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Wing Geometry Design Using Glauert's Method

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Abstract: Glauert's solution of Prandtl's lifting line theory is a quick method widely used for analysis of the spanwise lift distribution on planar wings. In this article, its use on an inverse problem is demonstrated. The concept is tested by morphing the initial rectangular wing planform to reach demanded lift distribution. Results are compared with theoretical assumptions, solution obtained from CFD simulation and tunnel measurement results.

At the beginning of each aircraft design its concept and configuration has to be set. Planform of the wing in this early stage of the project results mostly from designer's experience. Then is the geometry modified iteratively until desired spanwise lift coefficient distribution and stall characteristics of the wing are reached. Glauert's solution of Prandtl's lifting line theory is suitable for this type of preliminary analysis on wings with higher aspect ratio. This paper demonstrates feasibility of this method also for preliminary design of the wing planform from known lift coefficient distribution.

For testing purposes, the initial rectangular wing planform was modified to reach the target shape with lift coefficient known from literature or CFD computations. Since the lift coefficient in each section is proportional to its chord, based on equation

$$c(\theta) = \frac{4 \cdot b \cdot \sum_n A_n \cdot \sin(n \cdot \theta)}{c_l(\theta)} \tag{1}$$

from the lifting line theory it is possible to manipulate dimension directly. Then the normalization of the wing area is necessary, so the aspect ratio of the wing remains constant. Number of iterations needed depends on required accuracy and complexity of the target function, but entire process is very fast on today's computers.

Early test cases were very simple and compared only against the also lifting line based software Glauert III, which is used at the Institute of Aerospace Engineering for preliminary analyses of the lift coefficient distribution. Then more realistic arrangements were examined, where the best fitting variant was that including complete lift curves of used airfoils at the input. This approach requires higher effort in pre-processing stage and longer computational times, but considering the overall speed of computations with the lifting line theory is this cost still tolerable.

Fig. 1 shows the wing cord distribution along the wingspan designed according to the reserve in lift coefficient prescribed for each section. Because of better accuracy nonlinear inputs for each of 75 sections were used. Approximately 30 iterations were needed to complete the solution with total wall clock time less than 30 seconds. It was found, that the best performance of this design method corresponds to prescribed reserve with the form of the smooth curve.

As is presented, the method can be used especially for design of composite wings, where the planform shape can be manipulated freely. Accuracy of results is sufficient for the preliminary design unaffected by the fuselage, which can change aerodynamic characteristics of the aircraft significantly. The main advantage of this method is absence of the manually driven iterative design process, but the result represents only the aerodynamicist's point of view and in some cases can be rejected by structural engineers as unacceptable. In conclusion, additional constrains for the wing planform and also the manipulation of the spanwise twist distribution should be involved.

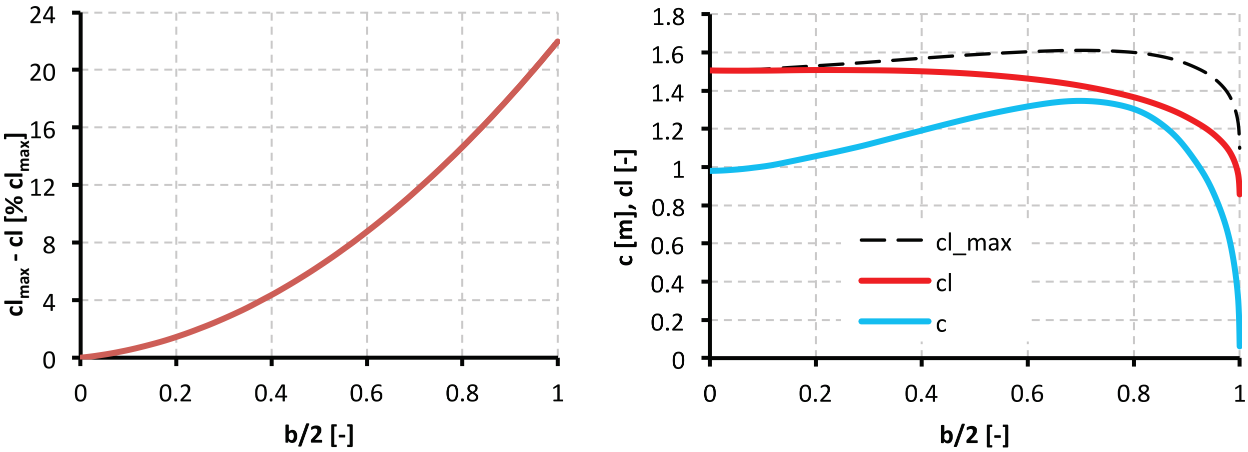

Fig. 1: Prescribed reserve in sectional lift coefficient (left) and corresponding wing chord and lift coefficient distribution obtained from nonlinear lifting-line theory (right)

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