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STATIC STABILITY OF VEHICLES WHICH USE THE LIFTING FORCE OF AIR--ETC(U)

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FOREIGN TECHNOLOGY DIVISION

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STATIC STABILITY OF VEHICLES WHICH USE THE LIFTING FORCE OF AIRFOILS

by

V. I. Koroley

FOREIGN TECHNOLOGY DIVISION

EDITED TRANSLATION

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STATIC STABILITY OF VEHICLES WHICH USE THE LIFTING FORCE OF AIRFOILS

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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ë 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 *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 ϵ	Rho	Ρ	ρ ϱ
Zeta	Ζ	ζ	Sigma	Σ	σ ς
Eta	Η	η	Tau	Τ	τ
Theta	Θ	θ ϑ	Upsilon	Υ	υ
Iota	Ι	ι	Phi	Φ	φ ϕ
Kappa	Κ	ϰ 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	sech^{-1}
arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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STATIC STABILITY OF VEHICLES WHICH USE THE LIFTING FORCE OF AIRFOILS

V. I. Koroley

In designing rapid transportation facilities which use the lifting force of airfoils near a solid or liquid screen, one important problem is that of providing stable motion of sufficient duration.

A characteristic feature of the operating conditions of these vehicles is that their effectiveness increases as the distance between the airfoil and the screen decreases. Here the optimal operating clearances between the trailing edge of the airfoil and the screen are no more than 5-10o/o of the wing chord. This is the reason for the extremely rigid requirement for stability of motion in the vehicles, which restricts the amplitude of vertical movement of design elements to indicated limits.

In the present article we discuss the problem of static stability in vehicles which have two airfoils - a leading and a trailing ("tandem" system) - separated by a certain distance, determined by the length of the cabin body.

Here it is assumed that the main load is carried by the trailing wing, which has greater dimensions and elongation (aspect ratio) per unit length; the leading wing serves to increase the arm of the developing moment.

In the general case the wings may have different angles of attack α_i, aspect ratios - λ_i, chords - b_i, and relative distances from the screen $h_i = h_i/b_i$. We must determine what combinations of these elements, and also what position of the center of gravity along the vehicle, will assure the greatest restoring moments in the case where the vehicle steadily deviates by a small angle from the calculated position.

We will assume that the angle of deviation is so small that the shift in the pressure centers of the wing can be ignored.

The magnitude of the lifting force of the wing is determined as follows [1]:

$$P = C_y \frac{\rho v^2}{2} S,$$

where

$$C_y = \frac{a_\infty \psi (\alpha_0 + \alpha_k - \Delta\alpha_0)}{1 + \frac{a_\infty \psi (1 + \tau_1) \xi}{\pi \lambda}}. \qquad (1)$$

Here $a_\infty = 5.45$;

α_K - is the edge angle of attack;

$$\mu = \frac{0{,}77\delta}{1 - 0{,}6\delta};$$

$$\psi = \psi_0 [1 - (\alpha_0 + \alpha_k)\tau];$$

$$\psi_0 = 1 - (1 + \mu)^2 \left(-\tau^2 + \tau^4 - \frac{3}{4}\tau^6 + \frac{5}{8}\tau^8 - \frac{3}{8}\tau^{10}\right);$$

$$\xi = 1 - 0{,}5\tau_\lambda^2 - 0{,}25\tau_\lambda^4 - 0{,}0625\tau_\lambda^6 - 0{,}0469\tau_\lambda^8 - 0{,}0237\tau_\lambda^{10} - 0{,}0188\tau_\lambda^{12};$$

$$\tau = \sqrt{4\bar{h}^2 + 1} - 2\bar{h};$$

$$\tau_\lambda = \sqrt{4\left[\frac{\bar{h}}{\lambda} K_2\right]^2 + 1} - 2\left[\frac{\bar{h}}{\lambda} K_2\right];$$

$$\Delta\alpha_0 = -\frac{\varkappa \alpha_0}{\psi_0} + \frac{K\delta\tau^2}{2\psi_0};$$

$$\varkappa = 0{,}5\tau^2 - \tau^4 + 0{,}813\tau^6 - 0{,}625\tau^8 + 0{,}3125\tau^{10}.$$

For the segmented wings which rectangular in pepective, studied in the given case, $\tau_1 = 0.171$; $K = 1$; $\delta = 0.06$; $K_2 = 1$, $\alpha_0 = 2°$.

From statics conditions (Fig. 1) we can write

$$P_1 = D\left(1 - \frac{l_1}{l}\right) = D(1 - \bar{l}_1),$$
$$P_2 = D\frac{l_1}{l} = D\bar{l}_1. \qquad (2)$$

The change in the lifting force on the trailing wing with the change in angle of attack by quantity $\Delta\alpha$

$$\Delta P_1 = \frac{\partial P_1}{\partial\alpha}\Delta\alpha + \frac{\partial P_1}{\partial h}\Delta h = \frac{\partial C_{y_1}}{\partial\alpha}\frac{\rho V^2}{2}S_1\Delta\alpha + \frac{\partial C_{y_1}}{\partial h}\frac{\rho V^2}{2}S_1\Delta h. \qquad (3)$$

Bearing in mind that $\Delta h = -l_1\Delta\alpha$, and also considering (2), we get

$$\Delta P_1 = D(1 - \bar{l}_1)\left(1 - \frac{\frac{\partial C_{y_1}}{\partial \bar{h}}}{\frac{\partial C_{y_1}}{\partial\alpha}}\bar{l}_1\bar{b}_1\right)\frac{\Delta\alpha}{a_1}, \qquad (4)$$

where $\bar{b}_1 = l/b_1$ and $\bar{h} = h/b_1$.

Determined analogously is

$$\Delta P_2 = D\bar{l}_1\left[1 + \frac{\frac{\partial C_{y_2}}{\partial \bar{h}}}{\frac{\partial C_{y_2}}{\partial\alpha}}(1 - \bar{l}_1)\bar{b}_2\right]\frac{\Delta\alpha}{a_2}, \qquad (5)$$

where $\bar{b}_2 = l/b_2$.

The restoring moment in this case is determined as follows:

$$\Delta M = l_1 \Delta P_1 - (l - l_1) \Delta P_2. \quad (6)$$

or, in dimensionless form:

$$\frac{\Delta M}{Dl} = \bar{l}_1 (1 - \bar{l}_1) \left[(1 - C_1 \bar{l}_1 \bar{b}_1) \frac{1}{a_1} - \{1 + C_2 (1 - \bar{l}_1) \bar{b}_2\} \frac{1}{a_2} \right] \Delta \alpha. \quad (7)$$

Here

$$C_i = \frac{\frac{\partial C_{yi}}{\partial \bar{h}}}{\frac{\partial C_{yi}}{\partial \alpha}}.$$

The moment derivative with respect to the angle, which determines the measure of stability of the vehicle in the case of angular slopes, is expressed in the form of

$$\bar{m}_\alpha = \frac{1}{Dl} \frac{\partial M}{\partial \alpha} = \bar{l}_1 (1 - \bar{l}_1) \left\{ (1 - C_1 \bar{l}_1 \bar{b}_1) \frac{1}{a_1} - \left[1 + C_2 (1 - \bar{l}_1) \bar{b}_2 \right] \frac{1}{a_2} \right\}. \quad (8)$$

Direct analysis of the obtained expression is difficult, since the unknown quantity is a function of nine parameters - the arm of the lifting force of the trailing wing $\bar{l}_1$, the reverse chord values of the wing $\bar{b}_1$ and $\bar{b}_2$, angles of attack α_1 and α_2, relative distances between wings and screen $\bar{h}_1$ and $\bar{h}_2$, and relative aspect ratios λ_1 and λ_2.

It is true that parameters $\bar{b}_1$ and $\bar{b}_2$ are not entirely independent: there exist between them a connection which follows from the statics condition:

$$-\frac{C_{y_1}\lambda_1\bar{b}_1}{C_{y_2}\lambda_2\bar{b}_2}=\frac{1-\bar{l}_1}{\bar{l}_1}. \qquad (9)$$

However, realization of this equation for the elimination of one of the parameters is difficult because of significant complication of the main dependence (8).

Determining the extrema of function $\bar{m}_\alpha$ by the standard method, by calculating the derivatives with respect to independent variables, is extremely awkward and complex, since quantities $\bar{h}_i$ and λ_i (and particularly) α_1 are contained in expression (8) in implicit form. Thus, the study is conducted by the calculation-graphic method.

First, the C_i values are determined. For this derivatives $\frac{\partial C_y}{\partial h}$ and $\frac{\partial C_y}{\partial \alpha}$ are calculated within the following limits:

$$h=0{,}05-0{,}3;\quad \lambda=2-5;\quad \alpha=2-10^\circ.$$

The indicated limits were selected from the condition of optimality of the wings (assuring the highest quality value $k = C_y/C_x$) and from design considerations (the leading wing must have a somewhat lower aspect ratio). Since $\frac{\partial C_y}{\partial h}$, and, consequently, also C_i, have a linear dependence on α_i, it was possible to approximate this dependence by the simple formula

$$C_i = a\frac{2+\alpha^\circ}{4}. \qquad (10)$$

The values of a are given in Fig. 2.

Depending on attack angles α_i and the values of $\bar{l}_1$ the limits of change in values $C_1\bar{b}_1$ and $C_2\bar{b}_2$ (Tables 1-2) were determined. Here it was assumed that $\bar{h}_1$ = 0.05-0.2; λ_1 = 2-5; α_1 = 4-10°; $\bar{h}_2$ = 0.05-0.2; λ_2 = 2-4; α_2 = 2-10°.

Calculated in the range of $\bar{l}_1$ = 0.1-0.6 and α_1 = 4-10° were quantities

$$\begin{aligned}\bar{m}_{\alpha_1} &= \bar{l}_1(1-\bar{l}_1)(1-C_1\bar{l}_1\bar{b}_1)\frac{1}{\alpha_1},\\ \bar{m}_{\alpha_2} &= \bar{l}_1(1-\bar{l}_1)[1+C_2(1-\bar{l}_1)\bar{b}_2]\frac{1}{\alpha_2}.\end{aligned} \qquad (11)$$

at two fixed values of $C_i\bar{b}_i$, equal to 1 and 7.

The straight lines passing through the obtained points on curves with coordinates $\bar{m}_{\alpha_1}-C_1\bar{b}_1$ and $\bar{m}_{\alpha_2}-C_2\bar{b}_2$, respectively (Figs. 3-4), determine the value $\bar{m}_{\alpha_1}$ and $\bar{m}_{\alpha_2}$ at fixed angles of attack and different values of $\bar{l}_1$ or different values $C_i\bar{b}_i$.

Here and henceforth the symbol $\bar{m}_\alpha$ denotes relative values of the derivative of the restoring moment with respect to the angle or, in other words, the magnitude of increase in the relative recovery moment during deviation of the vehicle by an angle equal to one radian. To determine the moment which develops during deviation of the vehicle by 1° we must divide this quantity by 57.3.

The limiting values $C_i\bar{b}_i$ for each value $\bar{l}_1$ are determined on the indicated straight beams of the points corresponding to the upper and lower limits $\bar{m}_{\alpha i}$, which can be obtained for the given α_i and $\bar{l}_1$. In this case we are not interested in the lower limits. The upper limits are determined by the family of curves of constant values of $\bar{l}_1$.

As we see from the curves (Figs. 3-4), the component of the restoring moment $\bar{m}_{\alpha_1}$ and $\bar{m}_{\alpha_2}$ attain their highest values at minimal angles of attack of the trailing wings and the maximal angles of the leading for completely determined values of $C_i\bar{b}_i$. Here the limiting values of $\bar{m}_{\alpha i}$ are to a certain degree conditional, since generally the angles of attack can exceed the limits of the selected boundaries, which leads to a considerable decrease in the quality of the wings. For this reason determining $\bar{m}_{\alpha i}$ outside of the indicated limits is not of practical interest.

However, the values of $\bar{m}_{\alpha i}$, which correspond to fixed values of the angles of attack α_i and relative arms $\bar{l}_1$ are completely determined quantities which determine the restoring moment for specific vehicle parameters.

In order to determine which combination of angles of attack of the leading and trailing wing will give the maximum restoring moment during deviation of the vehicle by 1° it is sufficient to plot curves of the sum $\bar{m}_{\alpha}$ for the same values of $\bar{l}_1$ and different angles α_1 and α_2.

As an example of the obtained dependence Fig. 5 shows the values of $\bar{m}_{\alpha}$ for $\alpha_1 = 4°$ and different values $\bar{l}_1$ and α_2.

For other α_1 values the magnitude of $\bar{m}_{\alpha}$ can be calculated with sufficient accuracy by the following approximate formula

$$\bar{m}_{\alpha} = \bar{m}_{(\alpha_1 = 4°)} + b(\alpha_1^{\circ} - 4°). \quad (12)$$

Values of b for different values of $\bar{l}_1$ are shown in Fig. 6.

It is obvious that quantity $\bar{m}_{\alpha}$ have a maximum which is not very pronounced at $\bar{l}_1 \approx 0.35$. At lower values $\bar{l}_1$ the magnitude of $\bar{m}_{\alpha}$ declines drastically with a decrease in $\bar{l}_1$, and at $\bar{l}_1$ = 0.4-0.6 is virtually independent of arm $\bar{l}_1$. An increase in the angle of attack of the leading wing α_2 leads to a certain increase in quantity $\bar{m}_{\alpha}$.

Figure 7 shows the values of maximal moment $\bar{m}_\alpha$ which can be obtained in the studied range. These correspond to the maxima of curves similar to those presented in Fig. 5. In all cases these maxima correspond to values $\bar{l}_1 \approx 0.35$.

The obtained results permit us to solve the following problems:

a) make a rational selection of the elements of the airfoils to provide maximum duration of vehicle stability at full speed;

b) determine the magnitude of restoring moments for a vehicle with known elements;

c) determine the values of restoring moments for the different moving regimes of the vehicle.

The first of these problems can be conveniently solved in the following order: If we must obtain the maximal values $\bar{m}_\alpha$ and the overall design allows us to do this, then quantity $\bar{l}_1$ should be selected equal to 0.35, while angles α_1 and α_2 should be minimal (although we must consider the possibility of a considerable loss in quality for very low angles of attack). When, however, due to the conditions of the overall arrangement, the optimal value of the arm $\bar{l}_1$ cannot be perserved, then it can be increased if the angles of attack of the leading wing are relatively large.

Decreasing $\bar{l}_1$ leads to a considerable decline in the restoring moment. In any case, according to the curves presented in Fig. 5 and formula (12) we can easily estimate the magnitude of moment loss as a result of deviation from optimal ratios.

From the values $\bar{l}_1$, α_1, and α_2 thus selected, on the curves (Figs. 3-4) the values of $C_1\bar{b}_1$ and $C_2\bar{b}_2$ which correspond to them are determined by interpolation.

These values in turn depend on the following factors: angles of attack α_1 and α_2, chord of wings b_1 and b_2, relative distances from screen $\bar{h}_1$ and $\bar{h}_2$, and relative aspect ratio of the wings λ_1 and λ_2.

Since α_1 and α_2 are already determined, then we now select six quantities - b_1, b_2, $\bar{h}_1$, $\bar{h}_2$, λ_1 and λ_2 - which are related by three equations - the equation of (9) and equations:

$$C_1\bar{b}_1 = F_1(\alpha_1, b_1, \bar{h}_1, \lambda_1),$$
$$C_2\bar{b}_2 = F_2(\alpha_2, b_2, \bar{h}_2, \lambda_2). \quad (13)$$

Thus, three parameters remain undetermined and are selected by design consideration. Consequently, the designer still has a wide range of possibilities for selecting the three independent parameters without impairing static stability, since conditions (13) automatically assure the restoring moment.

Determining the values of restoring moments for a vehicle with known elements of the lifting system is reduced to calculating values $c_i \bar{b}_i$, determining the $\bar{m}_\alpha$ components from the curves on Figs. 3 and 4, and subsequent summation of them.

The third of these problems is solved in a similar manner, provided we have a diagram obtained through calculation or experiment for the landing (distances from screen and angles of trim) for the vehicle at different rates of motion. Values $\bar{h}_i$ and α_i with the trim and the trajectory of motion of the vehicle considered are introduced into the calculation.

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Fig. 1.

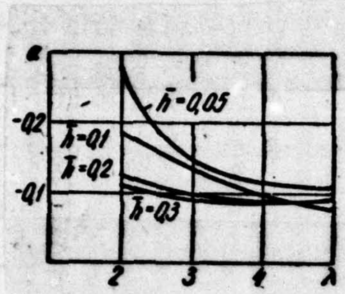

Fig. 2.

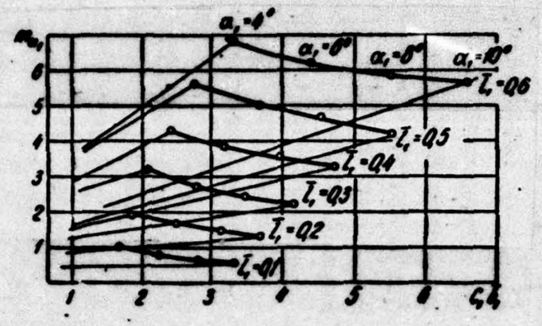

Fig. 3.

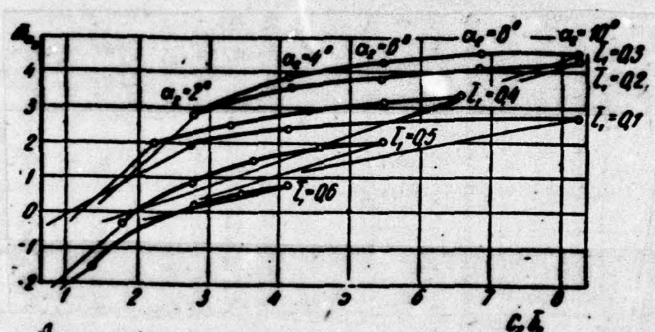

Fig. 4.

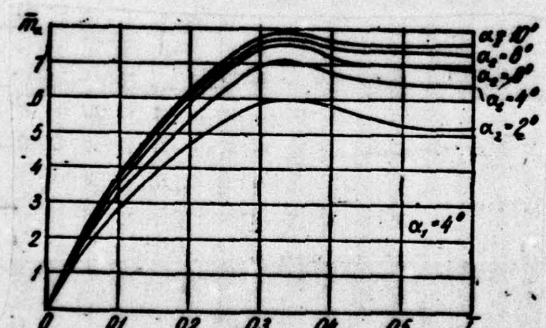

Fig. 5.

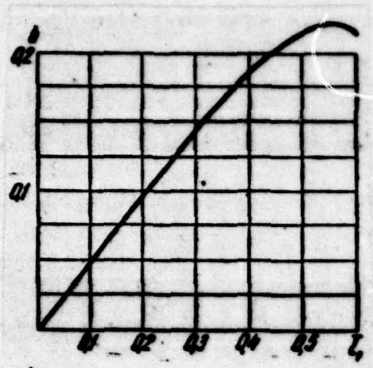

Fig. 6.

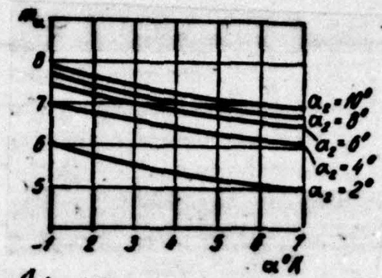

Fig. 7.

Table 1.

$\bar{l}_1$	0,1	0,2	0,3	0,4	0,5	0,6
$\bar{b}_1$	4—2,5	4,45—2,7	5—2,95	5,7—3,25	6,67—3,6	8—4
a_1	$C_1\bar{b}_1$					
4°	1,65—0,263	1,835—0,284	2,06—0,309	2,36—0,339	2,75—0,375	3,3—0,42
6°	2,2—0,35	2,44—0,378	2,75—0,412	3,14—0,452	3,66—0,5	4,4—0,56
8°	2,76—0,437	3,06—0,472	3,44—0,515	3,93—0,565	4,59—0,625	5,5—0,7
10°	3,3—0,525	3,67—0,567	4,12—0,618	4,72—0,678	5,5—0,75	6,6—0,84

Table 2.

$\bar{l}_2$	0,1	0,2	0,3	0,4	0,5	0,6
$\bar{b}_2$	10	10—6,67	10—5	8—4	6,67—3,33	5—3,33
a_2	$C_2\bar{b}_2$					
2°	2,75—0,85	2,75—0,567	2,75—0,425	2,2—0,34	1,83—0,283	1,375—0,283
4°	4,13—1,28	4,13—0,853	4,13—0,64	3,3—0,512	2,75—0,427	2,06—0,427
6°	5,5—1,7	5,5—1,135	5,5—0,85	4,4—0,68	3,67—0,567	2,75—0,567
8°	6,88—2,13	6,88—1,42	6,88—1,06	5,5—0,852	4,59—0,71	3,44—0,71
10°	8,25—3,55	8,25—2,37	8,25—1,77	6,6—1,43	5,5—1,18	4,12—1,18

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