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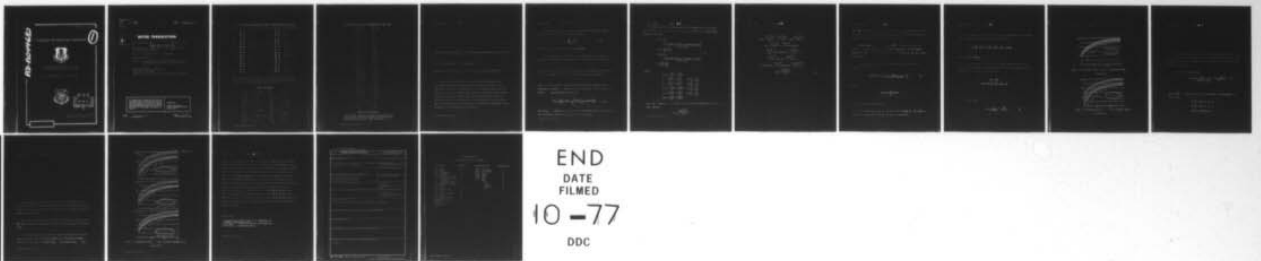
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HYDROMECHANICAL PROPERTIES OF AN ISOLATED WING MOVING ABOVE A S--ETC(U)  
FEB 77 S V KOVALCHUK; I P TKACHENKO

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HYDROMECHANICAL PROPERTIES OF AN  
ISOLATED WING MOVING ABOVE A SCREEN

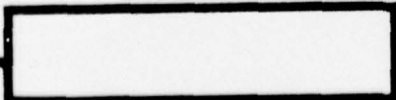
By

S. V. Koval'chuk, I. P. Tkachenko



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## EDITED TRANSLATION

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HYDROMECHANICAL PROPERTIES OF AN ISOLATED WING  
MOVING ABOVE A SCREEN

By: S. V. Koval'chuk, I. P. Tkachenko

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Sheh, sheh
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

\*ye initially, after vowels, and after ъ, ь; e elsewhere.  
 When written as ё in Russian, transliterate as yë or ë.  
 The use of diacritical marks is preferred, but such marks  
 may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α α	•	Nu	Ν ν
Beta	Β β		Xi	Ξ ξ
Gamma	Γ γ		Omicron	Ο ο
Delta	Δ δ		Pi	Π π
Epsilon	Ε ε	•	Rho	Ρ ρ ϱ
Zeta	Ζ ζ		Sigma	Σ σ ς
Eta	Η η		Tau	Τ τ
Theta	Θ θ	•	Upsilon	Υ υ
Iota	Ι ι		Phi	Φ φ ϕ
Kappa	Κ κ	•	Chi	Χ χ
Lambda	Λ λ		Psi	Ψ ψ
Mu	Μ μ		Omega	Ω ω

## RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	$\operatorname{sech}^{-1}$
arc csch	$\operatorname{csch}^{-1}$
—	
rot	curl
lg	log

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## HYDROMECHANICAL PROPERTIES OF AN ISOLATED WING MOVING ABOVE A SCREEN

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When a wing moves near the interface of two mediums, its hydromechanical characteristics change relative to those in an unbounded fluid. It is impossible to create devices which use the effect of a solid or liquid wall without considering these changes. Increasing lift, decreasing drag, and displacing the center of pressure along the wing chord are all factors which are considered when constructing airfoil systems and determine the approach to the problem of the stability of the device.

We will start with the general differential integral equation for a hydrofoil [2]. The boundary condition

$$\left. \frac{d\varphi}{dy} \right|_{y=0} = 0. \quad (1)$$

corresponds to small Froude numbers ( $Fr_s \rightarrow 0$ )

We can replace the fluid for a solid wall<sup>1</sup>, i.e., return to condition (1), during movement at high speeds above the interface.

[Footnote: <sup>1</sup>See the correct derivation of the boundary conditions in A. N. Panchenkov's article in this collection. End footnote]

Thus, there is complete correspondence between the movement of a hydrofoil at  $Fr_s \rightarrow 0$  and that of a wing above a fluid surface at  $Fr_s \rightarrow \infty$ . The solution to equation

$$\Gamma(\bar{y}) = \frac{a_{\bar{y}}}{2\lambda(\bar{y})} \left\{ a(\bar{y}) - \frac{1}{2\pi} \int_{-1}^{+1} \Gamma'(\bar{\eta}) \left[ \frac{1}{\bar{y}-\bar{\eta}} + G(\bar{y}-\bar{\eta}) \right] d\bar{\eta} \right\} \quad (2)$$

for  $Fr_s \rightarrow 0$  determines the value of circulation over the span of a wing moving at a high speed above a fluid surface.

The procedure for solving equation (2) worked out in [1] gives the calculated formulae for finding the circulation at several nodal points on the span

$$\left. \begin{aligned}
 \Gamma^1 = \Gamma^7 &= \frac{f^1}{a_1} + \frac{k_5(1,9142k_4 - 0,1464k_2) + k_6(0,1464k_1 - 1,9142k_3)}{a_1(k_1k_4 - k_2k_3)} \\
 \Gamma^2 = \Gamma^8 &= \frac{k_5k_4 - k_6k_3}{k_1k_4 - k_2k_3} \\
 \Gamma^3 = \Gamma^5 &= \frac{f^3}{a_3} + \frac{k_5(0,9142k_4 - 0,8536k_2) + k_6(0,8536k_1 - 0,9142k_3)}{a_3(k_1k_4 - k_2k_3)} \\
 \Gamma^4 &= \frac{k_1k_6 - k_5k_2}{k_1k_4 - k_2k_3}
 \end{aligned} \right\} (3)$$

where

$$\begin{aligned}
 k_1 &= a_2 - \frac{1,9831}{a_1} - \frac{1,0921}{a_3}; & a_1 &= \frac{2\lambda_1}{a_0} + \frac{2}{\sin \tau_1}; \\
 k_2 &= -\frac{0,2144}{a_1} - \frac{1,4421}{a_3}; & a_2 &= \frac{2\lambda_2}{a_0} + \frac{2}{\sin \tau_2}; \\
 k_3 &= -\frac{0,1517}{a_1} - \frac{1,0196}{a_3}; & a_3 &= \frac{2\lambda_3}{a_0} + \frac{2}{\sin \tau_3}; \\
 k_4 &= a_4 - \frac{0,0164}{a_1} - \frac{1,3465}{a_3}; & a_4 &= \frac{2\lambda_4}{a_0} + \frac{2}{\sin \tau_4}; \\
 k_5 &= f^2 + \frac{1,036f^1}{a_1} + \frac{1,1945f^3}{a^3}; & & \\
 k_6 &= f^4 + \frac{0,112f^1}{a_1} + \frac{1,5774f^3}{a^3}; & &
 \end{aligned}$$

Here  $f(\bar{y})$  describes the change in the angle of zero-lift under the free surface:

$$f_1 = -\frac{O_{30} \left( \frac{\omega}{\tau} \right) A_0^1}{4};$$

$$\begin{aligned}
 f_2 = & -\frac{G_{41}\left(\frac{\omega}{\tau}\right)A_0^1}{2} + \frac{3G_{40}\left(\frac{\omega}{\tau}\right)A_1^1}{4} + \cos^2\tau \frac{3G_{40}\left(\frac{\omega}{\tau}\right)A_0^1}{4}; \\
 f_3 = & -\frac{3G_{62}\left(\frac{\omega}{\tau}\right)A_0^1}{4} + \frac{3G_{61}\left(\frac{\omega}{\tau}\right)}{4}(A_0^1 + A_0^3) - \\
 & -\frac{5G_{60}\left(\frac{\omega}{\tau}\right)}{64}(2A_0^1 + 3A_0^3 + A_0^5) - \frac{G_{41}\left(\frac{\omega}{\tau}\right)A_1^1}{2} + \\
 & + \frac{3G_{40}\left(\frac{\omega}{\tau}\right)}{16}(A_1^1 + A_1^3) - \frac{G_{20}\left(\frac{\omega}{\tau}\right)A_0^1}{4} + \\
 & + \cos^2\tau \left[ 3G_{61}A_0^1 - \frac{30G_{60}\left(\frac{\omega}{\tau}\right)}{16}(A_0^1 + A_0^3) + \frac{3G_{40}\left(\frac{\omega}{\tau}\right)A_1^1}{4} \right] - \\
 & - \cos^4\tau \frac{5G_{60}\left(\frac{\omega}{\tau}\right)A_0^1}{4}.
 \end{aligned}$$

(4)

(At  $f(\bar{y})$  the subscript designates the order of approximation and the superscript - the cross section number.) These formulae consider the planform of the wing and the state of motion.

At  $Fr_0 \rightarrow 0$   $\varphi_{mn} = -1$ . Function  $\xi \frac{\bar{h}}{\lambda}$ , which considers the effect of the interface on the angular coefficient of dependence  $C_{y\bar{h}} = f(\alpha)$  --- and is part of the formula for finding  $C_y$  and  $C_x$ , has a large value.

If we know the circulation distribution, we can find the function with the formula

$$\xi_1 = \xi \left( \frac{\bar{h}}{\lambda} \right) (1 + \tau_1) = \frac{2a_{geom}}{A_0 + A_1\tau^2 + A_2\tau^4 + A_3\tau^6 + m} - \frac{\pi\lambda}{\alpha_0}, \quad (5)$$

where

$$A_m = \Gamma_m^4 + 2 \sum_{n=1}^3 \Gamma_m^n \sin \theta_n$$

$\tau_1$  is the Glauert correction.

This formula was used to calculate corrections  $\xi_1$  for several series of wings with different geometric parameters.

Rectangular wing (Fig. 1). A series of wings with the following aspect ratios was selected for the calculation

$$\lambda_0 = \frac{a_0}{2}; \frac{3}{4} a_0; a_0; \frac{5}{4} a_0; \frac{3}{2} a_0; \frac{7}{4} a_0; a_0 = 5,45.$$

In this case,  $\lambda_0 = \lambda_R = \lambda$ .

Tapered wing (Fig. 2). Given a constant aspect ratio of  $\lambda_0 = 5,45$ , we will change the planform of the wing by changing the angle of taper; more precisely, by the value

$$q = 1 - \frac{C_e}{C_0};$$

$$q = 0,9; 0,75; 0,5; 0,25; -0,25; -0,5.$$

In this case,

$$\lambda_R = \frac{\lambda_0}{1 - q \cos \theta_R}; \quad \lambda = \frac{2\lambda_0}{2 - q} \quad (6)$$

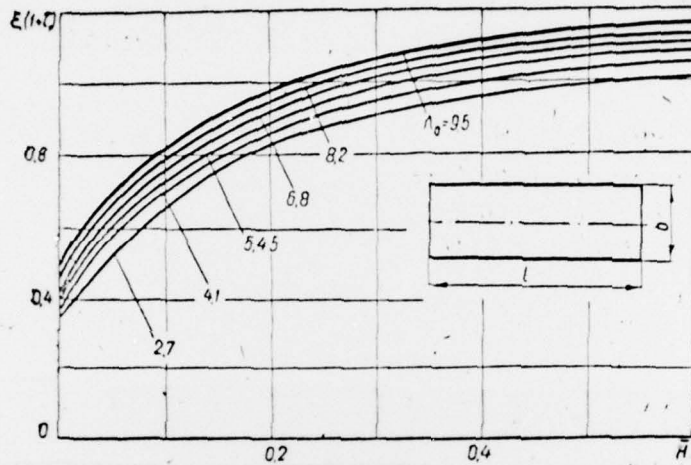


Fig. 1. Correction  $\xi(1+\tau_1)$  for a rectangular wing:

$$\lambda_0 = 5.45; \frac{\omega}{\tau} = 0.$$

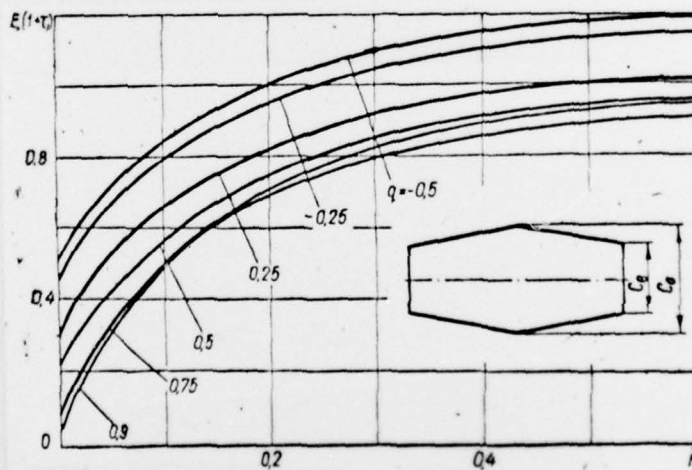


Fig. 2. Correction  $\xi(1+\tau_1)$  for a tapered wing:

$$\lambda_0 = 5.45; \frac{\omega}{\tau} = 0.$$

Double-tapered wing (Fig. 3). Its form can be changed by the size of the rectangular portion of the wing, as well as by the angle of taper. As in the previous case,  $\lambda_0 = 5.45$ ;  $q = 0.9$ ;  $0.75$ ;  $0.5$ ;  $0.25$ ;  $-0.25$ ;  $-0.5$ .

For a double-tapered wing

$$\lambda_k = \frac{\lambda_0}{1 - (\cos \theta_k - \chi) \cdot \frac{q}{1 - \chi}}; \quad \lambda = \frac{2\lambda_0}{2 + q(\chi - 1)}, \quad (7)$$

where  $\chi = \frac{b_1}{b}$ , and we will assign different  $\chi$ , determined by formula (7)

$$\chi = \frac{1}{3}; \quad \lambda_4 = \lambda_0; \quad \lambda_1; \quad \lambda_2; \quad \lambda_3;$$

$$\chi = \frac{1}{2}; \quad \lambda_4 = \lambda_3 = \lambda_0; \quad \lambda_2; \quad \lambda_1;$$

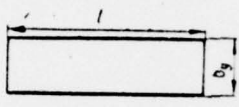
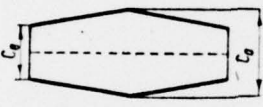
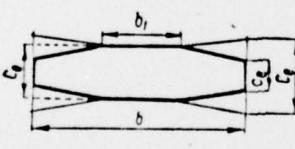
$$\chi = \frac{4}{5}; \quad \lambda_4 = \lambda_3 = \lambda_2 = \lambda_0; \quad \lambda.$$

Table 1.

№ крыла	H												
	0,00	0,05	0,10	0,15	0,20	0,25	0,30	0,35	0,40	0,45	0,50	0,55	0,60
1	0,33	0,515	0,651	0,75	0,822	0,876	0,917	0,949	0,973	0,992	1,01	1,02	1,03
2	0,364	0,556	0,693	0,791	0,863	0,916	0,956	0,987	1,01	1,03	1,04	1,06	1,07
3	0,997	0,592	0,729	0,826	0,897	0,949	0,989	1,02	1,04	1,06	1,08	1,09	1,10
4	0,427	0,625	0,761	0,858	0,928	0,98	1,02	1,05	1,07	1,02	1,10	1,14	1,19
5	0,456	0,654	0,79	0,886	0,955	1,01	1,04	1,07	1,10	1,12	1,13	1,14	1,15
6	0,482	0,68	0,816	0,911	0,98	0,03	1,07	1,10	1,12	1,14	1,16	1,17	1,18
7	0,464	0,656	0,791	0,887	0,957	1,01	1,05	1,08	1,10	1,12	1,13	1,15	1,16
8	0,517	0,709	0,843	0,937	1,00	1,06	1,10	1,12	1,15	1,17	1,18	1,19	1,20
9	0,314	0,514	0,654	0,754	0,827	0,881	0,922	0,953	0,977	0,997	1,01	1,02	1,03
10	0,212	0,422	0,569	0,675	0,751	0,808	0,850	0,883	0,908	0,928	0,944	0,966	0,967
11	0,093	0,329	0,494	0,612	0,69	0,757	0,803	0,838	0,865	0,886	0,902	0,916	0,927
12	0,028	0,301	0,491	0,623	0,787	0,785	0,835	0,873	0,901	0,928	0,941	0,955	0,969
13	0,488	0,671	0,806	0,902	0,970	1,02	1,06	1,09	1,11	1,13	1,15	1,16	1,17
14	0,557	0,743	0,877	0,971	1,04	1,09	1,13	1,16	1,18	1,20	1,21	1,23	1,24
15	0,308	0,508	0,649	0,749	0,821	0,875	0,916	0,948	0,972	0,991	1,00	1,02	1,03
16	0,217	0,425	0,572	0,677	0,753	0,809	0,851	0,884	0,909	0,929	0,945	0,957	0,968
17	0,135	0,361	0,521	0,635	0,717	0,777	0,822	0,857	0,888	0,904	0,920	0,933	0,944
18	0,105	0,353	0,528	0,651	0,74	0,804	0,852	0,888	0,916	0,937	0,954	0,968	0,979
19	0,473	0,666	0,801	0,896	0,966	1,02	1,06	1,09	1,11	1,19	1,14	1,16	1,17
20	0,545	0,737	0,870	0,965	1,03	1,08	1,12	1,15	1,17	1,19	1,21	1,22	1,23
21	0,319	0,518	0,658	0,758	0,831	0,884	0,925	0,956	0,981	1,00	1,01	1,03	1,04
22	0,244	0,460	0,595	0,699	0,774	0,83	0,872	0,904	0,998	0,948	0,964	0,977	0,987
23	0,184	0,403	0,557	0,667	0,747	0,806	0,85	0,883	0,909	0,93	0,945	0,959	0,97
24	0,169	0,4	0,504	0,681	0,765	0,827	0,873	0,907	0,934	0,955	0,972	0,985	0,996
25	0,450	0,644	0,78	0,876	0,946	0,998	1,04	1,07	1,09	1,11	1,13	1,14	1,15
26	0,504	0,696	0,831	0,927	0,997	1,05	1,09	1,12	1,14	1,16	1,18	1,19	1,20
27	0,346	0,543	0,682	0,780	0,851	0,904	0,944	0,975	0,999	1,02	1,03	1,05	1,06
28	0,3	0,5	0,64	0,74	0,812	0,866	0,906	0,937	0,961	0,981	0,996	1,01	1,02
29	0,263	0,466	0,609	0,710	0,784	0,839	0,88	0,911	0,936	0,955	0,971	0,983	0,994
30	0,248	0,454	0,599	0,702	0,777	0,832	0,874	0,906	0,930	0,950	0,966	0,978	0,989

KEY: (1) Wing No.

Table 2.

(1) Наименование крыла	(5) Форма крыла в плане	$\frac{l}{B(y)}$ $\lambda(y) = \frac{C_c}{B(y)}$	$\frac{C_c}{C_c - C_0}$ $q = 1 - \frac{C_0}{C_c}$	$\frac{B_1}{B}$ $\chi = \frac{B_1}{B}$	№ крыла	
(2) Прямо- угольное		2,725	0	1	1	
		4,0845			2	
		5,45			3	
		6,8125			4	
		8,175			5	
		9,5705			6	
(3) Трапеци- дальное		5,45	0	0	7	
					-0,25	8
					-0,5	9
					0,25	10
					0,5	11
					0,75	12
(4) Двоякотре- пещон- дальное		5,45	0	$\frac{1}{3}$	13	
					-0,25	14
					-0,5	15
					0,25	16
					0,5	17
					0,75	18
					0,9	19
					-0,25	20
					-0,5	21
					0,25	22
					0,5	23
					0,95	24
					0,9	25
					-0,25	26
0,5	27					
0,25	28					
0,5	29					
0,75	30					
0,9	30					

KEY: (1) Type of wing. (2) Rectangular. (3) Tapered. (4) Double-tapered. (5) Planform of wing. (6) Wing No.

Tables 1 and 2 show the results of the calculations for the selected series. The above calculations make it possible to come to certain conclusions about the selection of the planform of a wing working near a screen.

The curves in Figures 1-3 should be corrected at small depths. The small parameter method does not give us the correct solution at  $\bar{H} \rightarrow 0$ .

It is necessary to find further approximations which require very cumbersome calculations in order to obtain more accurate results. In the limiting case,  $\bar{H} = 0$ , functions  $\xi_1 = 0$ , and

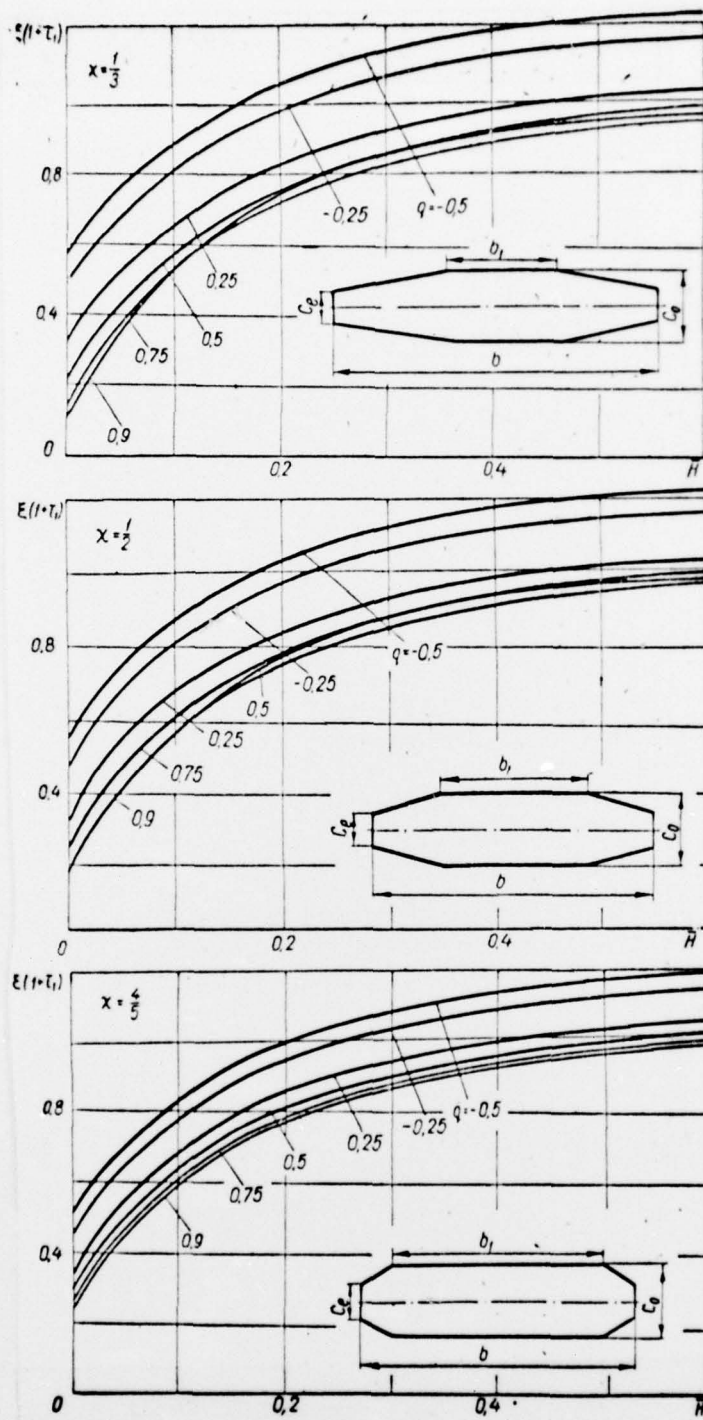


Fig. 3. Correction  $\xi(1+\tau_1)$  for a double-tapered wing:

$$\lambda_0 = 5.45; \frac{\omega}{\tau} = 0.$$

induced drag disappears. Even a superficial analysis of the curves shows that the change of the wing planform has a considerable effect on its hydromechanical properties when moving near a screen. Neither the free surface, nor the unbounded fluid are as sensitive to the change in the wing planform as the screen. For example, the taper value of function  $\xi_1$  can vary from 1.5-2 times, depending on the angle. This value changes very markedly for wings with large induced drag in an unbounded fluid, depending on the distance from the screen. Therefore, the selection of the planform of a wing near a screen requires very careful study. The value of  $\xi_1$  and its first derivative, which expresses the slope of the curve, are necessary for designing airfoil systems moving near a screen and for calculating their stability.

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