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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 759

THE EFFECT OF WEIGHT AND DRAG ON THE SINKING SPEED AND LIFT/DRAG RATIO OF GLIDERS

By R. Kosin

Luftfahrtforschung
Vol. 11, No. 5, October 25, 1934
Verlag von R. Oldenbourg, München und Berlin

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THE EFFECT OF WEIGHT AND DRAG ON THE SINKING SPEED AND LIFT/DRAG RATIO OF GLIDERS*

By R. Kosin

1. NOTATION

c_{w_R},	c_{D_p}	coefficient of residual drag.	
c_f,	C_{D_0}	coefficient of frictional drag.	
$\bar{t}$,	$\bar{c}$	mean wing chord,	m.
F_R,	f	equivalent residual drag,	m².
ϵ,		lift/drag ratio. $\frac{D}{L}$	
ϵ_{min},		minimum lift/drag ratio.	
v_z,		sinking speed,	m/s.
$v_{z_{min}}$,		minimum sinking speed,	m/s.
$v_{\epsilon_{min}}$,		flight speed for ϵ_{min},	m/s.
$\epsilon_{v_{z\,min}}$,		lift/drag ratio for $v_{z_{min}}$,	
$v_{v_{z\,min}}$,		flight speed for $v_{z_{min}}$,	m/s.
$\bar{t}_{\epsilon_{min}}$,		wing chord for ϵ_{min},	m.
$\bar{t}_{v_{z\,min}}$,		wing chord for $v_{z_{min}}$,	m.

*"Einfluss von Gewicht und Widerstand auf Sinkgeschwindigkeit und Gleitzahl bei Segelflugzeugen." Luftfahrtforschung, October 25, 1934, pp. 128-130.

2. APPRAISAL OF GLIDER PERFORMANCE

The factors for evaluating the performance of gliders are: minimum sinking speed, minimum gliding angle, cruising speed, cruising speed gliding angle, and smallest possible radius of turn. The most important of these are minimum sinking speed and minimum gliding angle. To assure their optimum value the energy necessary for flight, that is, the energy of lift and friction must be kept very low, or in other words, weight and total drag which have a decisive effect on the sinking speed and on the gliding angle, must be kept at a minimum.

How great the effect of a reduction of these two quantities is, shall be shown in the following.

DRAG/LIFT

3. WING DESIGNED FOR MINIMUM ~~LIFT~~/DRAG RATIO

We first treat the wings which make the lift/drag ratio a minimum. It is

$$\epsilon = \frac{c_{w_i}}{c_a} + \frac{c_{w_R}}{c_a} + \frac{c_{w_p}}{c_a}. \quad = \frac{C_D}{C_L}$$

With $\qquad c_{w_i} = \frac{\kappa\, c_a^2\, \bar{t}}{\pi\, b}$ and $c_{w_R} = \frac{F_R}{b\, \bar{t}}$

we have $\qquad \epsilon = \frac{\kappa\, c_a\, \bar{t}}{\pi\, b} + \frac{F_R}{b\, \bar{t}\, c_a} + \frac{c_{w_p}}{c_a}.$

The wing chord $\bar{t}_{\epsilon_{min}}$ corresponding to ϵ_{min} follows from the differentiation of ϵ according to t and equating the differential quotients

$$\frac{d\epsilon}{dt} = \frac{\kappa\, c_a}{\pi b} - \frac{F_R}{b\, \bar{t}^2\, c_a} = 0;$$

$$\bar{t}_{\epsilon_{min}} = \frac{\sqrt{\pi \cdot \frac{F_R}{\kappa}}}{c_a}$$

to zero:

With this $t_{\epsilon_{min}}$ the minimum ϵ is

$$\epsilon_{min} = \frac{2}{\sqrt{\pi/\kappa}} \frac{\sqrt{F_R}}{b} + \frac{c_{w_p}}{c_a}$$

and the flight speed corresponding to ϵ_{min} is:

$$v_{\epsilon\,min} = \sqrt{\frac{2g}{\gamma}} \sqrt{\frac{G}{b}} \frac{1}{\sqrt[4]{\pi \frac{F_R}{\kappa}}}$$

According to the equation for ϵ_{min} an improvement in effect of F_R on ϵ_{min} occurs only in 0.5th power, and then only on one summand which for very good gliders amounts to 1/2 to 3/5 of the total ϵ. And even then this improvement is contingent upon $\bar{t}_{\epsilon_{min}}$ becoming smaller, corresponding to the reduction of $\sqrt{F_R}$. Unless $\bar{t}$ is suitably reduced the improvement of F_R is effective only on one summand of the equation:

$$\epsilon = \frac{c_{w_i}}{c_a} + \frac{c_{w_R}}{c_a} + \frac{c_{w_p}}{c_a}$$

An improvement of $\frac{c_{w_p}}{c_a}$ is in both cases identically effective.

The sinking speed v_z for ϵ_{min} is:

$$v_{z_{\epsilon\,min}} = \epsilon_{min}\, v_{\epsilon_{min}};$$

ϵ_{min} is dependent on $\sqrt{F_R}$ and $\frac{c_{w_p}}{c_a}$, and $v_{\epsilon_{min}}$ on $\sqrt{G}$ and $\frac{1}{\sqrt[4]{F_R}}$, that is, the sinking speed of a glider designed according to ϵ_{min} is influenced by $\sqrt{G}$ and $\sqrt[4]{F_R}$. This readily discloses the preponderate effect of the weight over the residual drag on the sinking speed of a glider designed for ϵ_{min}.

4. WING DESIGNED FOR MINIMUM SINKING SPEED

Its best wing chord is:

$$\bar{t}_{v_z\ min} = \frac{F_R}{c_a\ b\left[\sqrt{\left(\frac{c_{w_p}}{6c_a}\right)^2 + \frac{F_R}{3\ \pi\ b^2\ \kappa}} - \frac{c_{w_p}}{6c_a}\right]} = \frac{F_R}{c_a\ b\ [X]}.$$

With this value, the lift/drag ratio becomes:

$$\epsilon_{v_z\ min} = \frac{F_R}{3\ \pi\ b^2\ \kappa\ [X]} + [X] + \frac{c_{w_p}}{c_a}.$$

As this term does not lend itself very readily to discussion because of its complicity, we have compiled the values for c_{w_p}, c_{w_i}, and c_{w_R} for a number of very satisfactory gliders designed for $v_{z_{min}}$ which are shown in figure 1. It reveals the smallness of the residual drag in proportion to the total drag. A change in residual drag without a corresponding reduction in wing chord does not afford much change in total drag; and, because of the relationship between v_z and ϵ, the sinking speed is likewise affected very little. The effect of the weight is $\sqrt{G}$.

In order to gain an insight into the conditions, we computed the aspect ratio, flight speed, lift/drag ratio, sinking speed, and c_w for a series of gliders with span increasing from 12 to 24 m (39.36 to 68.9 ft.), which were designed for ϵ_{min} and $v_{z_{min}}$ (see fig. 1).

The ϵ_{min} shown herein is referred to the gliders with wing area designed according to ϵ_{min}, the $v_{z_{min}}$ for gliders with wing area designed for $v_{z_{min}}$.

The figures serving as basis are those of a glider of 12 m (39.36 ft.) span, for which the most accurate data were available. It was assumed that the weight of fuselage and equipment + useful load remains ~ constant, while the wing weight rises as the 1.5th power of the span. This is slightly unfavorable, but it should be borne in mind that the aspect ratio increases considerably, so that the relative structural height becomes less. The residual drag consists of fuselage and control-surface drag. With a surface assumed at 6.5 m^2 (69.97 sq.ft.), its equivalent flat-plate area is surface c_{w_F}.

The coefficient of friction according to Wieselsberger's measurements is $c_{w_F} \sim 0.004$.

The control-surface drag increases proportional to the control-surface dimensions. We assumed it to increase proportional to the weight with increasing span, which is equivalent to an increase in span with unchanging wing loading.

$$F_{r_L} = 0.009\ F_L, \quad F_L = 2\ m^2\ (21.53\ \text{sq.ft.})\ \text{for}\ b = 12.$$

TABLE I

Span		12	14	16	18	20	22	24
Weight of fuselage + useful load + control surface	kg	120	120	120	120	120	120	120
Wing weight.........	kg	35	44	54	64	75	87	99
Equivalent residual drag-plate area of fuselage...	m^2	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Equivalent residual drag-plate area of control surfaces	m^2	.016	.017	.018	.019	.021	.022	.023
Total equivalent residual drag-plate area	m^2	.046	.047	.048	.049	.051	.052	.053

The figures given in table I with respect to gliders designed according to ϵ_{min}, may be exceeded with respect to residual drag by gliders designed for $v_{z_{min}}$.

However, one is not apt to build a glider defined by one of these minimum calculations, but rather to keep the chord always within the two extreme figures. The reasons for this are several, viz: To build the "optimum" wing implies an estimation relative to any quantity wherein both v_z and ϵ may become less satisfactory, while for a wing whose chord lies between the extreme figures, it simply means that sinking speed is gained at the expense of gliding angle or vice versa. The results of the optimum calculation are illustrated in figure 1: aspect ratio, optimum flight speed, gliding angle, and sinking speed. The wings for ϵ_{min} are seen to exceed by far the possible aspect ratios of the wings, especially when bearing in mind that for reasons of flight performances the taper is not to exceed a certain amount.

Using the quoted weights and the stipulation v_{min} = 25 m.p.h. for $c_a = 1.6$ to develop a glider series, give the data shown in figure 2.

5. DESIGN OF GLIDER WITH STIPULATED CRUISING SPEED

Here the problem is, how to design the glider so that the performances at this speed are as good as possible, or in other words, to assure an optimum ϵ with a certain speed.

The wing chord should be reduced up to near $\bar{t}_{\epsilon_{min}}$, since a smaller chord gives a higher speed and a better gliding angle, whereas a higher G gives only a higher speed. If $\bar{t}_{\epsilon_{min}}$ is reached, then G would have to be raised to raise the speed because any further reduction in $\bar{t}$ would vitiate the gliding angle again.

Now $\bar{t}_{\epsilon_{min}}$ is not obtainable in wood design on account of the high aerodynamic quality of modern aircraft; in fact, our present structurally attainable wing chords very closely approach $\bar{t}_{v_{z\,min}}$. Therefore, given a wing of stated chord, a certain flight speed can only be obtained by an increase in G or with flight at low c_a. Up to a certain dynamic pressure q (and thereby c_a) flight at low c_a improves the gliding angle.

$$\epsilon \doteq \frac{\kappa \, c_a \, \overline{t}}{\pi b} + \frac{c_{w_R}}{c_a} + \frac{c_{w_p}}{c_a};$$

$$\frac{d\epsilon}{dc_a} = \frac{\kappa \, \overline{t}}{\pi \, b} - \frac{c_{w_\kappa}}{c_a^2} + \frac{c_a \frac{dc_{w_p}}{dc_a} - c_{w_p}}{c_a} = 0$$

gives the c_a for the best ϵ.

To raise the flight speed beyond that of the best ϵ without vitiating the gliding angle, calls for an increase in G. But this increases the minimum sinking speed, and it would be a question of experience in practical flying as to whether or not a slightly poorer gliding angle in cruising flight is preferable in favor of a substantial improvement in minimum sinking speed. The extent to which the speed may be raised without vitiating the gliding angle depends altogether on the employed airfoil. Then the choice of airfoil would have to be made from the point of view of good lift/drag ratio at low c_a; that is, perhaps

$$\frac{c_{w_p}}{c_{a_{cruising}}}.$$

Figure 3 shows the velocity polars of two airplanes of 20 m (65.62 ft.) span, with 4,410 lb. and 4,586.4 lb. flight weight. They differ in wing area only (aspect ratio λ = 1:20 and 1:30). Here it is shown very definitely how the "flight performances" can be raised by reducing the wing chord, especially with concurrent light design. The increase in weight alone affords but a minor improvement in gliding angle (and thereby in sinking speed) at high speeds, while, as stated before, it vitiates the minimum sinking speed substantially, which may cause the interruption of flight (in long-distance flight).

In figures the cited examples disclose: With λ = 1:20 and G = 4,410 lb., a 40 percent increase in flight weight means an 18 percent poorer minimum sinking speed, while the gliding angle does not improve below ~ 37.2 m.p.h. For λ = 1:30 and G = 4,410 lb., a 40 percent raise in flight weight denotes a 20 percent poorer minimum gliding speed, while the gliding angle begins to improve only at ~ 41 m.p.h.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

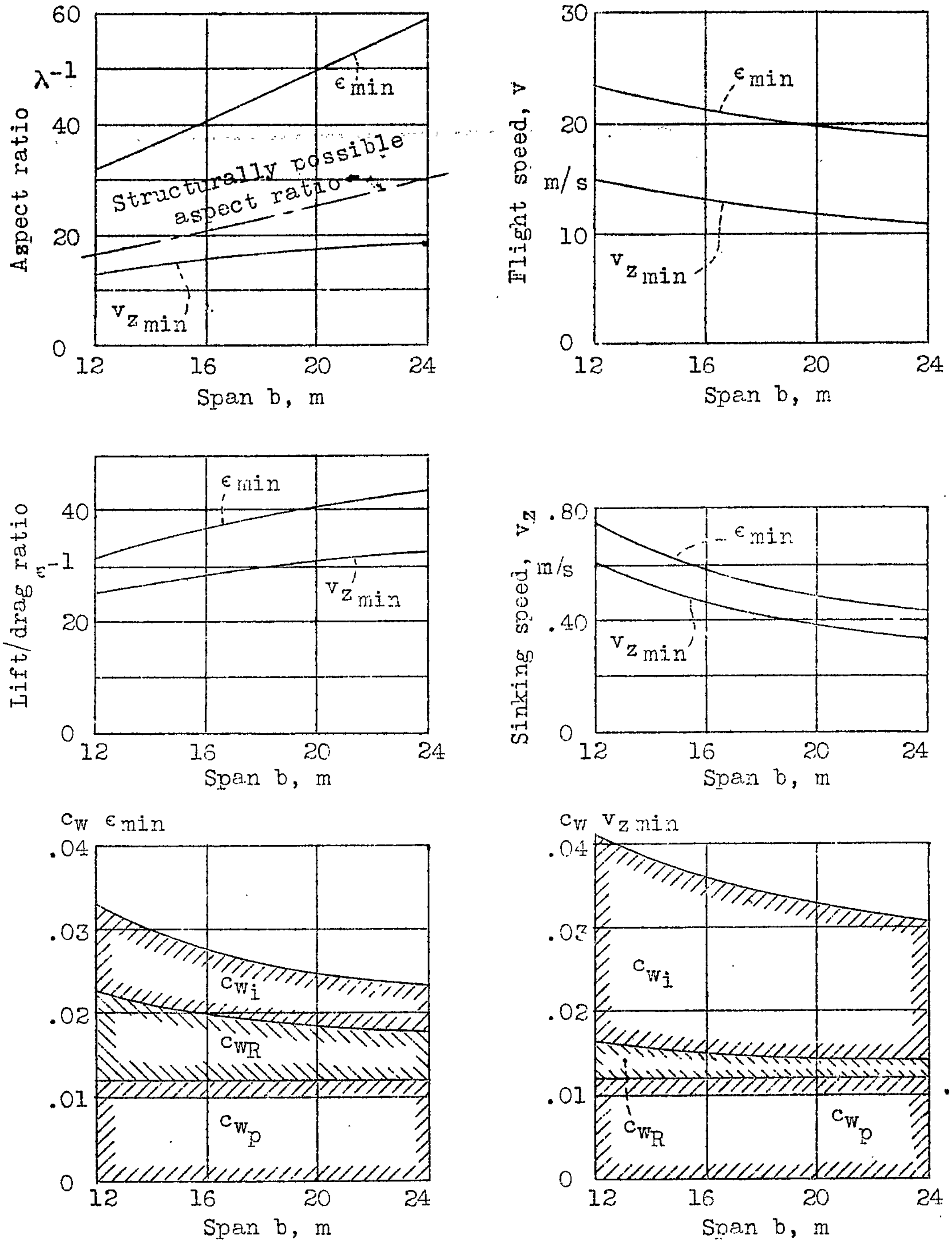

Figure 1.- Airplane series: $b = 12$ to $24\,m$; $G = 120 + 35 \left(\frac{b}{12}\right)^{1.5}$ kg;

$$c_{w_{R_x}} = 0.03 + 0.016 \frac{G_x}{G_{12}}; \quad \frac{c_{w_p}}{c_a} = 0.012$$

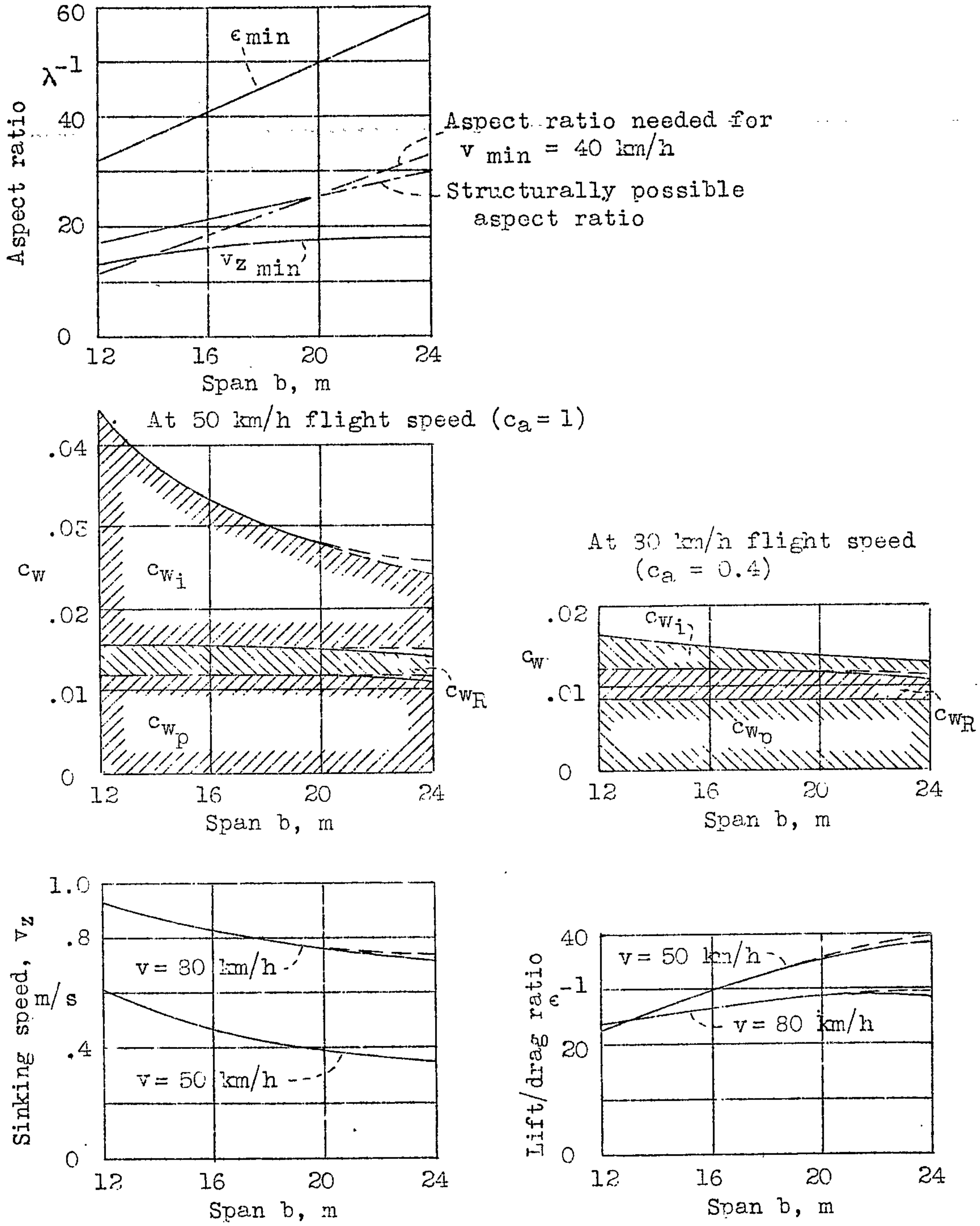

Figure 2.- Airplane series: b = 12 to 24 m; $G = 120 + 35(\frac{b}{12})^{1.5}$ kg; $v_{min\ c_a = 1.6} = 40$ km/h

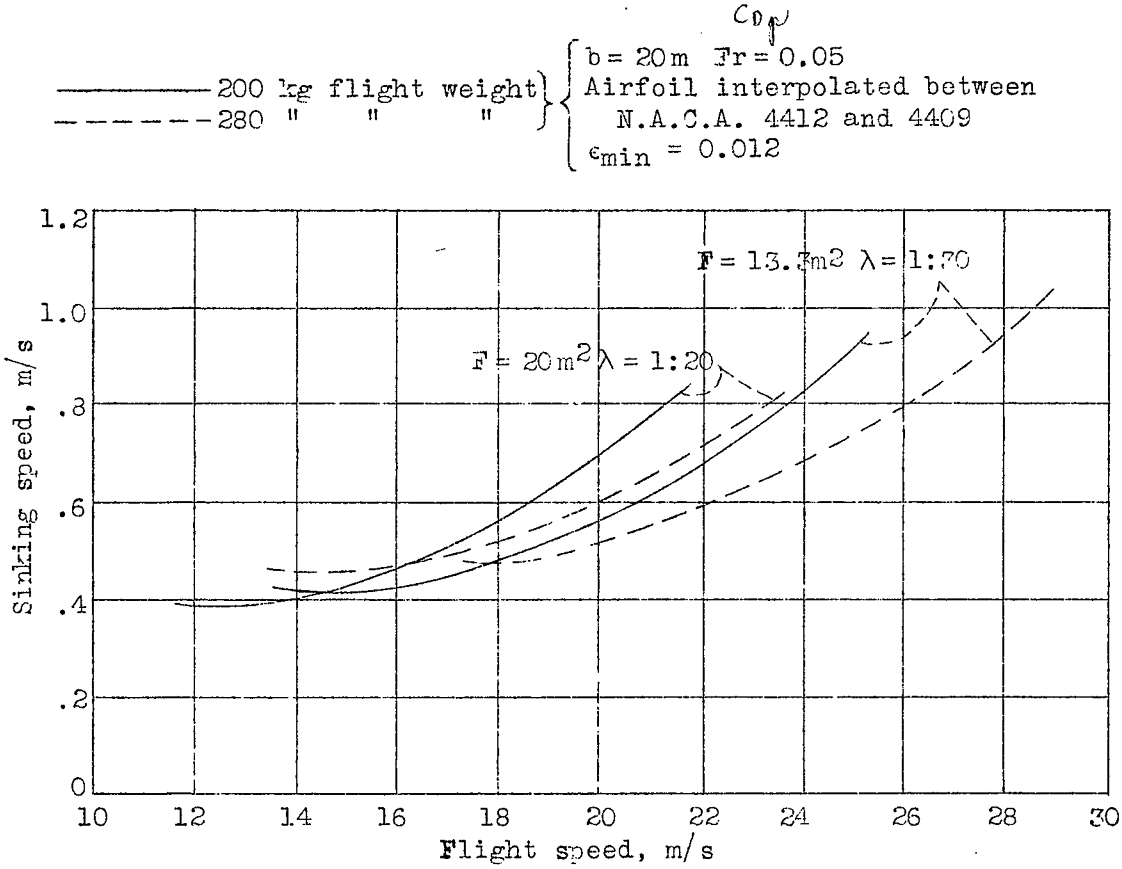

Figure 3.- Effect of G and λ on the velocity polars of a monoplane of 20m (65.6 ft.) span.

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