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Memo

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From:
Daniel Schiktanz
Aero – Aircraft Design and Systems Group
Department of Automotive
and Aeronautical Engineering
Hamburg University of Applied Sciences
Berliner Tor 9, 20099 Hamburg

Tel.: +49 40 42875 8827
Mail: daniel.schiktanz@haw-hamburg.de

To:
Prof. Dieter Scholz
Aero – Aircraft Design and Systems Group

Copy to:
Ricardo Caja-Calleja

Wing Incidence Angle and Twist Estimation of the Current Box Wing Configuration

Contents

Symbols

A	aspect ratio
C_L	lift coefficient
C_{L_α}	lift curve slope
k	free parameter
i	incidence angle
M	Mach number

Greek

α	angle of attack
ε	downwash angle
ε_t	wing twist
λ	taper ratio
φ	sweep angle

Indices

0	zero lift
25	25% of the chord length
50	50% of the chord length
aft	aft wing
CR	cruise
fwd	forward wing
H	height
M	at Mach number
M=0	incompressible
w	wing

1 Background

For the analysis of the flight dynamics of the box wing aircraft the aerodynamic derivatives for several flight conditions are needed, so a proper definition of the wing geometry is needed as well. This also includes the incidence angles as well as the twist of the wings.

The starting point is the requirement that the cabin floor is supposed to be horizontal in cruise, so that the crew/passengers do not have to walk uphill/downhill in the cabin.

2 Method of Estimation

According to **Roskam 1986** the incidence angle of a wing can be estimated with the following equation:

$$i_{w,root} = \frac{C_{L,CR}}{C_{L_\alpha}} + \alpha_0 - 0{,}4\,\varepsilon_t \tag{2.1}$$

where

$$\varepsilon_t = i_{w,tip} - i_{w,root} \quad . \tag{2.2}$$

Equation (2.1) is only applied to the forward wing. For the aft wing the incidence angle is incremented by the downwash angle ε due to the downwash of the forward wing, so:

$$\left(i_{w,root}\right)_{aft} = \left(\frac{C_{L,CR}}{C_{L_\alpha}}\right)_{aft} + \alpha_{0,aft} - 0{,}4\,\varepsilon_{t,aft} + \varepsilon \quad . \tag{2.3}$$

The downwash angle is estimated with

$$\varepsilon = \left(\frac{\mathrm{d}\varepsilon}{\mathrm{d}\alpha}\right)_{fwd} \cdot \alpha_{fwd} \tag{2.4}$$

where, according to **DATCOM 1978**,

$$\left(\frac{\mathrm{d}\varepsilon}{\mathrm{d}\alpha}\right)_{fwd} = 4{,}44 \cdot \left(k_A \cdot k_\lambda \cdot k_H \cdot \sqrt{\cos\varphi_{25}}\right)^{1{,}19} \cdot \frac{\left(C_{L_\alpha}\right)_M}{\left(C_{L_\alpha}\right)_{M=0}} \quad . \tag{2.5}$$

The k-parameters are given with

$$k_A = \frac{1}{A_{fwd}} - \frac{1}{A_{fwd}^{1,7}} \quad , \tag{2.6}$$

$$k_\lambda = \frac{10 - 3\lambda_{fwd}}{7} \quad \text{and} \tag{2.7}$$

$$k_H = \frac{1 - |z_H / b|}{\sqrt[3]{2l_H / b}} \quad . \tag{2.8}$$

The needed geometry parameters are shown in Fig. 2.1

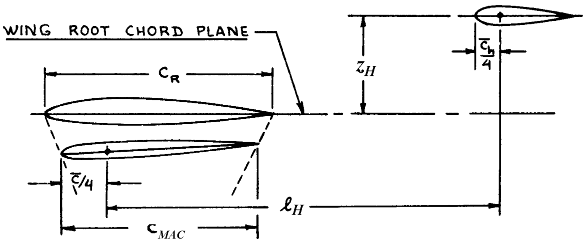

Figure 2.1 Geometry parameters for the determination of the downwash angle (**Roskam 1986**)

Effects of the upwash of the aft wing on the forward wing are neglected.

2.1 Cruise Lift Coefficients

The individual cruise lift coefficients are given according to the box wing sizing spreadsheet. They depend on the CG position of the aircraft (**Schiktanz 2011**). The lift coefficients shown in Fig. 2.2 result when assuming that the aircraft flies with a weight of 70 t under cruise conditions.

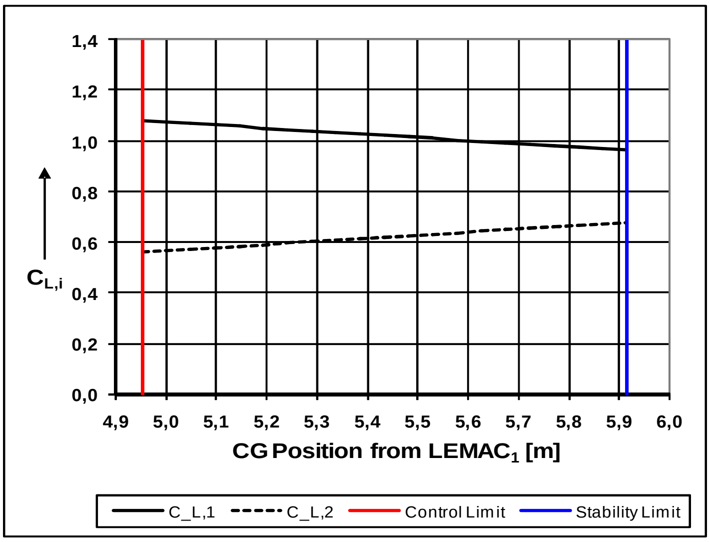

Figure 2.2 Individual lift coefficients depending on the CG position

The incidence angles have to be chosen for a single CG position. **For other CG positions the needed lift coefficients have to be achieved with the help of the control surfaces.** The approach is to set the incidence angles so that the lowest lift coefficient of each wing according to Fig. 2.2 is achieved without any control surface deflection. This way the wings have to produce extra lift by a downward control surface deflection for trimming the aircraft for deviating CG positions. If the incidence angles were chosen differently there are cases were the control surfaces would have to decrease the lift coefficient which does not make much sense. The adjustments of the individual lift coefficients may be realized with the help of **variable camber**.

2.2 Lift Curve Slopes

The lift curve slope of each wing is calculated acc. to Eq. (2.9) coming from **Scholz 1999**:

$$C_{L_\alpha} = \frac{2\pi A}{2+\sqrt{A^2\cdot\left(1+\tan^2\varphi_{50}-M^2\right)+4}} \quad . \tag{2.9}$$

Effects of the winglets on the lift curve slope of the individual wings are neglected at this stage.

2.3 Zero Lift Angles of Attack

The zero lift angles of attack α_0 depend on the airfoil. The chosen airfoils are supercritical and belong to the second generation of NASA supercritical airfoils. For the forward wing the airfoil SC(2)-1010 is chosen, for the aft wing the airfoil SC(2)-0712 (see Fig. 2.3). The first two digits after the dash stand for the design lift coefficient, the last two digits for the airfoil thickness. The coordinates of these airfoils are given in **Harris 1990**. According to **AID 2011** the zero lift angles of attack of these airfoils are:

SC(2)-1010: -7,5°
SC(2)-0712: -5,0° .

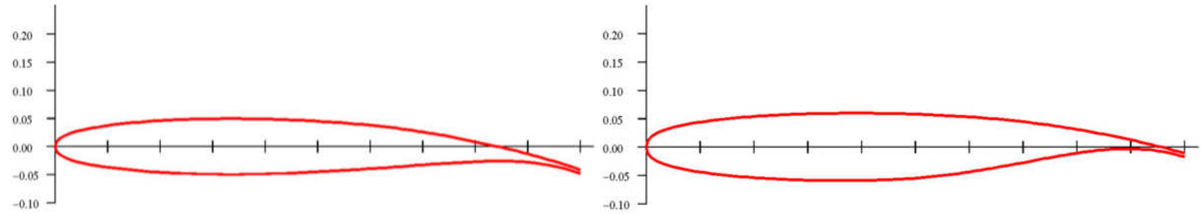

Figure 2.3 SC(2)-1010 airfoil (left) and SC(2)-0712 airfoil (right) (**AID 2011**)

2.4 Wing Twist

According to **Raymer 1992** wing twist typically ranges from 0° to -5°. This number applies to conventional wings which are swept aftwards. Here twist is used to avoid tip stall which is a characteristic of untwisted and aft swept wings. For untwisted forward swept wings the stall occurs first at the wing root. However, forward swept wings are also highly susceptible to static aeroelastic divergence. Since the aft wing of the box wing aircraft has a lower lift coefficient than the forward wing, stall plays a minor roll here. This is why a washout of the aft wing is desired for avoiding static divergence.

So at first the twist is estimated to be -3° for both the forward and the aft wing. At this stage of the investigation the effects of twist regarding the lift distribution are not considered in the estimation.

3 Results

The calculations acc. to Eqs. (2.1) and (2.3) are performed with the help of the box wing sizing spreadsheet for different CG positions. The results are shown in Fig. 3.1.

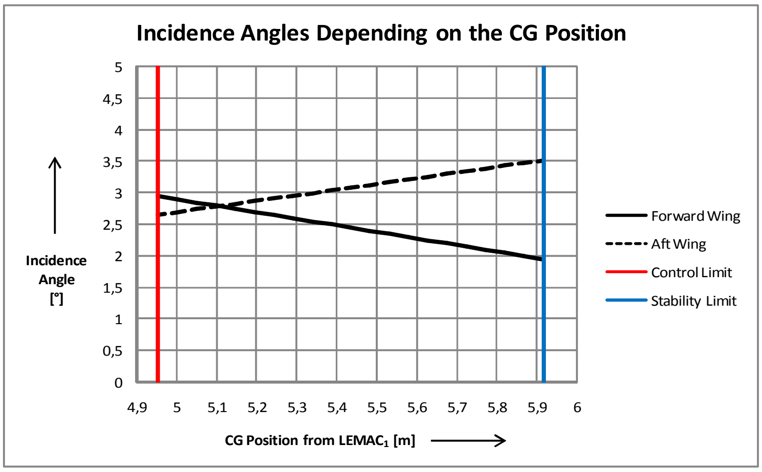

Figure 3.1 Wing incidence angles depending on the CG position

As it is shown in **Schiktanz 2011**, the lift coefficients of the individual wings depend on the CG position. Consequently the incidende angles of the wings of the box wing aircraft also depend on the CG position, as it can bee seen in Fig. 3.1. However, each wing can only have one single incidence angle. In section 2.1 it was argued that the incidence angles are chosen so that the lowest required lift coefficient is achieved without any control surface deflection. Hence the lowest value of each incidence angle is chosen according to Fig. 3.1. Consequently the incidence angle of the forward wing is 1,95° and that of the aft wing is 2,65°.

Taking account of the chosen wing twist, this results in the distribution of incidence angles shown in Fig. 3.2. At this point of the analysis it is assumed to be linear. Note that these numbers are preliminary and might be adjusted according to the results of forthcoming investigations.

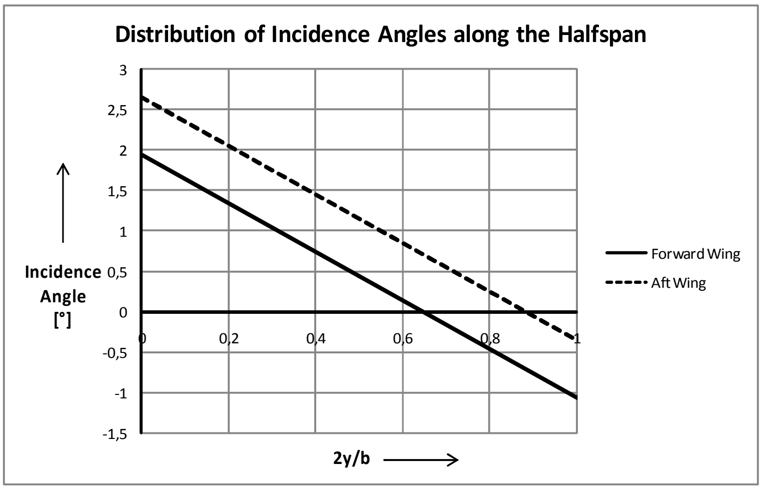

Figure 3.2 Distribution of incidence angles along the halfspan

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