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APPROXIMATE ANALYSIS OF LIFTING
FORCES ON A WING NEAR
A FREE SURFACE

(PRIBLIZHENNYI RASCHET PODEMNOI
SILY KRYLA VBLIZI SVOBODNOI
POVERKHNOSTI)

by

A. N. Panchenkov

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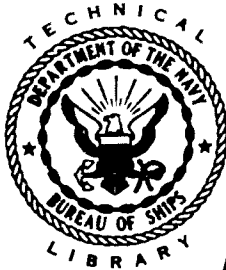
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APPROXIMATE ANALYSIS OF LIFTING FORCES ON A WING NEAR A FREE SURFACE

by A.N. Panchenkov (Kiev)

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Using the theory of small waves, the problem of the motion of a body submerged in a fluid has been investigated by many authors [1, 2].

With the aid of the general method of N.E. Kochin it is possible to obtain an approximate solution of the problem of the motion of a wing near a free surface.

If we satisfy the conditions of N.E. Zhukovskii's theorem on a small scale for the complex velocity, we can write the expression

$$V(z) = V_{\infty}(z) + V_z(z) \quad (1)$$

where $V_{\infty}(z)$ is the complex velocity of the motion of the wing in an unlimited flow,

$$V_z(z) = \frac{1}{2\pi i} \int_C \overline{V_{\infty}(\zeta)} \left[\frac{1}{z - \zeta} - 2i v e^{-i\gamma z} \int_{+\infty}^z \frac{e^{i v t}}{t - \zeta} d\zeta \right] \quad (2)$$

For the active forces of the flow we have the expressions

$$P_h = \rho v_0 \Gamma_{\infty} - \frac{\rho}{2\pi} \int_0^{\infty} |H(\lambda)|^2 d\lambda + \frac{\rho v}{\pi} \text{v.p.} \int_{-\infty}^1 |H(v - \lambda v)|^2 \frac{d\lambda}{\lambda} \quad (3)$$

$$Q = \rho v |H(v)|^2$$

where Γ_{∞} is the circulation around the wing in an unlimited flow and the function $H(\lambda)$ is determined by the expression

$$H(\lambda) = \int_C e^{-i\lambda z} V_{\infty}(z) dz \quad (4)$$

Here and later on, the following designations are used: h is the relative submer-
sion of the wing; b is a chord of the wing taken as a typical dimension; δ is the rela-
tive thickness of the wing; ζ is the correction to account for the finiteness of the span of
the wing near the free surface; τ is the coefficient representing the shape of the wing
viewed from above; α_k is the edge angle; α_0 is the angle of zero lifting force.

Formulas (2), (3) and (4) correspond to the formulas of Kochin in which, instead
of $V_h(z)$ and Γ_h at depth h we have $V_{\infty}(z)$ and Γ_{∞} . With a Froude number $F = v/\sqrt{g\delta} \rightarrow \infty$
the expression for the lifting force of a flat plate near the free surface is obtained by
hypergeometric functions in the form

$$P_h = \rho v_0 \Gamma_\infty - \frac{\rho \Gamma_\infty^2}{4\pi R \sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) - \frac{\rho v_0 \Gamma_\infty \cos \alpha_k}{2} \left[1 - \frac{4h}{\sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) \right] \quad (5)$$

or

$$\gamma_h = \frac{P_h}{P_\infty} = 1 - \frac{\sin \alpha_k}{\sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) - \frac{\cos \alpha_k}{2} \left[1 - \frac{4h}{\sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) \right] \quad (6)$$

For a Zhukovskii airfoil and wing the expressions for γ_h have the form

$$\gamma_h = 1 - \frac{\sin(\alpha_0 + \alpha_k)}{\sqrt{2} \sqrt{8h^2 + 1} \cos \alpha_0} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) - \frac{\cos \alpha_k}{2 \cos 2\alpha_0} \left[1 - \frac{4h}{\sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) \right] \quad (7)$$

$$\gamma_h = 1 - \frac{\sin(\alpha_0 + \alpha_k)}{\sqrt{2} \sqrt{8h^2 + 1} \cos \alpha_0} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) - \frac{(1 + \mu)^2 \cos \alpha_k}{2 \cos 2\alpha_0} \times \left[1 - \frac{4h}{\sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) \right] - \frac{k\delta(1 + \mu)^4 F\left(\frac{3}{4}, \frac{5}{4}, 2; \frac{1}{(8h^2 + 1)^2}\right)}{4 \sqrt{2} (8h^2 + 1)^{3/2} \sin(\alpha_0 + \alpha_k) \cos 3\alpha_0} \quad (8)$$

where \underline{k} is the ratio of thickness above the chord to the total thickness of the profile

$$\mu = \frac{0.77 \delta}{1 - 0.6 \delta}$$

For the coefficient of the lifting force of a wing of finite span we can write the expression

$$C_{yh} = \frac{\psi dC_{yco}/d\alpha}{1 + (\psi, \pi\lambda) (dC_{yco}/d\alpha) (1 + \tau) \zeta} (x_0 + \alpha_k - \Delta\alpha_i) \quad (9)$$

$$\psi = 1 - \frac{2 \sin(\alpha_0 + \alpha_k)}{\sqrt{2} \sqrt{8h^2 + 1} \cos \alpha_0} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) - \frac{(1 + \mu)^2 \cos \alpha_k}{2 \cos 2\alpha_0} \left[1 - \frac{4h}{\sqrt{2} \sqrt{8h^2 + 1}} F\left(\frac{1}{4}, \frac{3}{4}, 1; \frac{1}{(8h^2 + 1)^2}\right) \right]$$

$$\Delta\alpha_i = \frac{1}{\psi} \frac{k\delta(1 + \mu)^4}{4 \sqrt{2} (8h^2 + 1)^{3/2} \cos 3\alpha_0} F\left(\frac{3}{4}, \frac{5}{4}, 2; \frac{1}{(8h^2 + 1)^2}\right)$$

The results of calculation according to formulas (6) to (9) agree well with the experimental data for all relative submersions [3].

Submitted November 5, 1960

- [1.] Trudy konferentsii po teorii volnogo soprotivleniya. [Transactions of a conference on the theory of wave resistance]. TSAGI, 1937.
- [2.] Kochin, J.E. Writings. Vol. II, Izd-vo Akad. Nauk SSSR, 1949.
- [3.] Chudinov, S.D. "The lifting force of an underwater wing of finite span." Trudy VNITOSS, 1955, Vol. 6.