The solution of the flow field around the wing with a focus on the induced effects

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One of the possibility how to reduce costs of flying, is using various shapes of wing tips called winglets. To analyse these wing tips, it is useful, to develop objective method, which allows to compare aerodynamic characteristics of planar and nonplanar wing tips. This study was especially focused on the wing tips in the category of Light Sport Aircraft (LSA), where the research was not done sufficiently yet. The solving of the flow field around the wing was resolved by using numerical simulation, which was validated by experimental measurement provided by VZLU.

Keywords

Wingtip,winglet, induced drag, drag coefficient, lift coefficient, CFD, k-ω SST model

1 INTRODUCTION

The theme considering induced effects was discussed in the category of transport aviation and in the category of gliders a lot, but not enough in the category of Light Sport Aircraft (LSA). As we can observe, there are various shapes of the wingtips, some of them are curved upwards, some of them downwards and some of them are shaped in planar plane. This shows, that this aerodynamic approach is not quite clear yet.

So the goal is to analyse the most frequent shapes and develop objective method for comparing aerodynamic characteristics of the wing with various wingtips.

For validation of Computational Fluid Dynamics (CFD) simulation VZLÚ has provided experimental data from the wind tunnel. The goal in this case is to compare differences between the two types of wing tips using CFD simulation and using experimental data.

2 VALIDATION OF CFD SIMULATION BY EXPERIMENTAL RESULTS

2.1 Measurement in the wind tunnel

The goal of this validation is to find out, how accurate is the CFD simulation able to predict the relative differences between the wing with (Fig. 2-1) and without (Fig. 2-2) the winglet. The wing used in this experiment comes from small twin turboprop aircraft.

The aerodynamic measurements were performed in the Low Speed Wind Tunnel (LSWT) of 3m diameter in VZLÚ.

The model was mounted on a manipulator allowing to change continuously angle of attack. Forces acting on the model were measured by an internal six component strain gauge balance. The Reynolds number during the measurements was $0{,}7.10^6$. In addition there were used standard wind tunnel corrections.

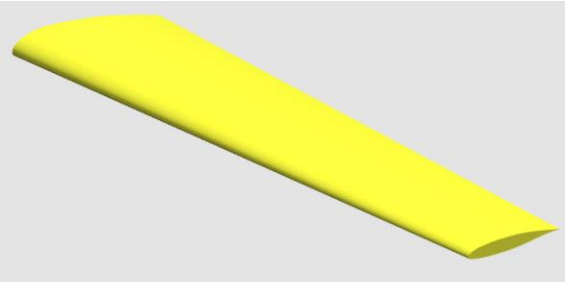

Fig. 2-1 Base Wing from the experiment without winglet

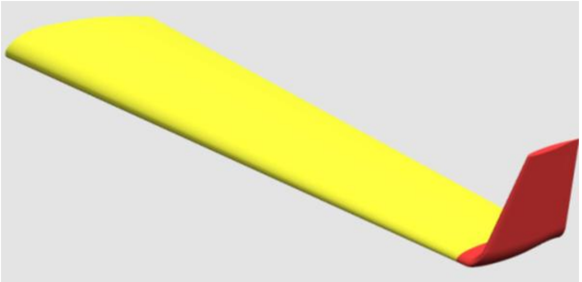

Fig. 2-2 Wing from the experiment with winglet

Span	2,0 m
Area	0,3937 m^2
Mean geometric chord	0,199 m
Aspect ratio	10,29
Taper ratio	0,60
Geometric twist angle	-3,4°
Dihedral	1,5°
Thickness of the root airfoil	17%
Thickness of the tip airfoil	13%

Tab.2-1 Characteristic parameters of the wing used in experiment

2.2 CFD simulation of the measured wing in the wind tunnel

The grid was made in preprocessor Gambit and the numerical solver Fluent was used as a processor. Since the measurement was performed without the yawing, the numerical simulation can be simplified by solving only the half span of the wing.

Because of higher count of wingtips and because of their complex shapes, the unstructured grid was used, which significantly reduces the time needed for the grid preparation. The control volume contains approx. of $2{,}5.10^6$ cells. Turbulence model was chosen k-ω SST, which is recommended for aeronautical applications.

2.3 Analysis of the CFD validation

Basic aerodynamic characteristics of the CFD simulation were evaluated in the same way as the measurement in the wind tunnel.

The drag coefficient and the lift coefficient were defined for the validation as follows:

$$c_D = \frac{2 \cdot D}{\rho \cdot v_\infty^2 \cdot S_{VZLU}} \quad \text{and} \quad c_L = \frac{2 \cdot L}{\rho \cdot v_\infty^2 \cdot S_{VZLU}} \quad , \qquad (1)$$

where the characteristic area S_{VZLU} was considered as a constant value for both configurations of the wingtip with and without winglet.

The moment coefficient was not available from the measurement.

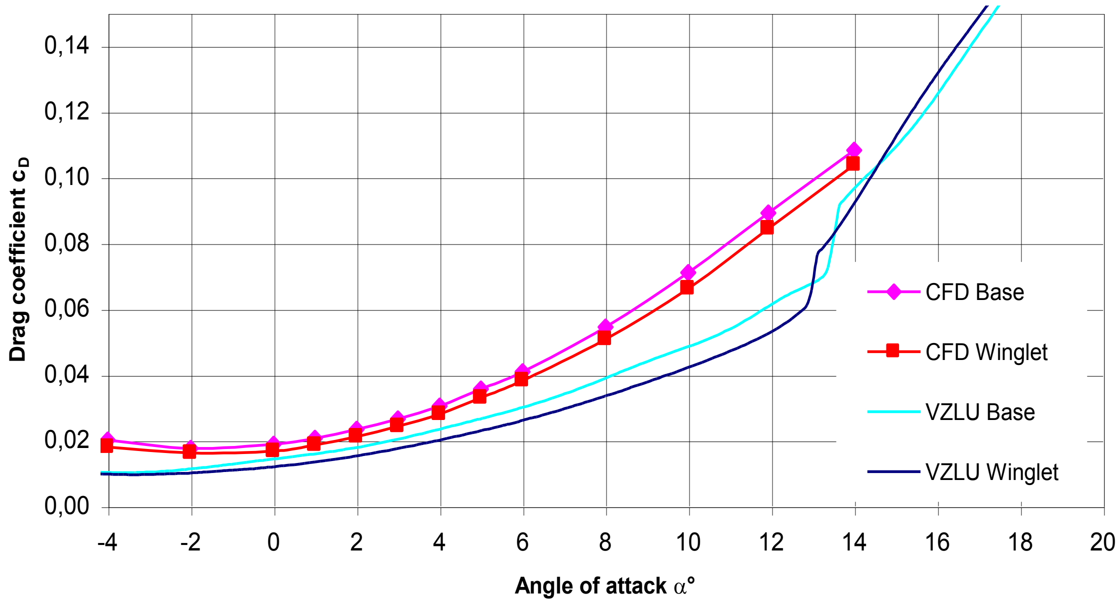

Fig. 2-3 Validation of the drag coefficient

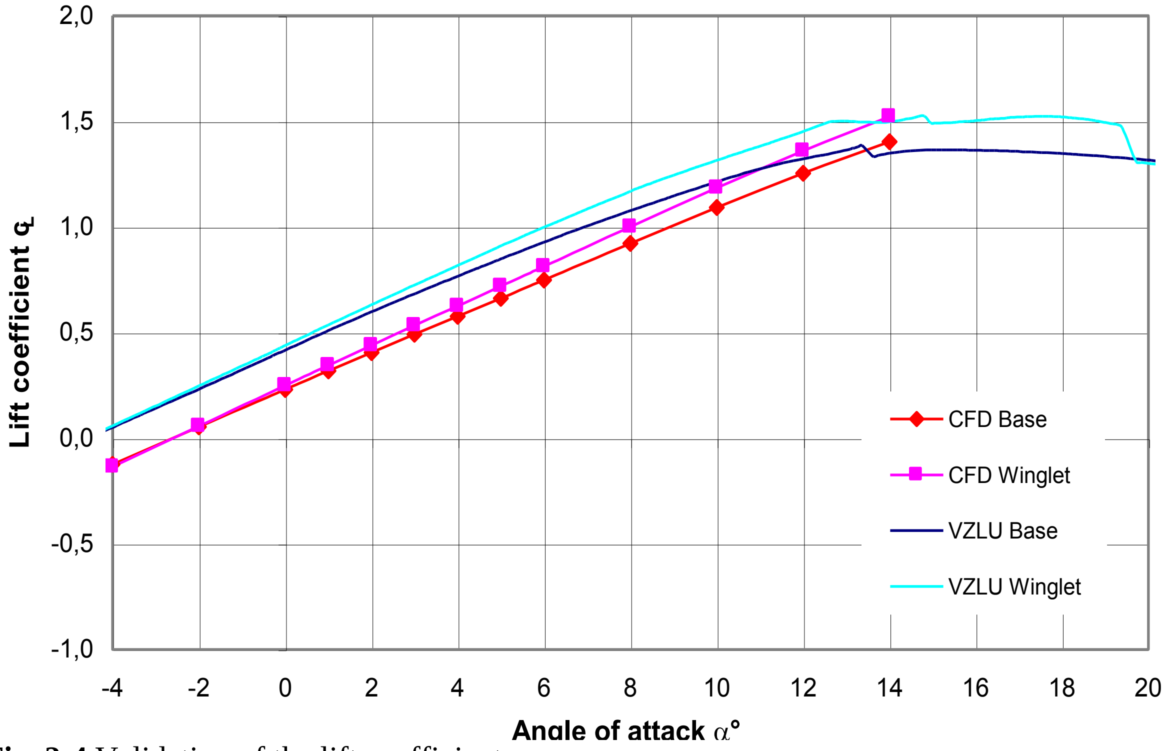

Fig. 2-4 Validation of the lift coefficient

The relative accuracy of prediction of the difference between the base wing (without the winglet) and the wing with the winglet is in the case of drag coefficient +/- 2% (Fig. 2-3) and in the case of lift coefficient +/- 1,25% (Fig. 2-4). Which is a very good agreement for both coefficients.

2.4 Method for comparison of wingtip devices

Since the induced drag c_{Di} is defined as:

$$c_{D_i} = \frac{c_L^2}{\pi \cdot \lambda} \cdot (1+\delta) \qquad (2)$$

and the total drag of the wing is defined as:

$$c_D = c_{D\infty} + c_{D_i} \qquad (3)$$

where $c_{D\infty}$ is profile drag and the induced drag in the equation (2) is proportional to the square of the lift coefficient, it is important to compare the total drag coefficient at the constant lift coefficient. So the typical flight regimes were chosen for the constant lift coefficients: v_{max} maximum speed, v_{opt} optimum speed, v_{ekon} economic speed, v_{min} minimal speed.

In Fig. 2-5 is shown relative specific drag coefficient, which was determined considering following assumption:

$$c_D \cdot S \approx c_{D_{spec}} \cdot S_{spec} \qquad (4)$$

where the left hand side of the equation (4) corresponds to the wing with an arbitrary shape of the wingtip and the right hand side corresponds to the specific drag coefficient c_{Dspec} and to the specific area S_{spec}, which is area of the basic wing.

So we can write for specific relative increase of the drag coefficient Δc_{Dspec} :

$$\Delta c_{D_{spec}} \approx \Delta c_D \cdot \frac{S}{S_{spec}} \cdot 100\% \tag{5}$$

Since arbitrary wingtips can be nonplanar and the total drag coefficient depends also on the wetted area, it is necessary to use nonplanar characteristic area S placed in centerlines of airfoils along the span.

In the same manner was determined the specific lift coefficient in Fig. 2-6.

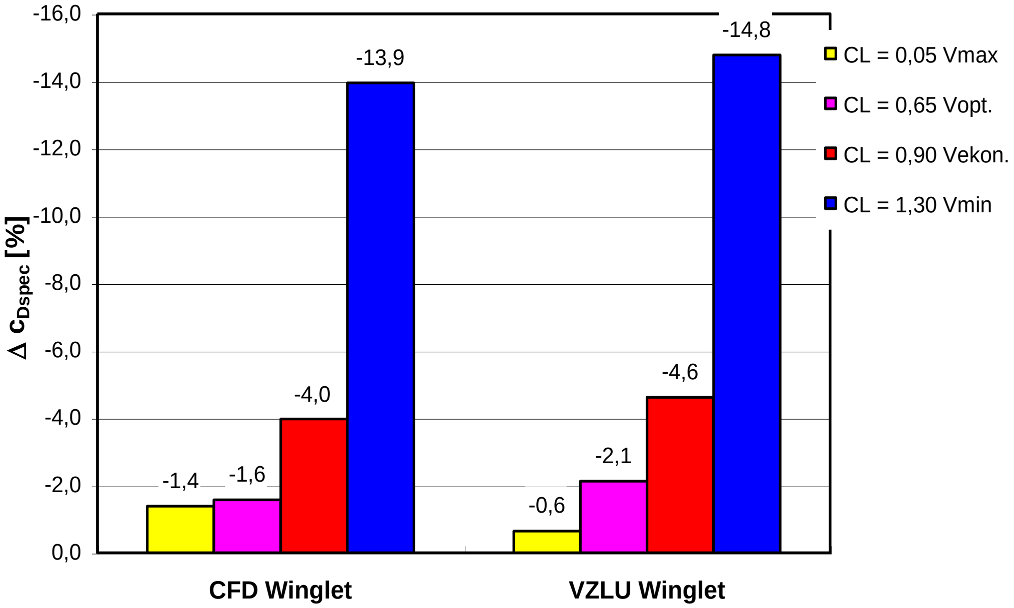

Fig. 2-5 Specific relative drag coefficient

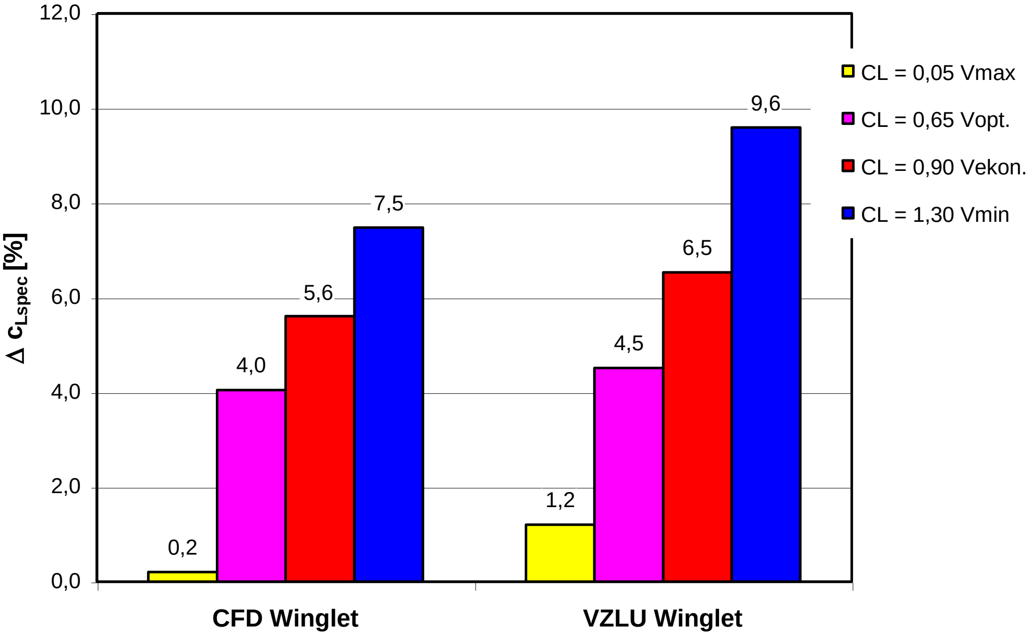

Fig. 2-6 Specific relative lift coefficient

Both Fig. 2-5 and 2-6 show very good agreement CFD simulation with measurement in the wind tunnel.

3 CFD ANALYSIS OF WINGTIP DEVICES

3.1 Overview of the wingtip devices

The firm TL Ultralight provided for this overview the geometry of their wing and two their wingtips (wingtip No. 1 and 5). That is the reason of using different wing for validation and for general analysis of the wingtips.

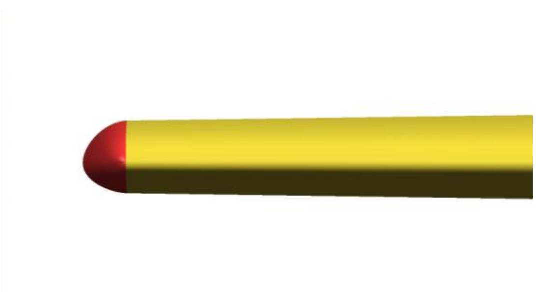

Fig. 3-1 Reference wingtip for the analysis

Fig. 3-2 Reference wingtip for the analysis

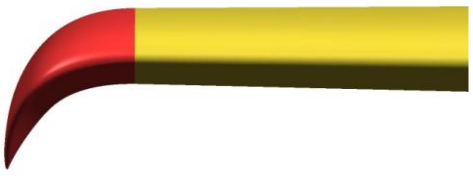

Fig. 3-3 Wingtip1

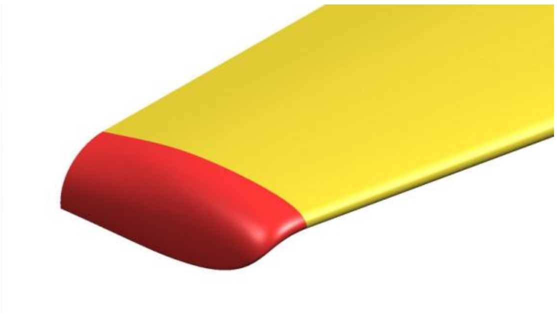

Fig. 3-4 Wingtip1

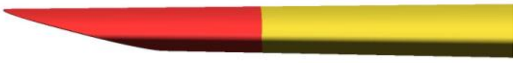

Fig. 3-5 Wingtip2

Fig. 3-6 Wingtip2

Fig. 3-7 Wingtip3

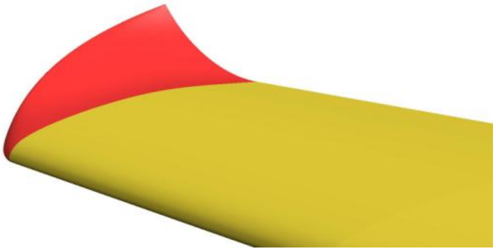

Fig. 3-8 Wingtip3

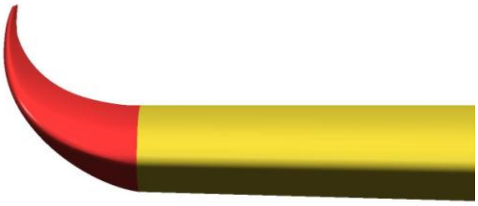

Fig. 3-9 Wingtip4

Fig. 3-10 Wingtip4

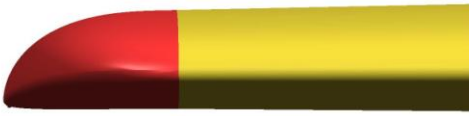

Fig. 3-11 Wingtip5

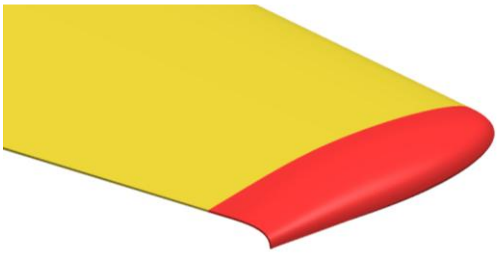

Fig. 3-12 Wingtip5

3.2 Results of analysis

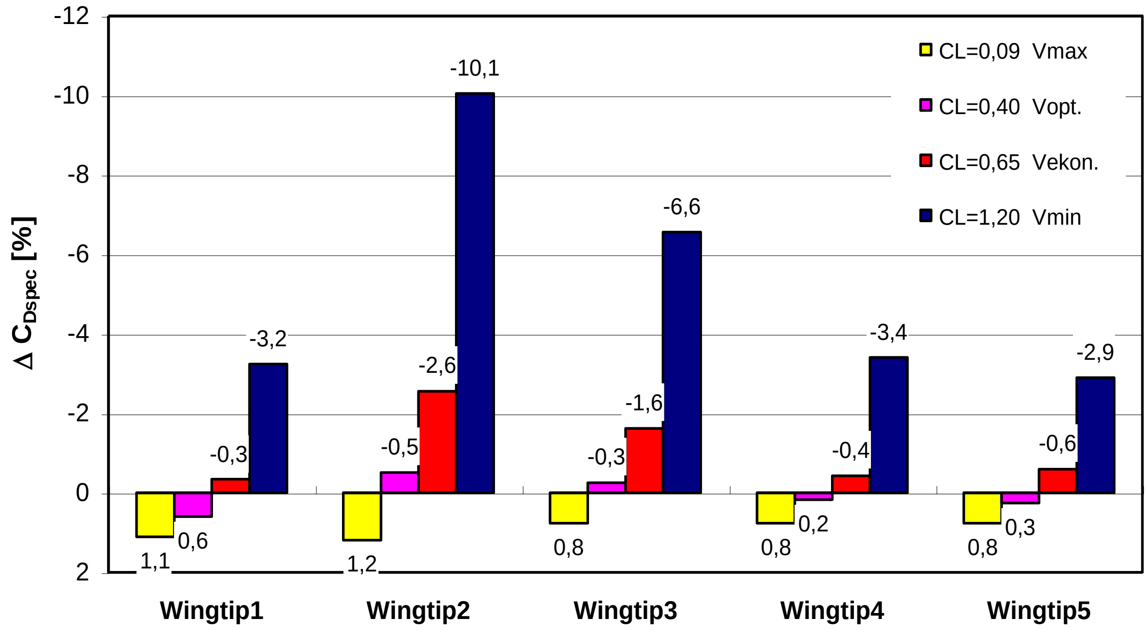

Fig. 3-13 Specific relative drag coefficient

It can be seen in Fig. 3-13, that there are not high differences in the regimes of maximal and optimal speed. Nevertheless in economic and minimal regimes the wingtip2 and also the wingtip3 reduce the specific relative drag coefficient significantly.

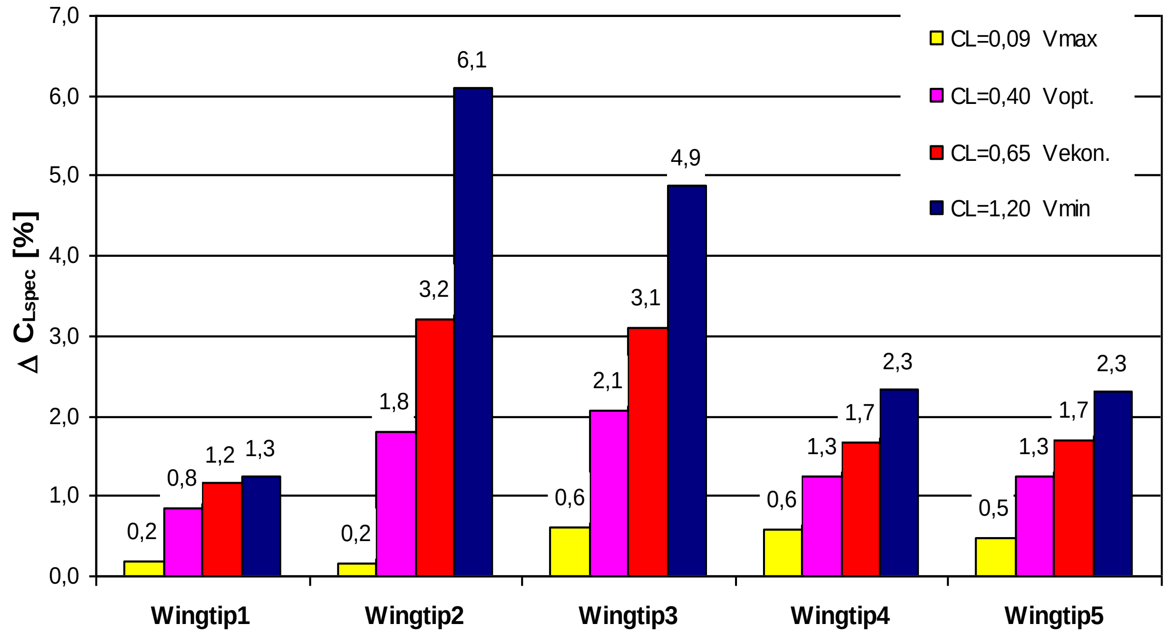

Fig. 3-14 Relative specific drag coefficient

In Fig. 3-14 the situation is very similar to previous graph. The wingtips No. 2 and 3 increase the specific relative lift coefficient in the flight regimes of minimal and economic speed. In the other regimes are the differences small.

4 ACKNOWLEDGEMENT

We would like to thank to VZLU for providing of wind tunnel measurements and then we would like to thank to the firm TL Ultralight, which provided geometry of the wing and two geometries of wingtips.

5 CONCLUSION

This work is focused on induced effects at the wingtips in the category of Light Sport Aircrafts. There are analysed various shapes using numerical simulation CFD, which is validated by measurement in the wind tunnel provided by VZLU. An objective method was developed allowing to compare nonplanar wingtips with respect to the various wetted area and with different characteristic area. The flight tests performed by the firm TL Ultralight have also shown, that the curvature of the wingtips strongly affects the lateral static stability, which should be more explored in the future.

Abbreviations:

c_D	Drag coefficient	[-]
$c_{D\,spec}$	Specific coefficient	[-]
$c_{D\infty}$	Profile drag coefficient	[-]
$c_{D\infty_f}$	Friction drag coefficient	[-]
c_{D_i}	Induced drag coefficient	[-]
c_L	Lift coefficient	[-]
$c_{L\,spec}$	Specific lift coefficient	[-]
D	Drag force	[N]
l	Span of the wing	[m]
L	Lift force	[N]
S	Area of the wing with arbitrary wingtip	[m^2]
S_{spec}	Specific area of the reference wing	[m^2]
S_{VZLU}	Reference area of the wing from VZLU	[m^2]
v_{ek}	Economic speed	
v_{max}	Maximum speed	
v_{min}	Minimal speed	
V_{opt}	Optimal speed	
v_∞	Free stream velocity	[m/s]
SST	Shear Stress Transport	[-]
Re	Reynolds number	[-]

α	Angle of attack	[°]
δ	Glauert coefficient	[-]
λ	Aspect ratio	[-]
ρ	Density	[kg/m^3]
CFD	Computational Fluid Dynamics	
k-ω	Turbulence model	
LSA	Ligt Sport Aircraft	
LSWT	Low Speed Wind Tunnel	
SST	Shear Stress Transport	

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