Delft University of Technology

Engineering Optimization – Concepts and Applications

ME46060

Final Project Proposal

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May 7, 2021

1 Background

As a result of the normal wash created by the circulation over the wing tip, a winglet generates a force with a forward component. This forward component acts as a thrust force, decreasing the aircraft induced drag, which accounts for around 40% of total drag in cruise and 80–90% in climb. Although adding a winglet to a wing can improve aerodynamic efficiency, it also increases the structural weight of the wing. As a consequence, purely aerodynamic optimization can result in an unacceptably heavy wing. Since more lift is needed to support the heavier aircraft, the beneficial effect of drag reduction can be negated, resulting in increased induced drag. As a result, designing a winglet is a clear multidisciplinary optimization process.

AVL [1] is to be used as the model of the optimization problem to provide the aerodynamic forces (lift and drag) for a certain wing design. The lift distribution over the wing chord is integrated using a quadrature rule, implemented in MATLAB to obtain the shear force as follows:

$$S = \int_0^{b/2} C_l c q dy \tag{1}$$

where q is the dynamic pressure, C_l is the lift coefficient of the airfoil (user defined) and c is the chord length at each wing section.

The wing structural weight can be assumed to be proportional to the root bending moment. The wing bending moment (M) is defined as the integral of the shear force over the span as shown in Equation 2 which is also performed externally in MATLAB.

$$M = \int_0^{b/2} S(y) dy \tag{2}$$

An example of an AVL wing setup is shown in Figure 1

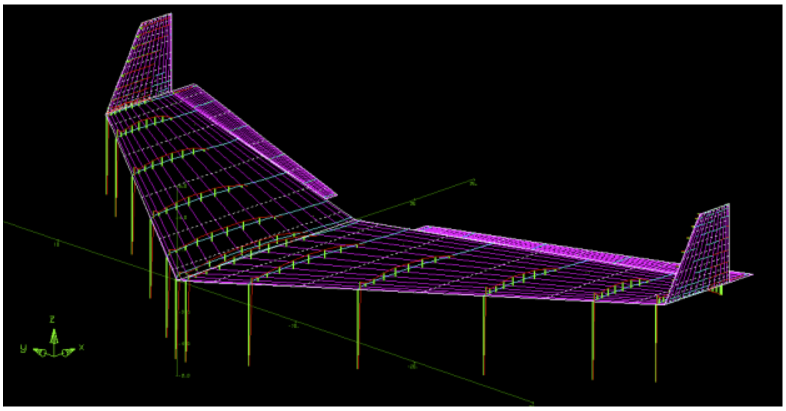

Figure 1: AVL wing setup

2 Problem Considered

2.1 Objective function

In this study the design of a winglet is to be optimized for both minimum induced drag (C_{D_i}) and minimum root bending moment (M_{r_0}) (a multi-objective optimization) for a given wing planform. The multi-objective function can be written as the weighted sum of the scaled individual objectives as:

$$J = k\frac{C_{D_i}}{C_{D_{i_0}}} + (1-k)\frac{M_r}{M_{r_0}} \tag{3}$$

Where $C_{D_{i_0}}$ and M_{r_0} are the induced drag and root bending moment of the planar (winglet-free) wing, respectively. The factor k is a weighting coefficient that signifies the relative importance of the objective function components and varies between 0 and 1.

[1] AVL is a program for the aerodynamic and flight-dynamic analysis of rigid aircraft of arbitrary configuration

2.2 Design Parameters

The winglet geometry can be defined using the parameters listed below and shown in Figure 2. Some of which can be used as design variables for the optimization problem.

- The root chord (C_{w_r})
- The taper ratio (λ_w)
- The length (l_w)
- The leading-edge sweep angle (Λ_w)
- The cant angle (ϕ_w)
- The twist (toe out) angle at the root (ϵ_{w_r})
- the twist at the tip (ϵ_{w_t})

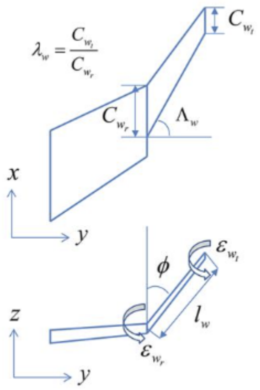

Figure 2: Winglet gometry

2.3 Constrains

The constraints are divided into two categories. The first is the design variables range to make sure that the optimized value is physically possible. The design variables should be bounded as follows:

$$
\begin{gathered}
l_{w_{min}} \leq l_w \leq l_{w_{max}} \\
\phi_{w_{min}} \leq \phi_w \leq \phi_{w_{max}} \\
C_{w_{r_{min}}} \leq C_{w_r} \leq C_{w_{r_{max}}} \\
\lambda_{w_{min}} \leq \lambda_w \leq \lambda_{w_{max}} \\
\Lambda_{w_{min}} \leq \Lambda_w \leq \Lambda_{w_{max}} \\
\epsilon_{w_{r_{min}}} \leq \epsilon_{w_r} \\
\epsilon_{w_t} \leq \epsilon_{w_{t_{max}}}
\end{gathered} \tag{4}
$$

The second category of constraints entails functions that should not exceed a certain value such as the skin friction drag. Having a larger winglet could be beneficial to reduced the induced drag, but it will cause an increase in the skin friction drag. The skin friction drag is a function of total surface area of the winglet and hence the winglet design variables. Therefore, the skin friction drag needs to be reevaluated at every possible optimal design points. For that purpose, a constraint needs to be imposed on the allowed increase in skin friction.

$$D_f \propto A$$

where D_f is the frictional drag and A is the total surface area of the wing which is a function of the winglet design parameters. The maximum allowed increase in skin friction drag could be set to 5% and formulated as follows:

$$\frac{D_f}{D_{f0}} - 1 < 5\%$$

Where D_{f_0} is the skin friction drag of the initial wing without the winglet.