

25<sup>th</sup> ABCM International Congress of Mechanical Engineering  
October 20-25, 2019, Uberlândia, MG, Brazil

## COB-2019-1386

# Winglet Design Optimization Using A Multi-Objective Genetic Algorithm

Lucas André Colombo Gewehr

Bruno Silva de Sousa

Federal University of Itajubá, Av. BPS 1303, 37500-903, Itajubá-MG

lucasandrecg@hotmail.com

bruno\_s\_sousa@unifei.edu.br

**Abstract.** *This project proposes a method for the design of a Blended Winglet configuration using a Multi-Objective Genetic Algorithm aided with AVL's VLM aerodynamic evaluations and takeoff estimations using an iterative algorithm. The results obtained with the evaluated method of design were very satisfactory and close with the theoretical estimations, showing a 2.96% of total cruise drag reduction.*

**Keywords:** *winglet, multi-objective optimization, aerodynamics, drag reduction*

## 1. INTRODUCTION

The idea of drag reduction and fuel saving is the main focus of all modern aircraft projects. For this purpose, since the early 20th century studies began on devices made to reduce lift-induced drag on wingtips, based on the already recognized fact that nonplanar wing systems have less induced drag than planar ones. However, the first projects of a vertical plate mounted to the wingtip did not live up to the theoretical estimations due to a big increase in profile and interference drag. Later on, (Whitcomb, 1976) realized that with a proper design, these devices could effectively reduce the total drag of the airplane.

Since Whitcomb's findings there has been several changes to the methods of design and mainly the shapes of wingtip devices. Today, the most used device is the Blended Winglet which was designed to significantly reduce the interference and profile drag problems. In modern aircraft those devices can be responsible for up to 3.2% of total drag reduction (McLean, 2005), which in a long distance flight can represent large fuel savings. Even with the new technologies of the modern winglets, the design process is based on very old concepts, with reference values for some basic parameters and a general geometry already defined, which can lead to a useful but non-optimal design.

In this paper a method is presented for a blended winglet design optimization, with a theoretical review and results of a winglet designed for a SAE Brasil Aerodesign competition aircraft.

## 2. THEORETICAL BACKGROUND

One of the main consequences of lift generation is the spanwise flow, Fig. 1. At the trailing edge, the inward flow from the lower surface (high pressure) and outward flow from the upper surface (low pressure) are merged and generate a certain vorticity which is the origin of induced drag and the vortex sheet, Fig. 2. This phenomena can also be seen as a downwash angle generated by the trailing-vortex system.

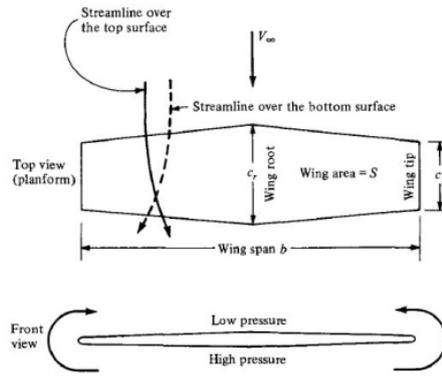


Figure 1. Spanwise flow due to pressure imbalance

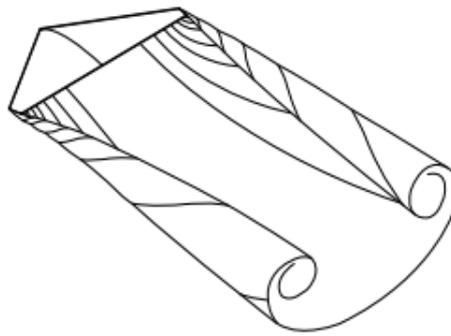


Figure 2. Vortex Sheet behind a lifting surface

The Vortex Lattice Method (VLM) is one of the most used low computational cost method for aerodynamic calculations. This method models the wing with a horseshoe vortex distribution along the wing’s span and chord and is mainly based on four classical theories: Biot-Savart Law, Kutta-Joukowski theorem, Hermann von Helmholtz theory and Prandtl Lifting-Line Theory. (Budziak, 2015) Another important consideration about VLM is the usage of a Trefftz Plane for induced drag calculations, this is what makes VLM methods suited for calculating a large variety of configurations including nonplanar wing systems.

### 3. OPTIMIZER

Considering all presented above, and specially the validity of the VLM method for the non-planar induced drag calculation, a ModeFRONTIER<sup>®</sup> workflow was built, with all aerodynamics coefficients evaluated with AVL<sup>®</sup> and takeoff parameters estimated through an iterative algorithm.

A large study was conducted to ensure that AVL<sup>®</sup> was suited for winglet calculations and the importance of  $Cl_{\alpha}$  and  $Cd_p$  corrections for the airfoil (done with CLAF and CDCL functions) was observed.

The ModeFRONTIER<sup>®</sup> algorithm used was the NSGA-II, with the controlled elitism configuration, for a better population spread and more precise convergence.

All the geometrical parameters that were varied are presented in the Tab. 1.

Table 1. Geometrical Parameters

| Parameter       | Variation Interval   |
|-----------------|----------------------|
| Initial Span    | [0,95; 1,125]m       |
| Final Span      | 1,25m                |
| Height          | [0,1; 0,3]m          |
| Tip Chord       | [0,02; 0,16]m        |
| Geometric Twist | [-2; 6] <sup>°</sup> |
| Airfoil         | [1; 9]               |
| Sweep           | [0; 40] <sup>°</sup> |

Table 2. Winglet Airfoils

| Reference Number | Airfoil      |
|------------------|--------------|
| 1                | PSU 94-097   |
| 2                | DAE-51       |
| 3                | FX 63-100    |
| 4                | GOE 596      |
| 5                | GOE 602 MOD  |
| 6                | MH 38        |
| 7                | MH 116       |
| 8                | RAF 32       |
| 9                | S4062-095-87 |

The intervals were determined according to previous studies and project limitations. Considering the general goal of the wingtip use and also the competition requirement, the main objective was set to be the total drag coefficient reduction in a cruise configuration, with an auxiliary constraint that helped maximize takeoff weight, since the competition points were based on it.

#### 4. RESULTS

After the optimizer convergence, a blended winglet was chosen. The geometrical parameters are presented in Tab. 3

Table 3. Winglet Characteristics

| Parameter       | Value         |
|-----------------|---------------|
| Initial Span    | 1.125m        |
| Final Span      | 1.25m         |
| Height          | 0.22m         |
| Tip Chord       | 0.06m         |
| Geometric Twist | 6°            |
| Airfoil         | 3 (FX 63-100) |
| Sweep           | 21,26°        |

A CFD study was conducted using StarCCM+® in a RANS configuration and the  $k-\omega$  SST  $\gamma-Re_\theta$  turbulence model with a prism layer adjusted for  $y^+ < 1$  as required for the model (Siemens, 2016).

After the CFD evaluation of the chosen model, an early boundary layer detachment was seen, this problem was fixed varying the winglet's sweep, with almost no increase in drag when compared with the VLM estimation. Figures 3, 4 and 5 show respectively both winglet geometries, the velocity over each winglet, and the comparison of the turbulent kinetic energy behind the wing with (right) and without (left) the final winglet.

The designed winglet configuration presented a cruise total drag reduction of 2.96%.

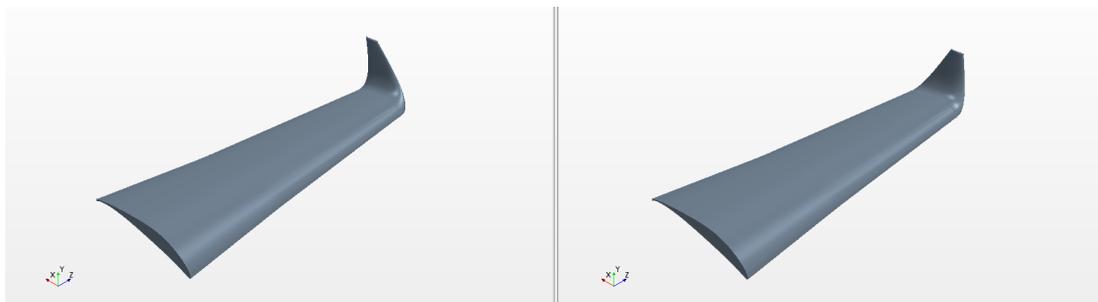


Figure 3. Winglet Geometries

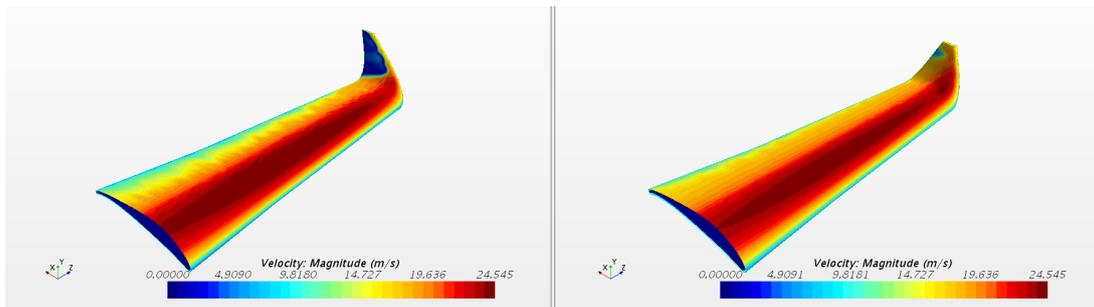


Figure 4. Velocity Distribution on Winglet Surfaces

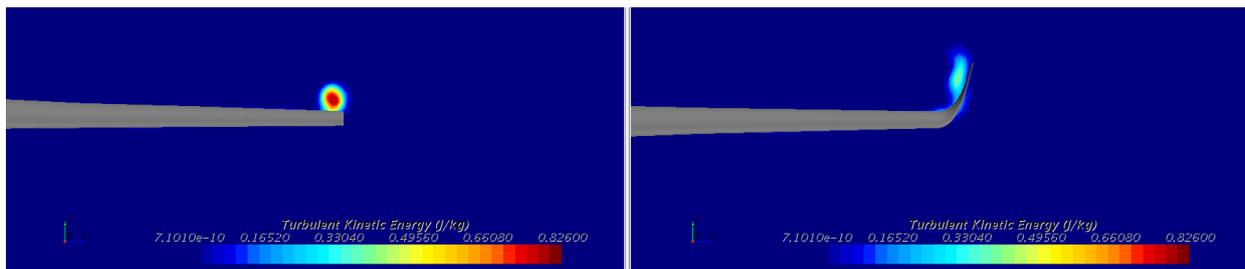


Figure 5. Turbulent Kinetic Energy

## 5. FUTURE WORK

Considering the good results of this optimization, in a close future the method will integrate cruise parameters, stability estimations and specially preliminary structural calculations, due to the increase in weight and bending moment.

## 6. REFERENCES

- Budziak, K., 2015. "Aerodynamic analysis with athena vortex lattice". *Hamburg University of Applied Sciences*.
- McLean, D., 2005. "Wingtip devices: What they do and how they do it". *Boeing Performance and Flight Operations Engineering Conference*.
- Siemens, 2016. "Star-ccm+ user guide".
- Whitcomb, R.T., 1976. "A design approach and selected wind tunnel results at high subsonic speeds for wing-tip mounted winglets". *NASA Technical Notes*, Vol. D-8260.

## 7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.