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Camber Derivatives and Two - dimensional Tunnel Interference at Maximum Lift

By

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of the Aerodynamics Division, N P.L.

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Camber Derivatives and Two-dimensional Tunnel Interference at Maximum Lift.

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19th April, 1950

The following discussion concerns the corrections due to lift effect* in tunnel tests of an aerofoil in two-dimensional flow. The circulation round the aerofoil is usually represented by a bound vortex at the centre of pressure, the influence of the boundaries of the working section being deduced from the induced field of the appropriate system of images. The chordwise variation of the upwash (i.e. the transverse component of the induced velocity) gives rise to an effective curvature of flow, which produces an effective change of aerofoil camber (aerodynamic camber) combined with an effective change of incidence corresponding to the upwash at mid-chord. These are discussed separately below, and several alternative forms for the corrections in a closed-throat tunnel are set out in Tables 1-5.

Aerodynamic Camber.

In practice the correction due to aerodynamic camber is converted to an equivalent change in lift, pitching moment, etc. (Table 1). It is therefore necessary to know the values of the camber derivatives $\partial C_L/\partial\gamma$, $\partial C_m/\partial\gamma$, etc. It is usually assumed that these may be taken to be the same as the theoretical values for a parabolic arc, or preferably (to allow for boundary-layer effects) those given by the semi-empirical relations suggested in Ref.1, namely

$$a' \left(= \frac{\partial C_L}{\partial \gamma} \right) = 4\pi \frac{a_1}{a_{1T}}$$

and

$$m' \left(= \frac{\partial C_m}{\partial \gamma} \right) = -\pi \frac{a_1}{a_{1T}}$$

where a_1 denotes $\partial C_L/\partial\alpha$ and a_{1T} its theoretical value. These equations are probably sufficiently accurate at low incidence, but in the neighbourhood of the stall they are no longer applicable because on physical grounds the effect of aerodynamic camber would be expected to remain finite and positive whereas a_1 becomes zero and then negative. Presumably the value of $\partial C_L/\partial\gamma$ in the neighbourhood of the stall lies between 4π and 0, and $\partial C_m/\partial\gamma$ between $-\pi$ and 0; in Table 2 values of $4\lambda\pi$ and $-\mu\pi$ have been assumed where λ and μ lie between 0 and 1. If λ and μ were

taken/

* The further constraint due to wake blockage is also likely to become considerable in the neighbourhood of the stall.

taken to be 0.5, the uncertainty in the correction when $c/h = 0.4$ would be ± 1.6% on lift and ∓ 0.004c on the position of the centre of pressure.

Hence it would be desirable to obtain experimental values of the camber derivatives at the stall, particularly for $\partial C_L/\partial \gamma$. These data might possibly be estimated from tests of families of aerofoils with varying amounts of parabolic camber (with maximum camber at mid-chord), but as the results would depend on the evaluation of small differences it is doubtful whether sufficient accuracy would remain. It would seem preferable to make direct determinations, either on a whirling arm or in a two-dimensional curved-flow tunnel, a possibility which is examined in Ref.2. The tests should cover a range of Reynolds number.

Correction due to Upwash at Mid-chord.

This correction to incidence is basically straightforward. If, however, it is converted to an equivalent change in lift at constant (tunnel) incidence (Tables 3 and 4), in the neighbourhood of the stall it is particularly important to use a value of $\partial C_L/\partial \alpha$ appropriate to the incidence considered, and not to use the theoretical value of 2π per radian. Further, corresponding corrections should be applied to C_m, C_D, etc., as well.* This upwash has no effect on the value of $C_{L\,max}$.

Conclusions and Recommendations.

(1) Experimental values of the camber derivatives are needed for the evaluation of the tunnel interference due to lift effect, particularly $\partial C_L/\partial \gamma$ at maximum lift. A range of Reynolds number should be covered.

(2) When applying the interference corrections it is essential to distinguish between the correction due to aerodynamic camber and that due to the upwash induced at mid-chord. The basic form of the corrections is set out in Table 1.

(3) Until experimental values of the camber derivatives are available there is little one can do except to use the semi-empirical values $4\lambda\pi$ for $\partial C_L/\partial \gamma$ and $-\mu\pi$ for $\partial C_m/\partial \gamma$. The resulting corrections are given in Table 2. In the absence of further information a value of 1/2 is suggested for λ and μ at the stall.

(4) If the incidence correction due to mid-chord upwash is converted to an equivalent change of lift at constant incidence (Table 3 or Table 4) it is important to use a value of $\partial C_L/\partial \gamma$ appropriate to the particular incidence being considered, and not the theoretical value of 2π which at best is only applicable at low incidence (Table 5). Moreover, corresponding corrections should also be applied to C_m, C_D, etc: these have been included in Tables 3 and 4.*

Corrections/

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* This method of applying the incidence correction, however, is not recommended near the stall.

Corrections due to Lift Effect: Rectangular Closed-throat Tunnel

(Two-dimensional Flow).

Table 1 - Basic Form of the Corrections.

Correction	For aerodynamic camber	For mid-chord upwash
To α (radians)	0	$+\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)$
To C_L	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_L}{\partial\gamma}$	0
To C_m	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_m}{\partial\gamma}$	0
To C_D	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_D}{\partial\gamma}$	$+\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)C_L$

Table 2 - Values assuming $\frac{\partial C_L}{\partial\gamma} = 4\lambda\pi$ and $\frac{\partial C_m}{\partial\gamma} = -\mu\pi$

Correction	For aerodynamic camber	For mid-chord upwash
To α (radians)	0	$+\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)$
To C_L	$-\lambda\frac{\pi^2}{48}\left(\frac{c}{h}\right)^2 C_L$	0
To C_m	$+\mu\frac{\pi^2}{192}\left(\frac{c}{h}\right)^2 C_L$	0
To C_D	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_D}{\partial\gamma}$	$+\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)C_L$

Table 3 - Equivalent Corrections at Constant Incidence (Cf. Table 1)

Correction	For aerodynamic camber	For mid-chord upwash
To α (radians)	0	(0)
To C_L	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_L}{\partial\gamma}$	$-\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m) \frac{\partial C_L}{\partial\alpha}$
To C_m	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_m}{\partial\gamma}$	$-\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m) \frac{\partial C_m}{\partial\alpha}$
To C_D	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L \frac{\partial C_D}{\partial\gamma}$	$+\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)\left(C_L - \frac{\partial C_D}{\partial\alpha}\right)$

Table 4/

Table 4 - Equivalent Corrections at Constant Incidence when $\frac{\partial C_L}{\partial \gamma} = 4\lambda\pi$ and $\frac{\partial C_m}{\partial \gamma} = \mu\pi$ (Cf. Table 2)

Correction	For aerodynamic camber	For mid-chord upwash
To α (radians)	0	(0)
To C_L	$-\lambda \frac{\pi^2}{48}\left(\frac{c}{h}\right)^2 \quad C_L$	$-\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)\frac{\partial C_L}{\partial \alpha}$
To C_m	$+\mu \frac{\pi^2}{192}\left(\frac{c}{h}\right)^2 \quad C_L$	$-\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)\frac{\partial C_m}{\partial \alpha}$
To C_D	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 \quad C_L\frac{\partial C_D}{\partial \gamma}$	$+\frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)\left(C_L - \frac{\partial C_D}{\partial \alpha}\right)$

Table 5 - Constant-incidence corrections at low incidence (only) assuming $\frac{\partial C_L}{\partial \gamma} = 4\pi$, $\frac{\partial C_m}{\partial \gamma} = -\pi$, $\frac{\partial C_L}{\partial \alpha} = 2\pi$ and $\frac{\partial C_m}{\partial \alpha} = 0$*

Correction	For aerodynamic camber and for mid-chord upwash
To α (radians)	(0)
To C_L	$-\frac{\pi^2}{24}\left(\frac{c}{h}\right)^2 (C_L + 2C_m)$
To C_m	$+\frac{\pi^2}{192}\left(\frac{c}{h}\right)^2 \quad C_L$
To C_D	$-\frac{\pi}{192}\left(\frac{c}{h}\right)^2 C_L\frac{\partial C_D}{\partial \gamma} + \frac{\pi}{96}\left(\frac{c}{h}\right)^2 (C_L + 4C_m)\left(C_L - \frac{\partial C_D}{\partial \alpha}\right)$

All the above corrections are to be added in order to convert the tunnel measurements to free-air values. The symbols c, h and C_m denote respectively aerofoil chord, tunnel height and aerofoil pitching moment coefficient about quarter-chord.

References/

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* $\partial C_D/\partial \gamma$ and $\partial C_D/\partial \alpha$ may also be negligible.

No.	Author(s)	Title etc.
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2	H. C. Garner.	Note on Aerodynamic Camber. A.R.C. 13,092. 19th April, 1950. (to be published)

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