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DETERMINING PARAMETERS OF AIRCRAFT WITH VARIABLE-SWEEP WING,(U)

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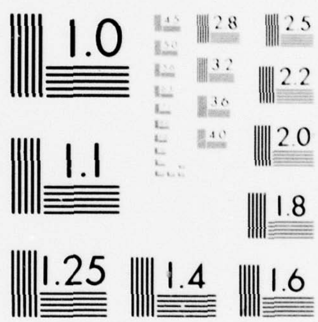

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DETERMINING PARAMETERS OF AIRCRAFT WITH VARIABLE-SWEEP WING

By

A. A. Krasotkin

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EDITED TRANSLATION

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DETERMINING PARAMETERS OF AIRCRAFT WITH VARIABLE-SWEEP WING

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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 ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

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

Russian	English
rot	curl
lg	log

DETERMINING PARAMETERS OF AIRCRAFT WITH VARIABLE-SWEEP WING

A. A. Krasotkin

One way of creating multimode aircraft is to use wings of variable sweep. A change in the plan shape of the wing makes it possible to change the aerodynamic characteristics of the aircraft over broad limits and to adjust it to specific flying conditions.

In the initial stage of planning of an aircraft with a variable-sweep wing we must determine the parameters which significantly influence its outward appearance: the plan shape of the original wing (for equal degrees of sweep in the leading edges of the moveable part of the wing (MPW) and immoveable part (IPW)), the relative thickness of the original wing profile, the arrangement of hinged joints over the span, specific load on the wing, and starting thrust-to-weight ratio.

A subsonic flow past the leading edges of the wing makes it possible to best utilize the effect of the swept wing. Thus, under all flying conditions the leading edge of the wing should be within the cone of disturbance from the impinging flow.

The flight range of the aircraft under cruising conditions L equals:

(1) $$L = 3.6\, a \frac{KM}{C_e} \ln \frac{G_0}{G_1},$$

where a - is the speed of sound;

k - aerodynamic quality;

M - Mach number of cruising flight;

C_e - specific fuel consumption;

G_0 - takeoff weight of aircraft;

G^1 - weight of aircraft before landing.

It is determined by two parameters - the range coefficient $\frac{KM}{Ce}$, which describes the degree of perfection of the "aircraft-engine" aerodynamic system and by the term $\ln \frac{G_0}{G_1}$, which describes its degree of weight perfection. The criterion for estimating the optimal combination of the studied parameters with respect to range can be their product:

(2) $$\tilde{L} = \frac{KM}{C_e} \ln \frac{G_0}{G_1}$$

where $\tilde{L}$ is the criterion of the estimation.

Obviously the optimal will be a combination of parameters in which $\tilde{L}$ has maximal value, provided that requirements for the remaining flight characteristics of the aircraft are satisfied.

The solution of the problem is achieved in two stages - formation of the geometry of the original wing and determination of the optimal values of the studied parameters for the purpose of obtaining maximal flight range. In the first stage the limitation of the sweep of the trailing edge is related to the conditions of possible turn in the MPW, creation of niches into which a portion of the MPW can enter when sweep is increased, an increase in the structural rigidity of the wing, a decrease in the aspect ratio, etc. These features do not make it possible to achieve complete optimization in the shape of the original wing in the initial stage of the project. Rather they influence its original plan shape, necessary for further analytical studies. In the second stage the solution of the posed problem is reduced to determining the roots of the following system of equations:

$$\frac{\partial \tilde{L}}{\partial \bar{C}_{ucx}}=0;\ \frac{\partial \tilde{L}}{\partial \bar{z}_{w}}=0;\ \frac{\partial \tilde{L}}{\partial p}=0;\ \frac{\partial \tilde{L}}{\partial t}=0 \qquad (3)$$

and meeting the conditions dictated by requirements for the aircraft:

$$M_{max} \geq M_{max}^{(T)};\ H_{noT} \geq H_{noT}^{(T)};\ \ell_{enn} \leq \ell_{enn}^{(T)}$$

where $\bar{C}_{ucx}$ - relative thickness of wing profile in initial position; $\bar{z}$ - relative span of hinged joints, equal to ratio of distance between hinges to wingspan in initial positions; P - specific load on wing; t_0 - starting thrust-to-weight ratio; M_{max} - maximal flight number; H_{noT} - static ceiling; ℓ_{enn} - length of takeoff-landing strip.

Quantities with the index (T) refer to parameters dictated by requirements for the aircraft.

In solving the problem the following assumptions, which have virtually no effect on the results, can be used:

a) Wing area is constant with a change in the position of the hinge joints and turning of the MPW.

b) The Mach number of subsonic cruising flight is below the critical Mach number by 0.03.

c) Cruising flight occurs at altitudes of $H \geqslant 11$ km.

d) In passing through the "throat" - that portion of the trajectory where we have altitude gain and acceleration to supersonic speed - the thrust reserve should exceed drag by 20-25°/₀.

The following transformations make it possible to express the range coefficient in the studied parameters:

(4) $$\frac{KM}{C_e} = \frac{3{,}42\sqrt{p\bar{t}_0\,\xi(M)}}{C_{x_0}\,C_{e_0}\,\psi(M)}\sqrt{\bar{\Pi}_{cw}\,\lambda_{cw}},$$

where C_{x_0} is the drag of the aircraft at zero lift; C_{e_0} - specific fuel consumption at H = 0 and M = 0; $\xi(M)$; $\psi(M)$ - functions which approximate engine thrust and fuel consumption with respect to Mach numbers; $\bar{\Pi}_{cw}$; λ_{cw} - relative half-perimeter of wing edges in stream, equal to ratio of perimeter of wing edges to wingspan and aspect ratio of wing with compression of the impinging flow considered.

The product of ($\bar{n}_{cw}$ λ_{cw}) can be expressed by the following dependence:

(5) $$\bar{n}_{cw}\lambda_{cw} = 2{,}25 + \lambda\sqrt{1-M^2\cos\chi_3},$$

where χ_3 is the sweep of the MPW along the trailing edge.

The drag coefficient, which is independent of the lift of the wing is:

(6) $$C_{x_0} = \eta_p(1+k\bar{C})(1+5\bar{C}M^4) + \eta_в\lambda C^2 + p(\eta_{мr}t_o + \eta_\varphi + \eta_{ro}\frac{A_{ro}}{L_{ro}} + \eta_{goб}),$$

where η_p; k; $\eta_в$; $\eta_{мr}$; η_φ; η_{ro}; $\eta_{goб}$ represent constant coefficients; λ; $\bar{C}$ - aspect ratio of wing and relative thickness of MPW profile in position corresponding to subsonic cruising flight, respectively; A_{ro} - static moment of horizontal tail unit; $\bar{L}_{ro}$ - arm of horizontal tail unit.

In (6) the first and second terms corresponds to the coefficients of wing resistance, the third - to the resistance coefficients of the engine nacelles, fuselage, horizontal tail unit, and other elements not considered, respectively. Under subsonic cruising conditions $\eta_\theta=0$.

Now let us look at the second term $\ell n \frac{G_0}{G_1}$. Under the condition that the takeoff weight of the aircraft is constant, the change in parameters which affect the weight of the structure or its power plant introduces a change in fuel reserves. If we represent the equation of relative weights of the aircraft in the form of:

$$\bar{G}_{nep} + \bar{G}_{nocm} + \bar{G}_{T} + \bar{G}_{rp} = 1$$

and assume that $G_1 = G_{nep} + G_{nocm}$, then we get:

$$\ell n \frac{G_0}{G_1} = \ell n \frac{1}{\bar{G}_{nep} + \bar{G}_{nocT}} \tag{7}$$

where $\bar{G}_{nep}$. $\bar{G}_{nocT}$ represent, respectively, the components of relative weights which are dependent and independent of the studied parameters; $\bar{G}_{T}$ - relative weight of fuel; $\bar{G}_{rp}$ - relative weight of disposed load (for military aircraft).

In turn:

$$\bar{G}_{nep} = \bar{G}_{\kappa p} + \bar{G}_{\kappa n} + \bar{G}_{ro} + \bar{G}_{c.y.} \tag{8}$$

where $G_{\kappa p}$. $G_{\kappa n}$. G_{ro} . $G_{c.y.}$ represent the relative weights of the wing, the mechanism for turning the MPW, the horizontal tail unit, and the power plant.

The weight of the variable-sweep wing:

$$G_{кр} = G_{исх} + \Delta G_{иг} \quad (9)$$

where $G_{исх}$ is the weight of a wing of fixed sweep, whose parameters coincide with the parameters of the variable-sweep wing in initial position; $\Delta G_{иг}$ - increase in weight of wing, associated with structural features (presence of hinges, niches, reinforcement, etc.).

$$\Delta G_{иг} = \frac{n_p G_0 \bar{S}_n [\bar{z}_w \cos\chi_n + (1-\bar{z}_w)] C}{\cos\chi_n [\bar{z}_w \cos\chi_n + (1-\bar{z}_w)\cos\chi_n]} \sqrt{\frac{\lambda_{исх} G_0}{p}} \quad (10)$$

where n_p - calculated loadfactor; $\bar{S}_n$ - relative area of MPW; $\bar{S}_n = \frac{S_n}{S_{кр}}$; $\chi_n, \chi_н$ - sweep of MPW and NPW, respectively; C - constant coefficient which depends on plan shape of original wing.

The limitations imposed on the system (3) are determined by the possibilities of achieving the maximal Mach flight number and the static ceiling, the "throat" passage and the takeoff run of the aircraft during takeoff.

The limitation with respect to Mach number:

(11)
$$\frac{0{,}0147\sqrt{P\bar{t}_0}\,\xi(M)}{C_x} \geqslant M^{(T)}$$

The limitation with respect to the ceiling (expressed in terms of limitation on relative air density Δ):

(12)
$$\frac{1{,}66}{\bar{t}_0\sqrt{C_{x0}A_{ucx}}\,\xi(M)} \leqslant \Delta^{(T)}$$

where A_{ucx} is the drop in the polar of the original wing for $M=M^{(T)}$.

The "throat" limitation:

(13)
$$\frac{5580\cdot M(C_{x\,max})C_{x\,max}}{\xi(M)} \leqslant \bar{t}_0 P$$

where $M(C_{x\,max})$ is the flight Mach number corresponding to the maximal value of the drag coefficient.

The limitation with respect to the takeoff run of the aircraft:

(14)
$$\frac{1}{2g}\,\frac{16P}{C_{y\,взл}(0{,}95\bar{t}_0-f_{тр})} \leqslant \ell_{разб}$$

where $f_{тр}$ is the friction coefficient on the runway.

To eliminate the nonreal values of optimums and to narrow the range of the search, let us limit the fields of studied parameters:

$$C_{ucx} > 0; \quad 1 > \bar{z}_w > 0; \quad 1500 \geq p > 0; \quad 1 > \bar{t}_0 > 0 \tag{15}$$

To solve the problem we must also have the geometrical dependences which describe wing geometry in plan and the arm of the horizontal tail section in function $\bar{z}_w$.

In Fig. 1 we see the effect of the studied parameters on the range criterion $\bar{L}$. The imposed limitations do not make it possible to achieve the optimum specific load on the wing.

In Fig. 2 we see the results of solving the problem of determining the optimal parameters of a long-range aircraft with variable-sweep wing.

The possibility of adjusting the aerodynamics of the wing to the specific flight conditions has made it possible to increase the load on the wing up to ~700 kgf/m² and to increase the relative thickness of the original wing profile to 6.3⁰/₀. In combination with a power plant of moderate weight, determined by the starting thrust-to-weight of the aircraft ($\bar{t}_0$ = 0.34), and a small increase in the weight of the wing (ΔG_{ur} = 0.044), determined by the position of the hinged joints for turning the MPW ($\bar{z}_w$ = 0.58). We can obtain the maximal flight range characteristic of subsonic aircraft and also meet requirements for efficient flight at supersonic speeds and landing at airports with runways of a certain length.

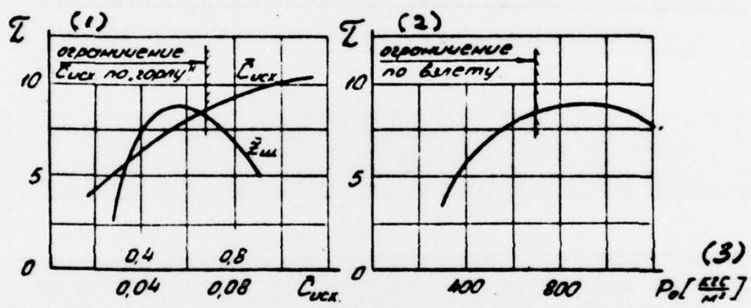

Fig. 1. Effect of studied parameters on range criterion. KEY: (1) "Throat" limitation, (2) Takeoff limitation, (3) kgf/m².

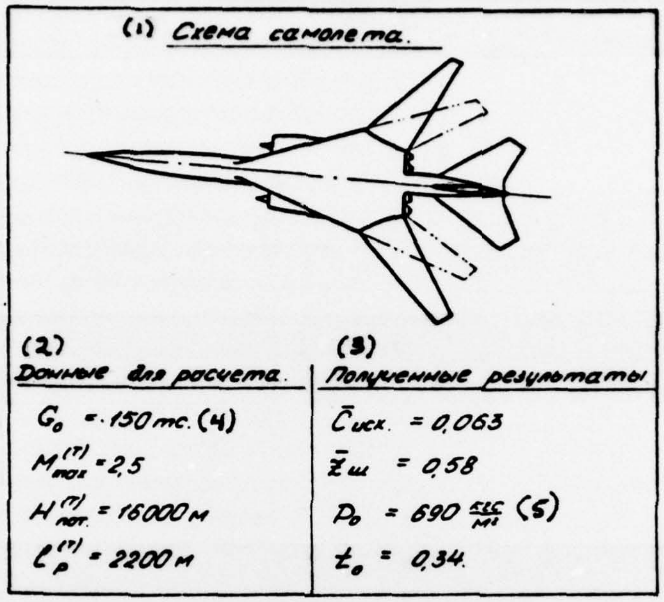

Fig. 2. Results from solution to problem. KEY: (1) Scheme of aircraft, (2) Calculation data, (3) Obtained results; (4) ms, (5) kgf/m².

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