Assignment 4: Vortex induced drag analysis of planar and non-planar wings

Academic year: 2024-2025

Full Name:	
Student Number:	
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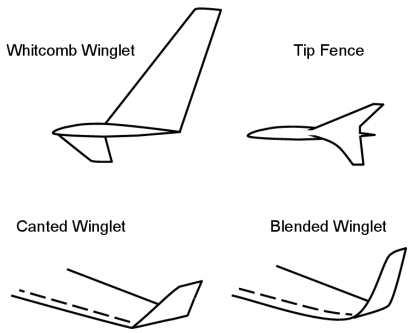

Requirements

- Personal / group task: personal
- Handwritten drawings must contain a visible signature to its side
- Be as complete as necessary, as succinct as possible

Background

Examining aircraft performance enhancement, it is interesting to explore the optimization possibilities for the aerodynamics and associated structural loading of wings with non-planar configurations. Since Whitcomb's early work, winglets have been employed for decades to enhance the aerodynamic efficiency of aircraft. For a detailed understanding of the aerodynamic principles governing winglets, refer to [1]. In essence, a winglet generates a force, primarily forward due to the normalwash created by the circulation over the wing tip. This forward force acts as thrust, mitigating the induced drag of the aircraft, which constitutes approximately 40% of total drag during cruise and 80–90% during the second climb segment. While adding a winglet may seem appealing for aerodynamic performance, it has implications for the structural weight of the wing.

Consequently, a purely aerodynamic optimization might yield a winglet with an undesirable weight penalty. This additional weight could counteract the positive effects of drag reduction. Thus, designing a non-planar wing involves a complex multidisciplinary optimization process. In this assignment we only concentrate on the aerodynamics of non-planar wings and winglets. The structural aspects, that would change the optimum layout is left to other courses.

Tasks

In a wing design process, the choice of either selecting a winglet or a tip extension for performance improvement is quite a challenge. For example, in the recent designs of Boeing and Airbus, the Boeing 787 has a *raked* wing tip, while the Airbus A350 has a *blended* winglet, see Fig. 1.

Fig. 1 B787 raked wing tip (left) vs. A350 blended winglet (right).

In these tasks you will perform the analysis of wings with and without a winglet. The initial wing planform geometry (referred to as Wing-1) and dimensions are shown in Fig. 2, as well as the adapted wings whose planform will affect the vortex induced drag.
In principle, the winglet geometry can be defined using 7 design variables, to wit: 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, the twist (toe out) angle at the root, ϵ_{w_r}, and at the tip, ϵ_{w_t} (see Fig. 3).

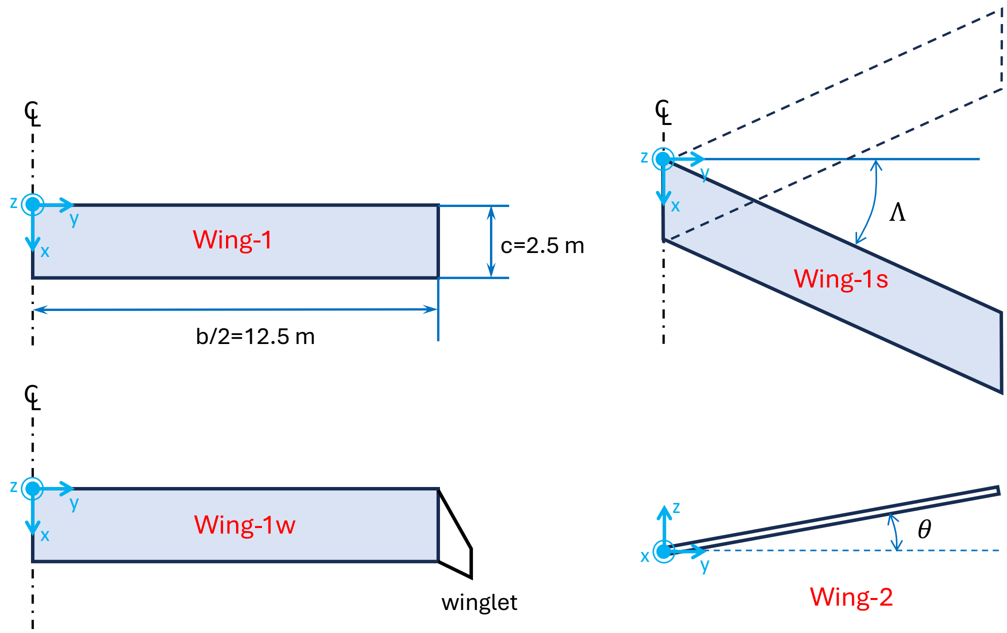

Fig. 2 The wing planforms used in this assignment. Dimensions in meters. Wing-2 is the same as wing-1 but now with non-zero dihedral angle.

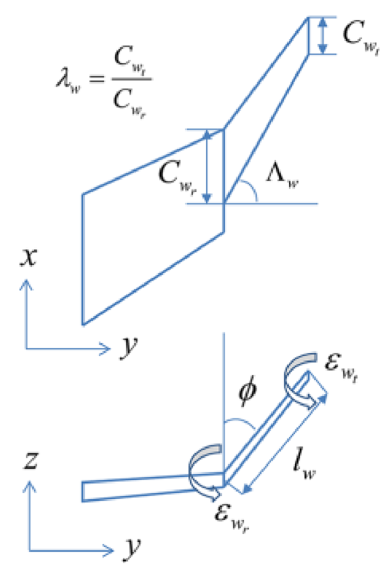

Fig. 3 General parameters defining the winglet geometry.

With respect to the geometry of wings and winglet the following constraints apply:

- For all wings **maintain the aspect ratio**, A, and the **wing area**, S_{ref}, as defined by *wing-1*. The value of S_{ref} is based on the main wing only (thus without the winglet).
- Keep the taper ratio of the wing at $\lambda = 1$
- The winglet root chord is equal to the wing chord: $c_{w_r} = c$.

With respect to the flight conditions select the following:

- Mach number, $M = 0.4$
- Altitude, $h = 5000m$
- Wing lift coefficient, $C_L = 0.4$

Qualitative information.

1. For a minimum induced drag winglet, a relation exists between the so-called normalwash velocity, V_n, and the dihedral angle, θ (this is not the cant angle). Provide this relation and explain, in your own words, what this means for the aerodynamic design of a winglet. Support your explanations with **hand-drawn sketches** in the boxes below

2. Explain in your own words why adding a winglet to a wing with fixed span might increase the aerodynamic performance.

3. Discuss and add drawings on how a zero-degree cant angle winglet design/layout (so vertical) might be adapted to prevent:
    a. detrimental effect of boundary layer growth
    b. compressibility effects (if the winglet is applied in a high Mach number design).

4. For the analysis of the induced drag of a wing we may use the so called Trefftz Plane Analysis. Write down (handwritten) the integral and explain what this equation entails.

Discuss the advantages and limitation of applying the Trefftz plane technique both in windtunnels and numerical simulations.

Quantitative analysis

1. Perform the following analysis to investigate the difference between tip extensions and winglets.
   a. Download and install the vortex lattice model of *AVL* and make yourself familiar with it (download: http://web.mit.edu/drela/Public/web/avl).
   b. Calculate the induced drag of *wing-1* for the given flight conditions.
   c. Then add a winglet to produce *wing-1w*. The dimensions of the winglet that you select should be typical as found on existing aircraft designs. Provide an image of wing-1w.

d. Calculate the induced drag of wing-1w for cant angles, ϕ, from 0 to 90 degrees. (a 90 degrees canted winglet is in fact a tip extension). Plot the induced drag versus the cant angle under the above stated flight conditions.

e. Discuss the effect of the cant angle on the induced drag and compare with the result for *wing-1*. Discuss which is the best design considering <u>only the aerodynamic performance</u>.

In the following tasks we are interested in the effect of <u>wing sweep</u> and <u>dihedral</u>.

f. Select a (moderate) sweep angle (either positive or negative) to produce *wing-1s* and calculate the induced drag. Do the same using a dihedral angle of $\theta = 10\ deg$ to produce *wing-2*. Show the planforms of these wings in the box below.

g. Calculate the induced drag of the adapted wings and compare the results to those of the straight wings, *wing-1* and *wing-1w* (provide plots and table). Make sure that the lift coefficient(s) at which the data are compared is clearly stated.

h. Discuss which wing you would prefer for a regional aircraft flying at the above stated cruise condition.

References

[1] Engineering Science Data Unit (ESDU), 98013, Aerodynamic Principles of Winglets, June 1998.