Solving of the flow field around the wing focused on the induced effects

Ing.Štěpán Zdobinský

Supervisor: Doc. Ing Luboš Janko, CSc.

Abstract

This theme is solved within the dissertation thesis and the goal is to find out, how the shape of the wing tip can influence the induced drag. The cases of the wing tips are focused in the Ultra light category of aircrafts. The analysis of the wing tips is being carried out in CFD and is being verified by experiments.

Keywords

Wing tips, induced drag, CFD, k-ω SST model, lift/drag ratio

1. Introduction

This theme considering induced effects was discussed a lot in category of transport aviation and in category of gliders, but not in the category of UL (Ultra Light) aircrafts. As we can observe, there are various shapes of the wing tips sometimes influenced more by styling than by physics of aerodynamics in this UL category.
So the goal is to evaluate the most frequent shapes and compare their efficiency and their shape complexity.

Since every simulation has to be verified by any experiment, so there was used one made by Ing. Anderle, PhD. This experiment contains measurements of the flow field in the wake behind the wing. In this case the force measurement was not proceeded.

Another verifying experiment provided by VZLÚ was force measurement with two types of wing tips. The goal in this case is to compare differences between the two wing tips using CFD and using experiment. This comparison is still in progress.

2. Wing tips

The shapes of wing tips are created on a wing of a UL aircraft provided by the firm TL Ultralight. There were chosen cases, which often occur on UL aircrafts, see Tab.1.

Table 1. *–Overview of wing tips*

Winglet - this case was used in the experiment made by Ing. Anderle, PhD. The wing comes from a glider.

Fig. 1.

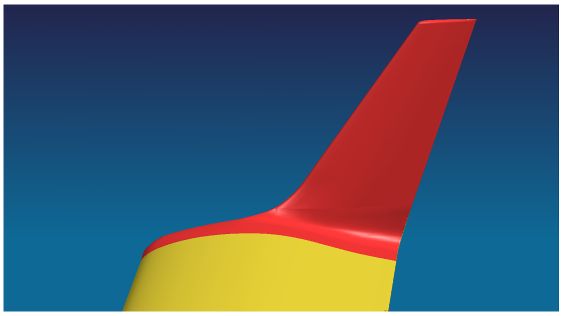

Fig. 2.

Rounded - this is a reference case. The wing was provided by the firm TL Ultralight for this and the rest of the cases.

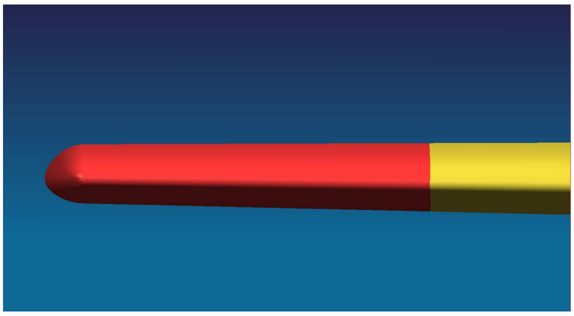

Fig. 3.

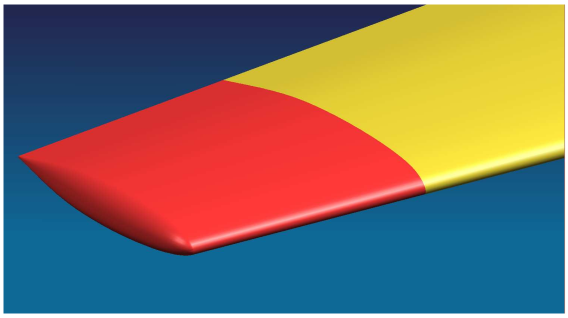

Fig. 4

Droped - this wing tip was provided by the firm TL Ultralight.

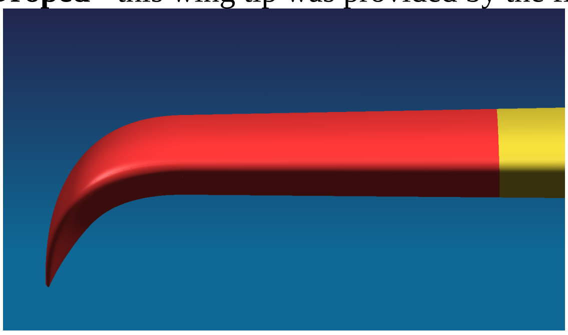

Fig. 5

Fig. 6

Cut – this simple case was made by cutting off the wing at 15deg.

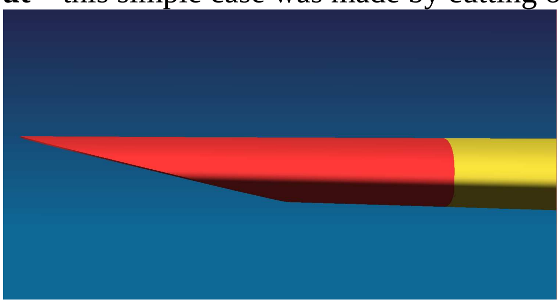

Fig. 7

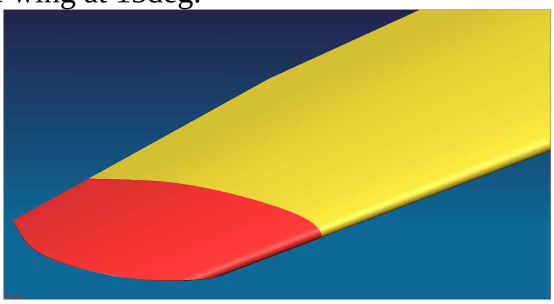

Fig. 8

Upward – this case incurred by the modification of the wing tip Droped.

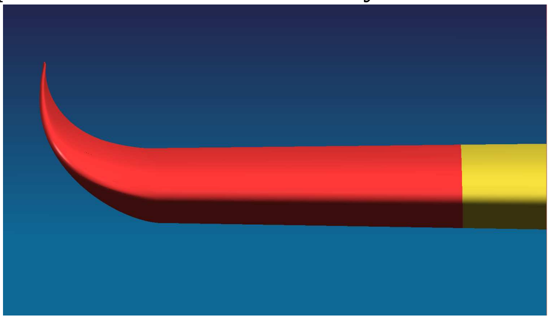

Fig. 9

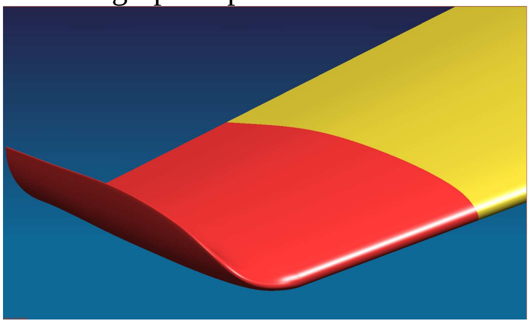

Fig. 10

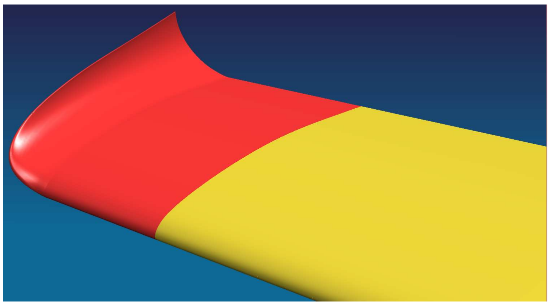

Fig.11

Elliptic - this case was provided by the firm KAPPA.

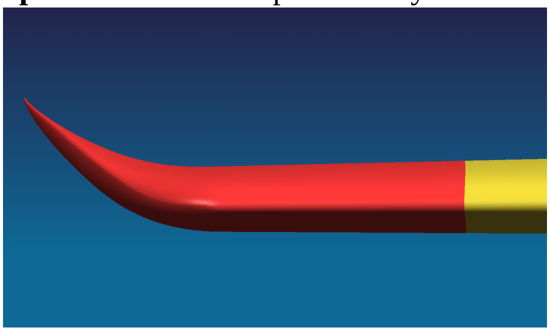

Fig. 12

Fig. 13

Fig. 14

3. Analysis of the results

The computational control volume corresponds to the wind tunnel (Fig. 15), in which the first experiment from Ing. Anderle, PhD. was made.

The walls of the wind tunnel are considered as viscous in the boundary conditions. The turbulence model was chosen k-ω SST. The computational control volume consists of c. $2{,}5.10^6$ cells.

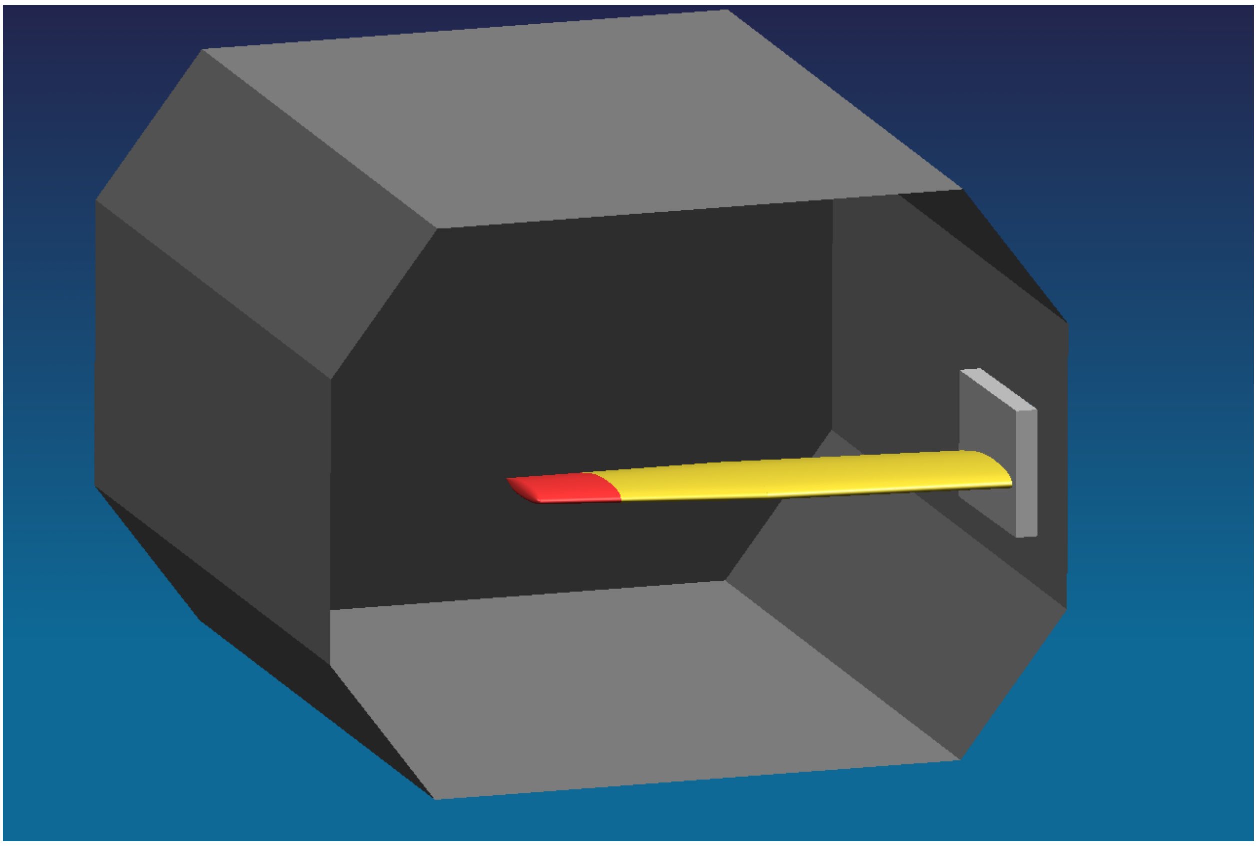

Fig. 15 *Computational control volume*

3.1. Comparing CFD and the first experiment

For the verification of the CFD method was used a wing of a glider with the wing tip called winglet from the first experiment provided by Ing. Anderle, PhD.

There was compared just the flow field behind the wing tip. Fig. 16 shows measured flow field of the experiment. Fig.17 represents computed velocity field in a plane at point of the trailing edge. The computed velocity field below and out of the winglet well corresponds with the mean velocity of the experiment with error up to 1%. The velocities above the wing are approaching more to fluctuations of the mean velocity from the experiment. The error of the CFD is up to 8% with respect to the mean velocity in this area.

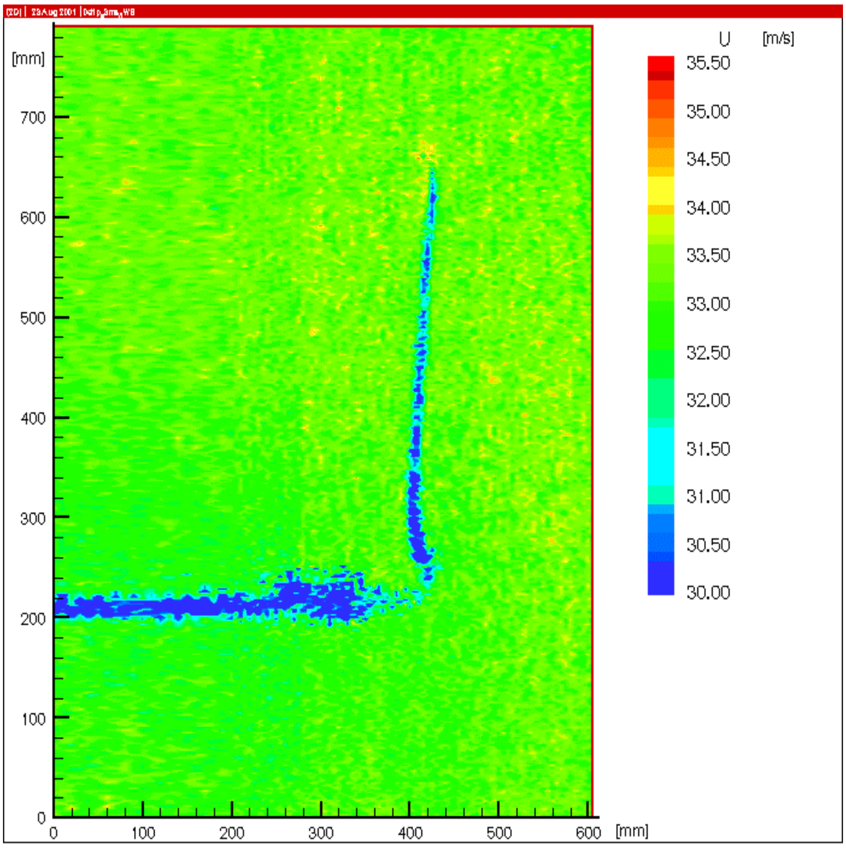

***Fig. 16** Measured velocity flow field from the first experiment*

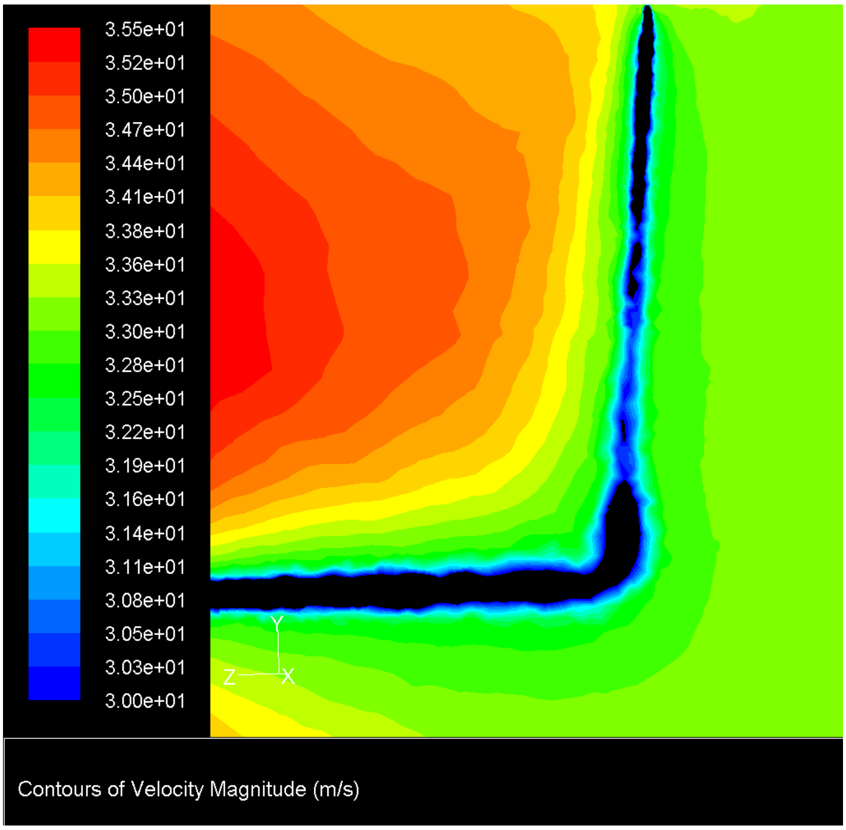

***Fig. 17** Computed velocity flow field*

3.2. CFD analysis of the wing tips

Up to now three typical flight regimes were computed: maximum horizontal speed at 0deg, optimal speed at 4deg and economical speed at 14deg. Later on there will computed also regimes for other angles of attack.

Drag coefficient and lift coefficient are defined as follows:

$$c_D = \frac{2 \cdot D}{\rho \cdot v_\infty{}^2 \cdot S} \quad \text{and} \quad c_L = \frac{2 \cdot L}{\rho \cdot v_\infty{}^2 \cdot S} \tag{1}$$

where D is drag force and L is lift force. Since some wing tips are nonplanar and the drag coefficient depends on the wetted area, it is necessary to use nonplanar reference area S placed in centerlines of the airfoils.

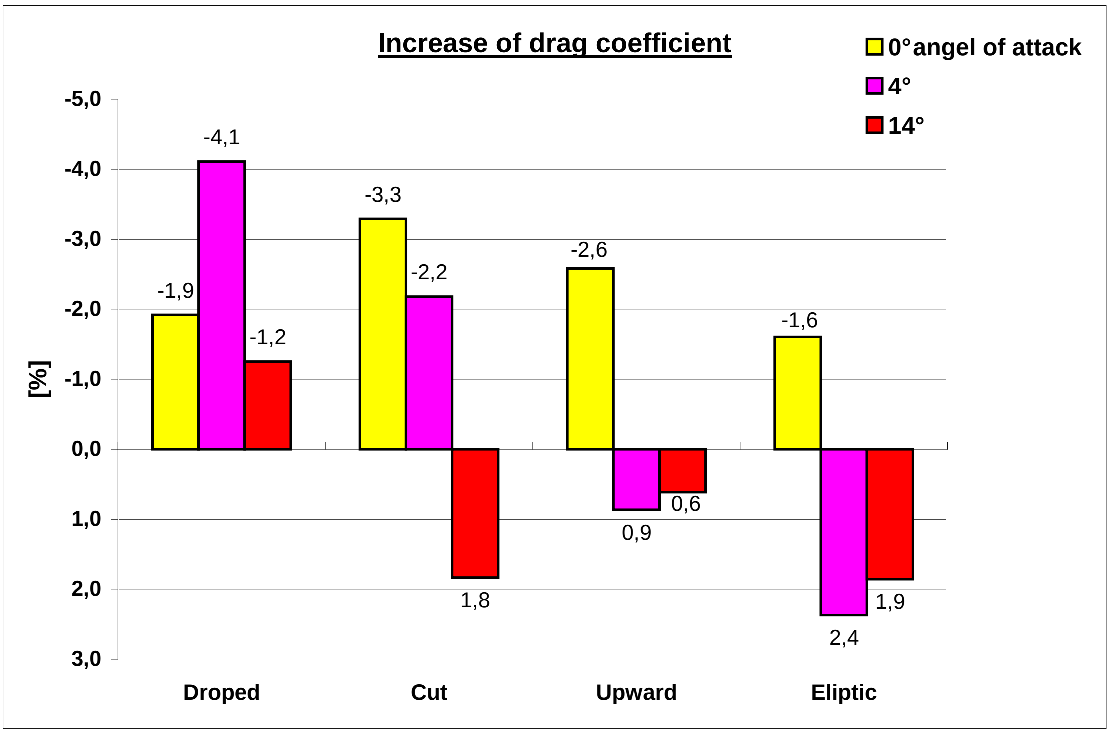

***Fig. 18** Increase of drag coefficient with respect to the reference wing tip Rounded*

The highest decrease of drag coefficient reaches the wing tip Droped up to 4% at optimal speed, see Fig. 18. It is obvious, that the wing tip oriented downwards reduce more drag than the horizontal case Cut and furthermore than the wing tip Elliptic. Except the case Droped, the influence of each wing tip descends with increasing angle of attack.

Nevertheless the flight tests have shown, that the aircraft using the wing tip Droped behave as lateral unstable. So this wing tip was modified and the new one (blue color) will be solved in CFD later, see Fig. 19.

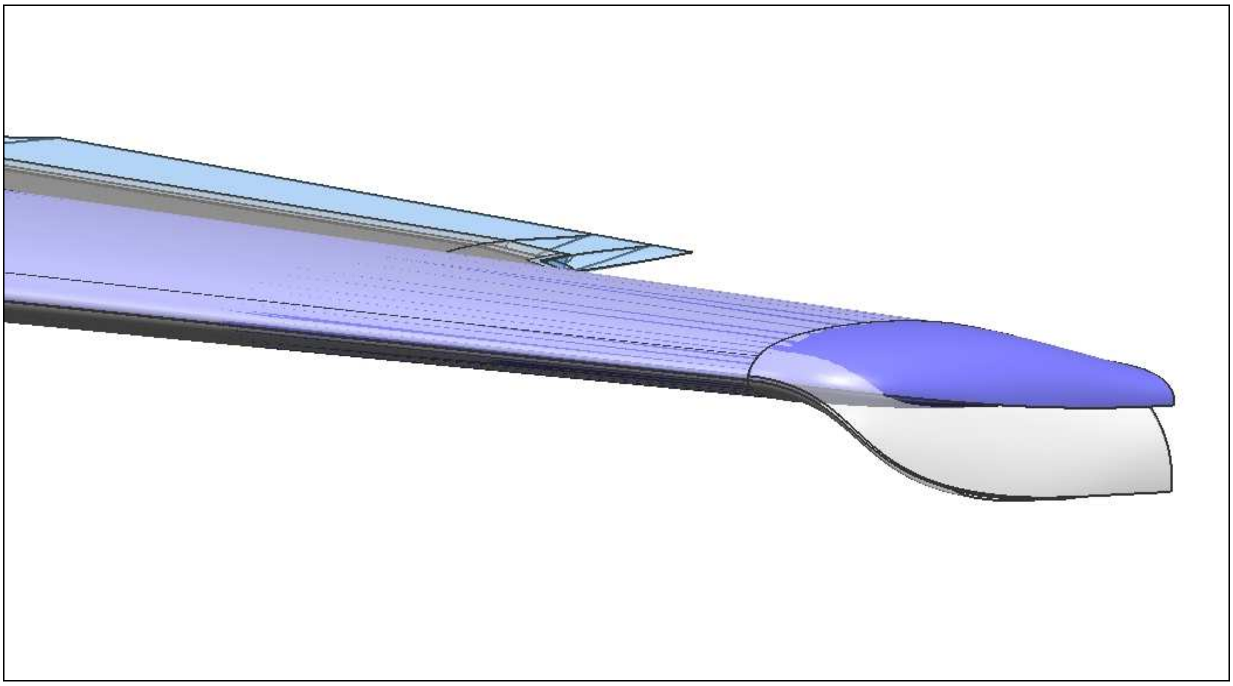

Fig. 19 *Modification of the wing tip Droped (new-blue, original-white)*

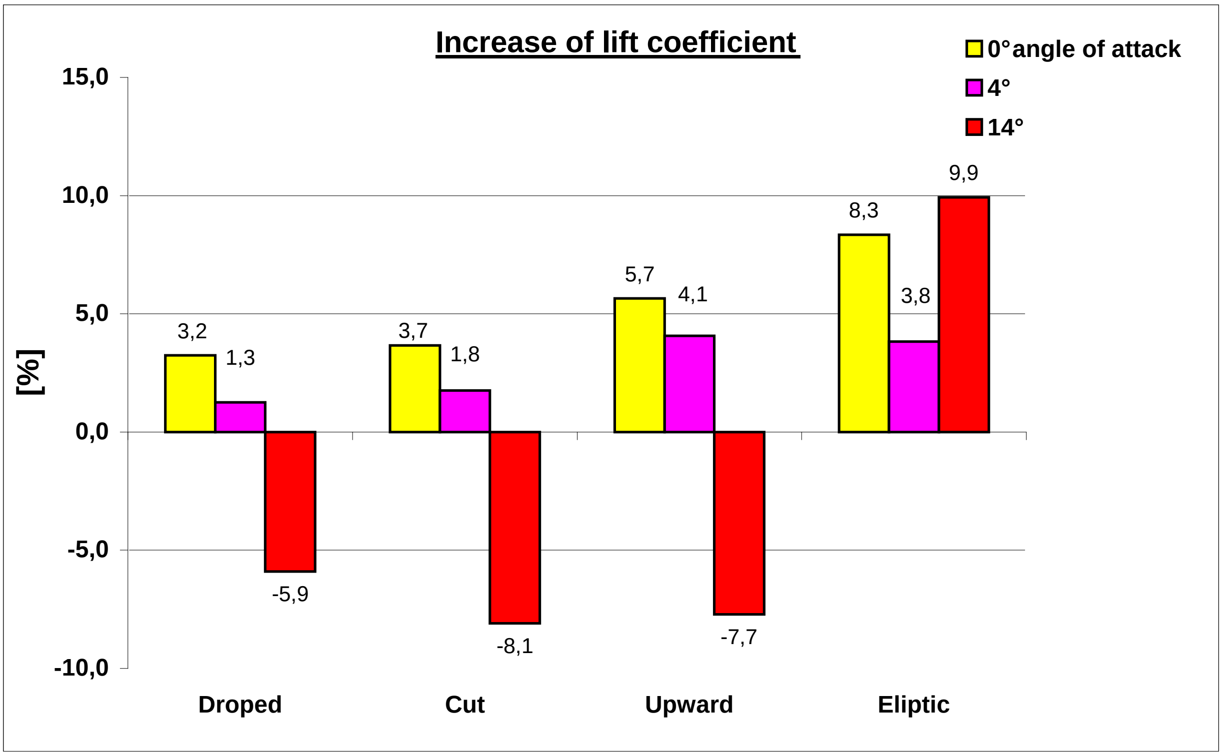

Fig. 20 *Increase of lift coefficient with respect to the reference wing tip Rounded*

Maximum increase of lift coefficient reaches the wing tip Elliptic in all flight regimes, see Fig.20. Except the wing tip Elliptic the increase of lift coefficient descends with growing angle of attack. It is obvious, that the wing tips oriented upwards gain more lift than the horizontal case Cut and furthermore than the wing tip Droped.

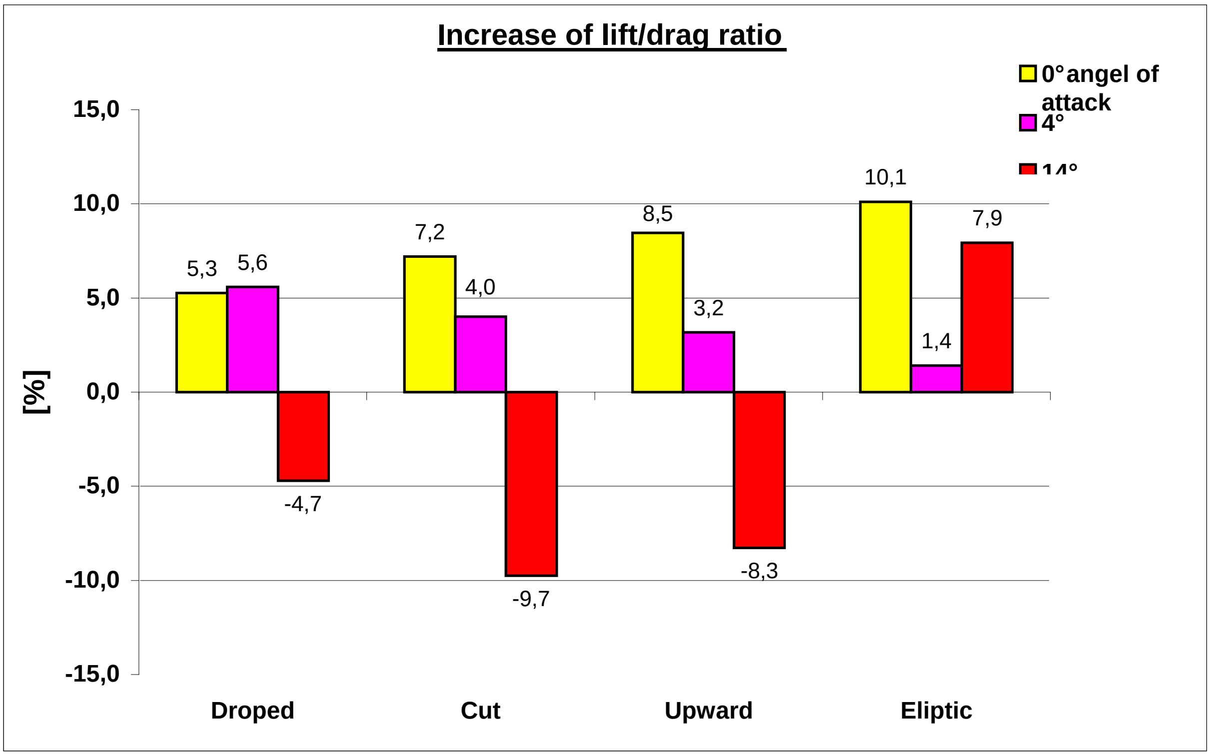

Fig. 21 *Increase of lift/drag ratio with respect to the reference wing tip Rounded*

Most of the wing tips embodies descending trend in lift/drag ratio with increasing angle of attack but except of the case Elliptic, see Fig.21. Maximum increase of lift/drag ratio reaches the wing tip Elliptic up to 10% in flight regime of maximum horizontal speed, but also even at economical speed with increase of 8%.

4. Conclusion

So far there was performed comparison with the experiment provided by Ing. Anderle, PhD. There was compared just velocity flow field with maximum error of the CFD simulation at 8%. Another comparison containing force measurement provided by VZLU is going to be proceeded later on.

Till now the wing tip Elliptic seems to be optimal in lift/drag ratio in all three flight regimes and has positive increase of lift coefficient in all flight regimes. Another advantage is the orientation of this wing tip upwards, which increases the effective dihedral and consequently improves the lateral stability.

For some aircrafts, which often operate in the flight regime of the maximum horizontal speed, would be more suitable wing tip similar to the shape like Droped or Cut. The modified shape of the wing tip Droped (Fig. 19) could be suitable, because the flight tests have already proved sufficient lateral stability. How aerodynamic efficient will be shown after CFD analyses.

In the next steps will be other wing tips analyzed. The goal is to build up general rules for design or optimalization of the shape of the wing tip for desired flight regime. These general rules are supposed to be a contribution of the dissertation thesis.

Abbreviations:

c_D	drag coefficient	[-]
c_L	lift coefficient	[-]
D	Drag force	[N]
L	Lift force	[N]
S	reference area – nonplanar surface connecting centers of airfoils	[m^2]
v_∞	free stream velocity	[$m.s^{-1}$]
ρ	density	[$kg\cdot m^{-3}$]

References:

[1] Atkinson, R.: A New Wing Tip With Improved Lift, Drag and Stall Performance; Volume 21, Number 3, Technical Soaring, July 1997

[2] Nicks, O.: A Physical View of Wing Aerodynamics; Volume 21, Number 3, Technical Soaring, July 1997

[3] Jupp, J.: Wing aerodynamics and the science of compromise; Paper No. 2686, November 2001

[4] Jupp, J.: Winglet design for sailplanes; Paper No. 2686, November 2001

[5] Butt, G.: Untersuchungen über die strukturmechanischen und aeroelastischen Einflosse von Winglets; Fakultät von Maschinenwesen, Bellshill/Schottland, Februar 1987

[6] Nicks, O.: Experimental Comparison of Two Wing Tips; Volume 14, No 3, Technical Soaring, July 1990

[7] Nicks, O.: Effects of Wing Tip Shape on Climb Performance of Gliders; Proceeding of the 4th International Symposium on the Science and Technology of Motorless Flight, February, 1984

[8] Horstmann, K.H.: Ein Mehrfach-Traglinienverfahren und seine Verwendung für Entwurf und Nachrechnung nichtplannarer Flügelanforderungen, DFVLR, Institut für Entwurfsaerodynamik, Braunschweig, DFVLR-FB 87-51, 1987

[9] van Dam, C.P.: Analysis of Non-plannar Wing Tip Mounted Lifting Surfaces on Low-Speed Airplanes, NASA Comtractor Report 3684, 1983

[10] Mortara, K.W. and Maughmer, M.D.: A Method for the Prediction of Induced Drag for Planar and Non-planar wings, AIAA Paper 93-3420, August 1993

[11] Shoratal, J.A.: Effect of Tip Shape and Dihedral on Lateral Stability Characteristics, N.A.C.A. Report No. 548, August 25, 1935

[12] Cone, C.D.: The Theory of Induced Lift and Minimum Induced Drag of Non-planar Lifting Surfaces, NASA TR-139, 1962

[13] Butt, G. M.: Untersuchungen über die Strukturmechanischen und Aeroelastischen Einflüsse von Winglets, Dissertation, Schottland, 1987