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On the effect of deformation in a wing model on the correlation of the lift slope

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Deformed wing models with a NACA0012 airfoil are analyzed experimentally in a wind tunnel at the University of Malaga. Measurements show the influence of the level of the deformation on the lift coefficient and, therefore, on the slope of the lift coefficient versus the angle of attack. In general, the deformation increments the value of the lift coefficient. This gain is more noticeable for higher wind models (or higher aspect ratios) and when the wing models are tested at higher Reynolds numbers. We estimated the value of the lift slope with a correlation as a function of Reynolds number and aspect ratio, showing an excellent agreement.

1 Introduction

Traditionally, aerodynamic studies have focused on a few key aerodynamic parameters such as lift, drag and lift slope (change in lift with varying angle of attack). There are multiple studies on different wing models depending on the application. Nowadays, aircraft wings are made of lighter materials, resulting in thinner wing models. These wings have a deformation associated with flight conditions, see Afonsoa *et al.* (2017) for a review of recent developments in aerospace related to high aspect ratio wings with deformations.

The influence of wind deformation on the lift coefficient and, therefore, on the lift slope has only been recently studied by (Zhong *et al.*, 2018). Our experiments further analyze this influence using rigid models with imposed deformation to isolate the effect of the deformation. Specifically, this study focuses on including the effect of deformation on a correlation to compute the lift slope.

2 Results

As mentioned above, the lift slope is a key criterion for any initial wing design. Therefore, we aim to find a correlation to obtain $C_{L\alpha}$ (the slope of the lift coefficient versus the angle of attack) as a function of the aspect ratio and the Reynolds number. We have experimentally measured different wing models using rigid wings with and without an imposed deformation. The deformation is chosen from real measurements of wing deformations from Farnsworth *et al.* (2015). The effect of the deformation on the lift coefficient is clear for big aspect ratios and Reynolds numbers (see figure 1). Note also that the deformation level and the lift coefficient change are not linearly related.

At this point, it is interesting to discuss if a first approximation for the $C_{L\alpha}$ value for the NACA0012 profile can be computed by using the correlation provided by Gutierrez-Castillo *et al.* (2021) for the flat plate with non-infinite wing aspect ratio adjusting the parameters α_1 and α_2. The equation of that reference is repeated here for clarification purposes.

$$C^*_{L\alpha} = \left(\frac{2\pi}{1+\alpha_1 * AR^{-1}}\right)\left(\frac{\alpha_2}{1+10^6/Re}\right)^{1/5} \tag{1}$$

with $\alpha_1 = 5.21$ and $\alpha_2 = 14.61$ (for flat plate).

Adjusting the same formula to our results for the NACA0012 profile. We obtain a $R^2 = 0.98$ using the parameters $\alpha_1 = 4.89$ and $\alpha_2 = 4.72$ for models without deformation. Therefore, the correlation is still useful in our ranges of aspect ratio and Reynolds number.

It is interesting how this correlation can approximate cases even with the deformation. In order to try to isolate the effect of the deformation, the same correlation was used for the deformed cases but fixing $\alpha_2 = 4.72$. Therefore, including the changes con $C_{L\alpha}$ produced by the deformation in the parameter α_1 that is equivalent to changing the wing size.

For the intermediate deformation cases, we obtained $\alpha_1 = 4.59$ and $R^2 = 0.98$, and for the big deformation cases, we obtained: $\alpha_1 = 4.63$ and $R^2 = 0.99$. To provide a better understanding, we depict in figure 2 the representation of the measured lift slope $C_{L\alpha}$ and the estimated one $C^*_{L\alpha}$. Observing the good results, we can conclude that the effect of the de-

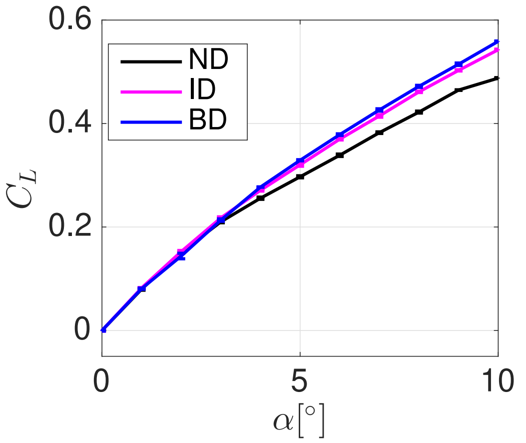

Figure 1: Lift coefficient versus angle of attack for models of $AR = 4$ at $Re = 160000$. Three wing models: non-deformed (black), intermediate deformation (pink), big deformation (blue)

formation can be absorbed in the α_1 parameter and, therefore, including a deformation in the spanwise direction is equivalent in terms of the $C_{L\alpha}$ to change the wingspan length in the wing model.

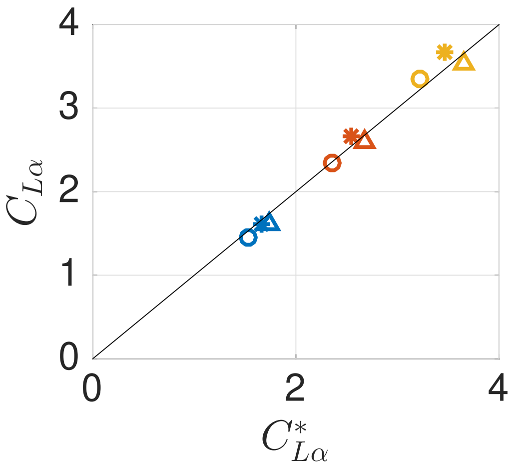

Figure 2: Lift slope $C_{L\alpha}$ versus the estimated lift slope $C^*_{L\alpha}$. Circles represent cases of Re=80000, starts Re=120000 and triangles Re=160000. Blue color corresponds to cases with $AR = 1$, red color $AR = 2$ and yellow color $AR = 4$.

3 Conclusions

We have shown that it is possible to properly include the level of the deformation of a wing model on a correlation to approximate the value of the lift slope for different cases with NACA0012 wing models. Remarkably, the effect of the deformation can be absorbed only by one geometric parameter. Therefore, the effect of deformation on the computation is equivalent to varying the wingspan length in the wing model.

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