angles of attack. Leading edge flap deflection in all cases was 30º. The results suggest the possibility to trim the plane longitudinally for the angles of attack range up to 50º and cover considered locations of the plane centre of gravity. It also seems possible to keep a relatively good manoeuvrability and lateral/directional stability in the same range of angles of attack, although it will require implementation of certain control laws (in this, combination of flaperon/rudder deflections to provide required lateral and directional aircraft movement) at high angles of attack. Location of the final stability and control characteristics on the Bihrle-Weizmann charts suggest the correct dynamic behaviour of the aircraft. It should be departure resistant with no pro-spin tendency and no aileron reversal.



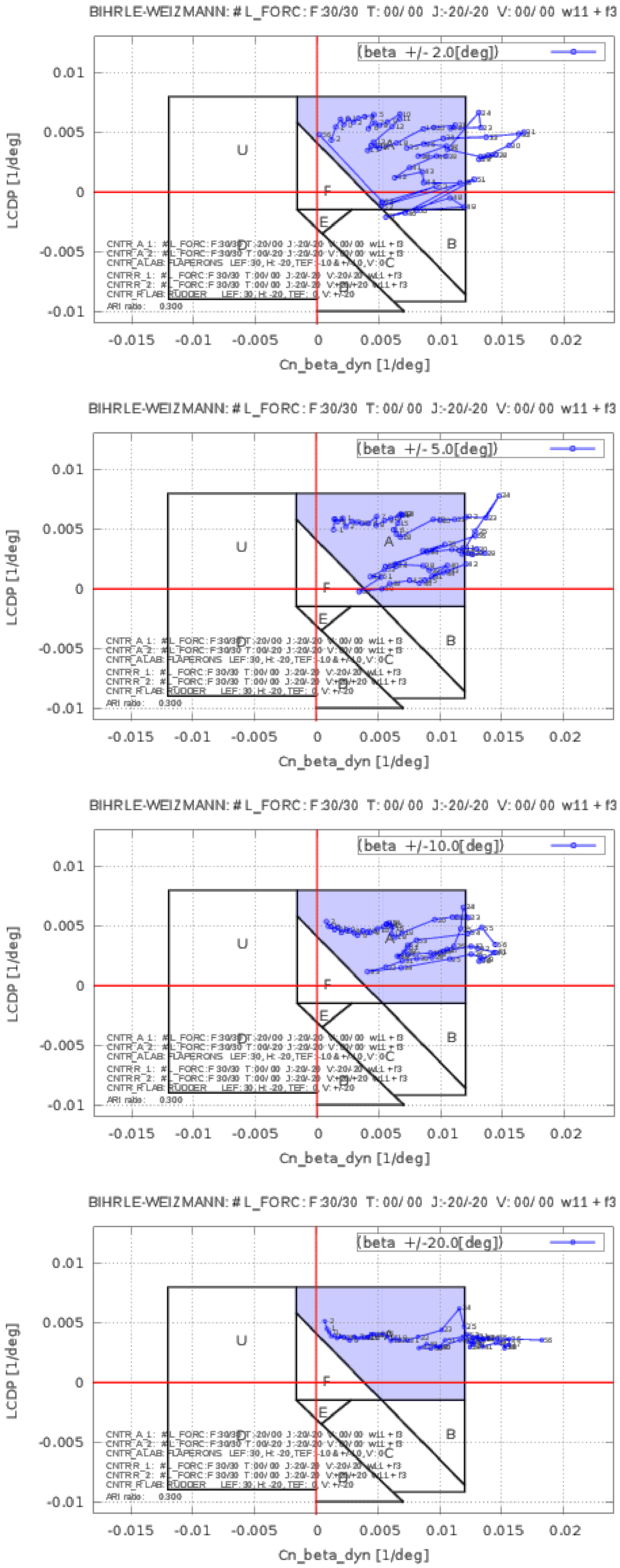
(a)

(b)

(c)

(d)

Fig. 7. Bihrle-Wizmann chart for the case of zero angle of horizontal tail deflection and four values of sideslip angles: +/-2º (a), +/-5º (b), +/-10º (c), +/-20º (d)



(a) (b) (c) (d)

Fig. 8. Bihrle-Wizmann chart for the case of horizontal tail deflection-20º and four values of sideslip angles: +/-2º (a), +/-5º (b), +/-10º (c), +/-20º (d)

Fig. 9. A quasi-free test of a remote-controlled model in the wind tunnel

References

[1] Kubryński, K., *Conceptual and Aerodynamiuc Study of a Highly Maneuverable Jet Trainer*, Journal of KONES Powertrain and Transport, Vol. 23, No. 4, 2016.
[2] High Angle of Attack Aerodynamics – AGARD Conference Proceedings, CP-247, 1979.
[3] Special Course on Aerodynamic Characteristics of Controls – AGARD Report, R-711, 1983.
[4] Mason, W. H., *High Angle of Attack Aerodynamics* – http://www.dept.aoe.vt.edu/~mason/ /Mason_f/ConfigAeroHiAlphaNotes.pdf.
[5] Whitford, R., *Design fir Air Combat,* Janes 1987.
[6] Technologies for Highly Maneuverable Aircraft – AGARD Conference Proceedings, CP-548, 1994.
[7] *Wind Tunnel Wall Corrections, AGARD AG-336, NATO, 1998.*