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## **Effect of Ground Proximity on The Aerodynamic Properties of Thin Airfoils**

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### **Abstract**

In this paper the variation of aerodynamic properties of a thin airfoil in ground effect is investigated. First, a formulation is developed to calculate the induced drag in ground effect, which correlates the experimental data better than the present standard methods. Then the single vortex method and the distributed vortex method are extended to include the ground effect. The results of the two methods are compared with the available exact solution results. Due to the better correspondence between the distributed vortex and the exact solution methods, in comparison to the single vortex method, the first was used to determine the effects of angle of attack, flap and camber in ground proximity. According to the results, ground effect could lead to an increase or decrease in the lift coefficient depending on the combined effects of the ground clearance, angle of attack and camber.

**Key words: Ground Effect, Camber, Flap, Thin Airfoil, Vortex Method**

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$$\sigma = \exp[-2.48(2h/b)^{0.0768}] \quad (1)$$

[1] "

[2,3]

[9]

[4,3,2]

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[5] "

: 1 - σ

[6].

$$1 - \sigma = \frac{W - W'}{W} = \frac{(16h/\pi b)^2}{1 + (16h/\pi b)^2} \quad (2)$$

W

h/b < 0/5

[ ]

$$W = \frac{k_0}{4\pi S'} + \frac{k_0}{4\pi S'} = \frac{k_0}{2\pi S'} \quad (3)$$

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[8]

$$W = U_\infty \alpha_i = U_\infty C_L / \pi \cdot AR \quad (4)$$

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W

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$$1 - \sigma = [1 - \frac{2}{\pi} + (\frac{16h}{\pi b})^2] / [1 + (\frac{16h}{\pi b})^2] \quad (5)$$

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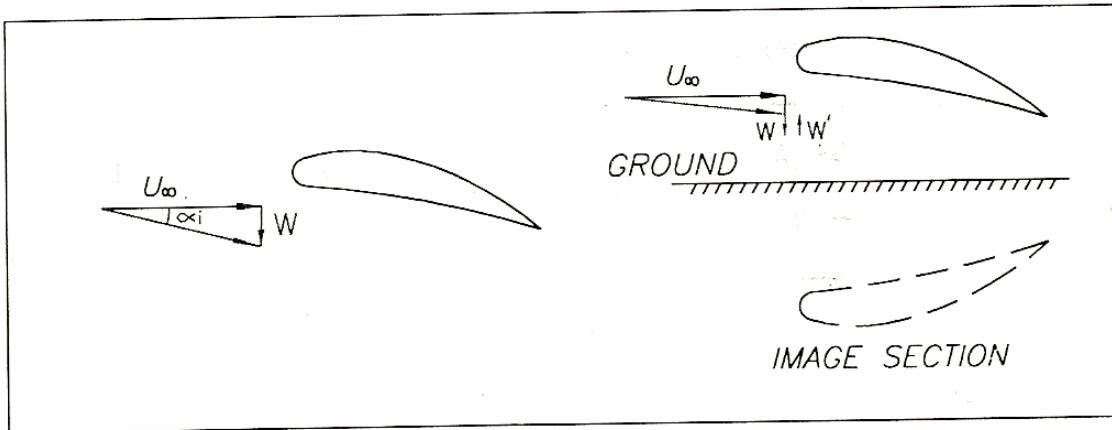
( )  
W'

[1]

σ

[10]

$$\frac{C_{Di}(IGE)}{C_{Di}(OGE)} = 1 - \sigma \quad (6)$$



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$$\frac{c'}{c'} \quad ( )$$

$$C_{L_\infty} = \frac{2\Gamma_\infty}{U_\infty C} = 2\pi \sin\alpha \quad ( )$$

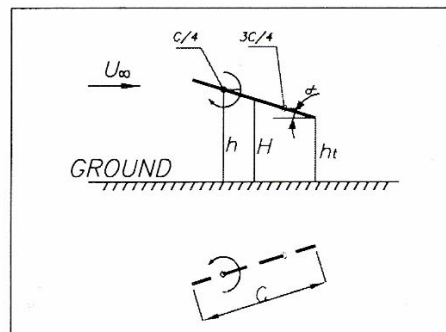
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$$n \cdot \nabla \phi = 0 \quad ( )$$

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$$\frac{\Gamma_g}{\Gamma_\infty} = 1 + \left[ \frac{\frac{1}{4}(c/h)^2 - (c/h)\sin\alpha}{4 - (c/h)\sin\alpha} \right] = F \quad ( )$$

$$\Gamma_\infty = \pi C U_\infty \sin\alpha$$

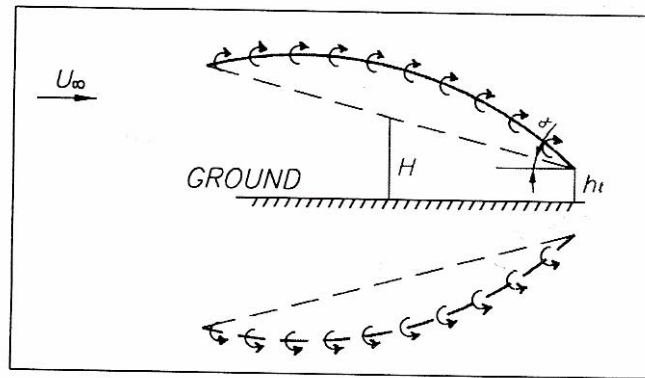


$$U_g = U_\infty - \frac{\Gamma_g}{4\pi h} \quad ( )$$

$$L = \rho U_\infty \Gamma_g$$

$$\frac{C_{Lg}}{C_{L\infty}} = F \left[ 1 - \frac{F}{4} \left( \frac{C}{h} \right) \text{Sin} \alpha \right] \quad ( )$$

N ( )



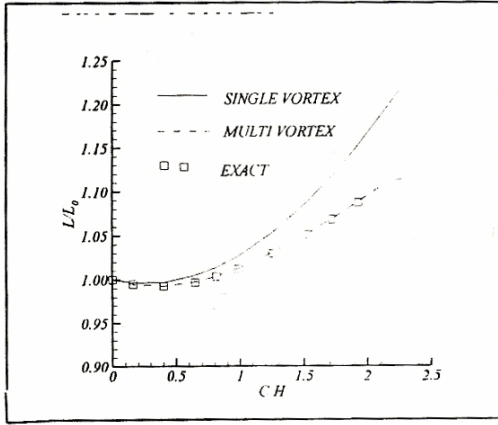
$$(u, w)_{ij}^{image}$$

$$(u, w)_{ij}^{image} = \frac{\Gamma_j(z_i - (-z_j - 2h), -(x_i - x_j))}{2\pi[(x_i - x_j)^2 + (z_i - (-z_j - 2h))^2]} \quad \left[ \sum_j [(u, w)_{ij} + (u, w)_{ij}^{image}] + (U_\infty, 0) \right] n_i = 0 \quad ( )$$

$$\sum_{j=1}^n A_{ij} \Gamma_j = -(U_\infty, 0) \cdot n_i, \quad i = 1, 2, \dots, N \quad ( )$$

$$(u, w)_{ij} = \frac{\Gamma_j(z_i - z_j), -(x_i - x_j)}{2\pi[(x_i - x_j)^2 + (z_i - z_j)^2]} \quad ( )$$

$$A_{ij} = [(u, w)_{ij} + (u, w)_{ij}^{image}]_{\Gamma_j=1} \cdot n_i \quad ( )$$



[ ]  
(C/H )

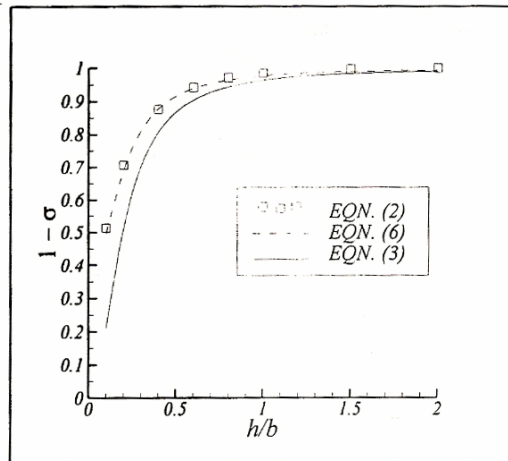
$\Gamma_{\sigma}$  N ( )

$\Gamma_g$

( )

$1-\sigma$  ( )

$h/b$



( )

C/H

( )

$h/b > 1$

(C/H )

( )

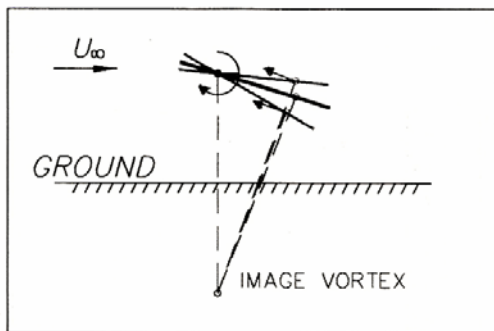
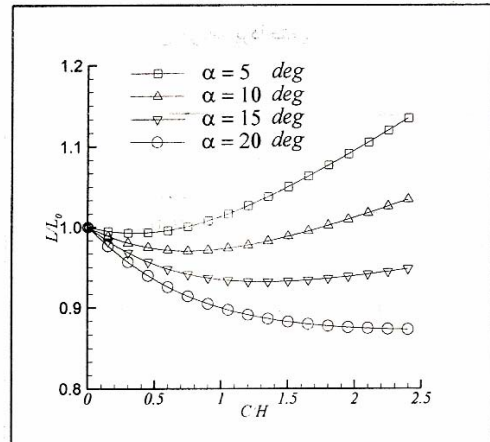
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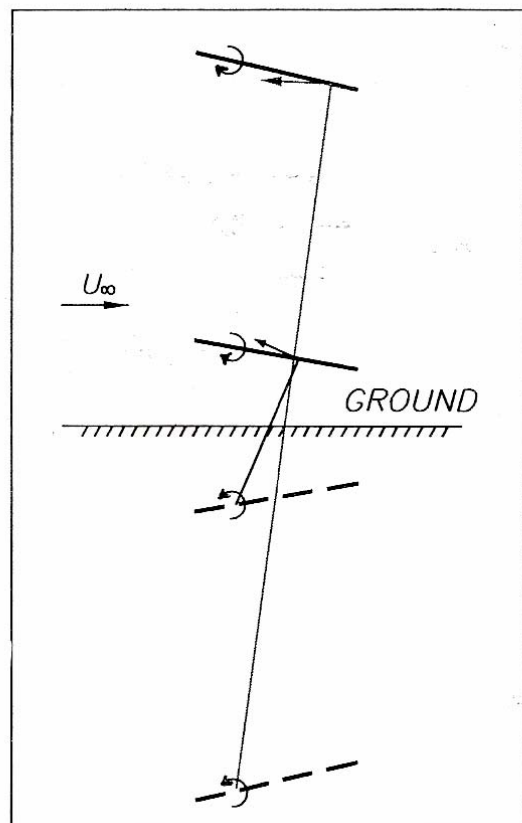
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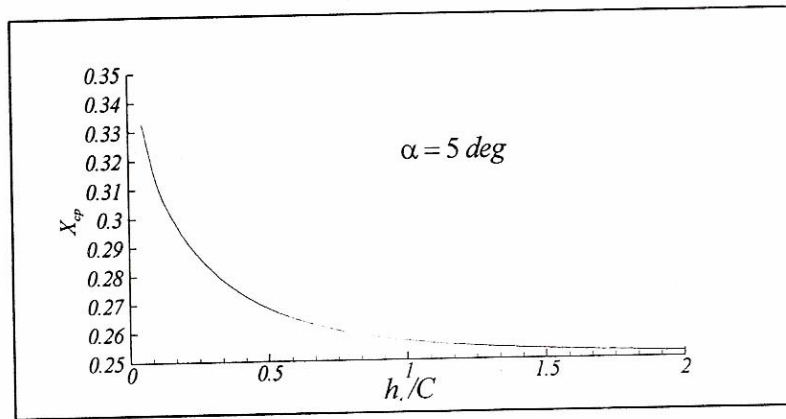
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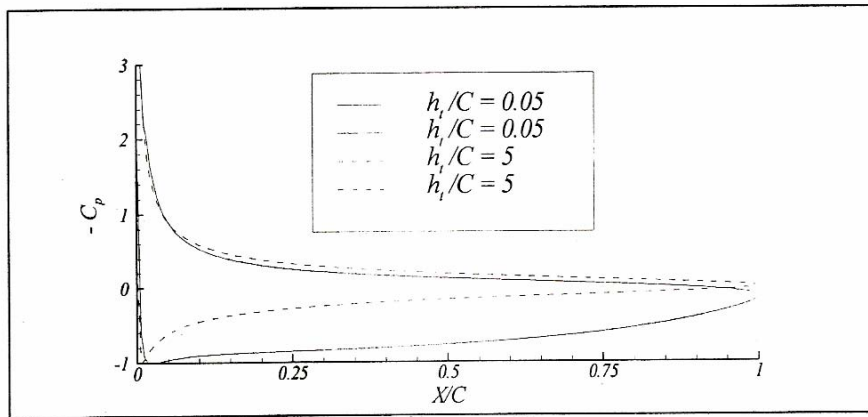
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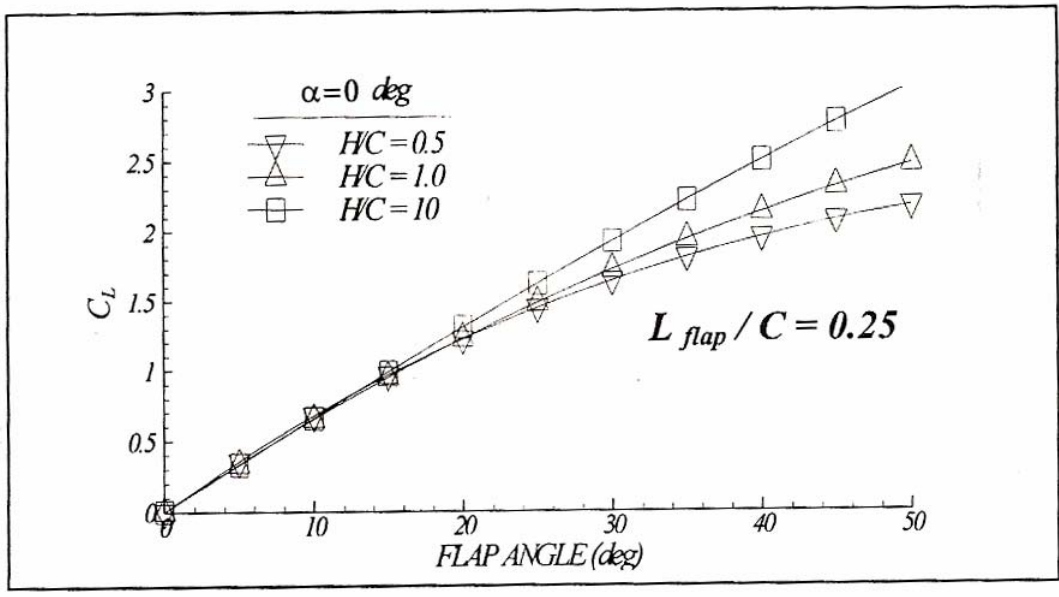
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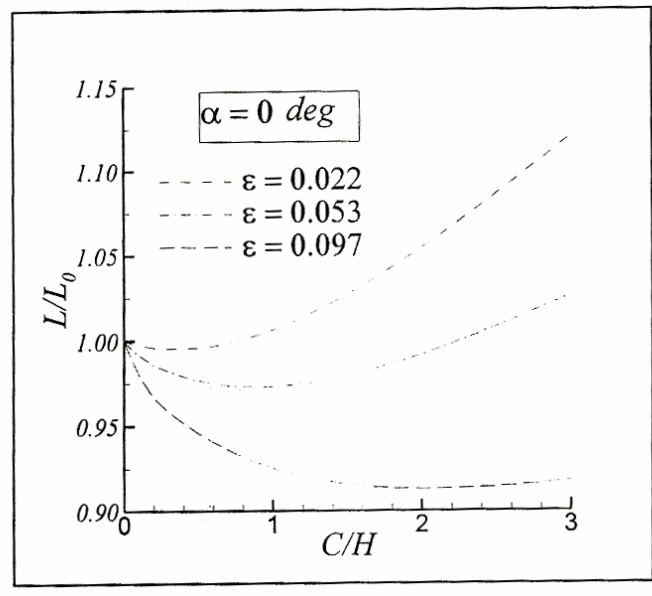
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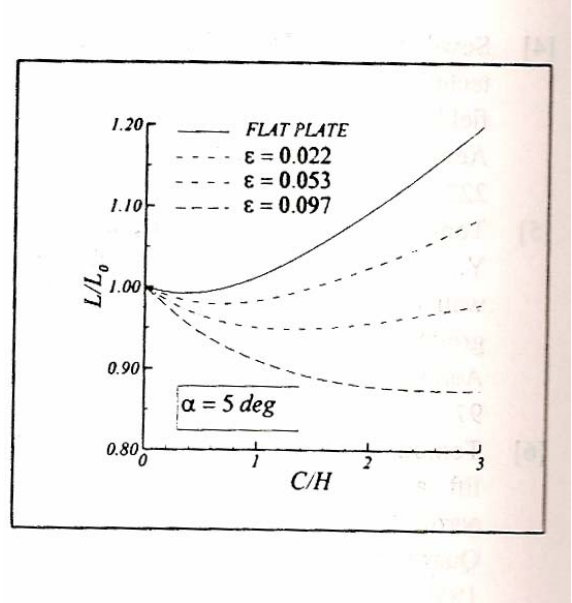
$$\frac{z(x)}{C} = 4 \frac{\varepsilon}{C} \left[ \frac{x}{C} \left( 1 - \frac{x}{C} \right) \right] \quad ( ) \quad \begin{matrix} \% \\ \% \\ \% \end{matrix} \quad C/H$$



$C/H$

( )





( )  
 ( )  
 ( )

( )

(  $C/H$  )

- A
- b
- C
- $C_{Di}(IGE)$
- $C_{Di}(OGE)$
- $C_{Lg}$
- CL
- $C_p$
- h
- $h_t$
- H
- $K_0$
- L
- $L_0$
- n
- N
- S'
- u

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(

$H/C = 1$

%

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