Some Notes on Seeking New Methods of Sailplane Lift-Drag-Curve Measuring

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With the improvement of sailplane performance the importance of flight measuring continues to increase but simultaneously difficulties in the accuracy and duration of testing become greater. If the "classical method" (i.e. measuring the rate of sink and air-speed in steady straight flight) is used, both these factors depend mostly on the meteorological conditions and their influence is increasing the higher the performance attained by the sailplane being tested. While seeking new and better methods, preliminary theoretical analysis and useful practical testing of two methods was carried out. One was the "deceleration method", by which the lift-drag curve has been estimated from dynamic pressure-time variation recorded during an exactly held horizontal flattening-out, and a somewhat modified "towed flight method". It was intended to assess roughly, with the most necessary means being at disposal, the possibilities of using these methods practically.

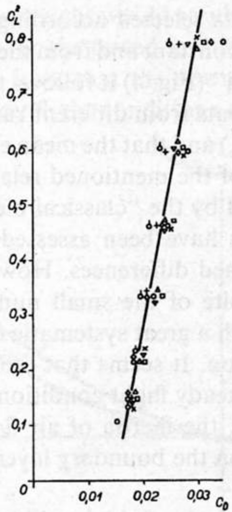

Fig. 1

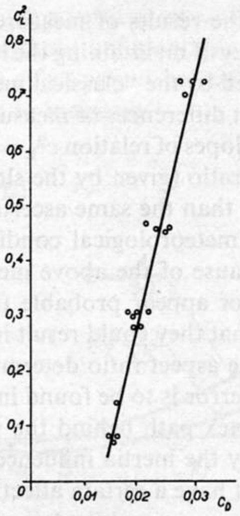

Fig. 2

Deceleration method

This method enables one to establish the lift-drag curve from one flattening-out, it being possible to perform about 10 flattening-outs during one flight. In this respect the method is apparently more favourable than the classical one. Among disadvantages there are mainly difficulties in piloting technique and measuring of very small values of deceleration.

The main difference from other measurements consisted in applying recorded dynamic pressure-time variation for the estimation of the deceleration.

Theoretical considerations

Drag and lift coefficients can be determined from the following equations:

$$\left.\begin{aligned} qSC_D &= -\frac{W}{g}\frac{dV}{dt} \\ qSC_L &= W \end{aligned}\right\} \quad (1)$$

We obtain

$$\left.\begin{aligned} c_D &= -\frac{3{,}250}{g}\frac{W}{S}\frac{dq}{dt}\frac{1}{q^{3/2}}\left(\frac{I}{\rho}\right)^{1/2} \\ c_L &= \frac{W}{Sq} \end{aligned}\right\} \quad (2)$$

Sources of errors

Results of measurements will be affected by position error, by error due to the lag in airspeed measuring system, by errors of instruments and by meteorological conditions.

Effect of position error

In addition to the normal effect on speed reading the position error causes the sailplane to change height during the flattening-out in spite of correctly held level indicator. The change of height is given by equations:

$$\left.\begin{aligned} \frac{dp_R}{dt} &= \frac{dp}{dt} - \frac{d(\delta p_a)}{dt} = \varnothing \\ \frac{dp}{dt} &= \frac{d(\delta p_a)}{dq_R}\frac{dq_R}{dt} \end{aligned}\right\} \quad (3)$$

Due to this effect the decrase of dynamic pressure differs from that which occurs in true level flight (the same happens in the case when the accelerograph is applied). The difference can be considered from the relation between kinetic and potential energy of the sailplane and between the height and atmospheric pressure:

$$\left.\begin{aligned} \frac{d(HW)}{dt} &= -\frac{d(\frac{1}{2}\frac{W}{g}V^2)}{dt} \\ dp &= g\rho dH \end{aligned}\right\} \quad (4)$$

Facts previously mentioned lead to the equation

$$\frac{dq}{dt} = \frac{dq_R}{dt}\left[1\text{-}2\,\frac{d(\delta p_a)}{dq_R}\right] \quad (5)$$

The lag effect

According to the fact that reading of static pressure p_R does not change during the flattening-out, dynamic pressure change is given exclusively by the total pressure change. The relation between the correct total pressure p_O and recorded pressure p_{OR} can be expressed:

$$p_O = p_{OR} + \lambda\frac{dp_{OR}}{dt} \quad (6)$$

Coefficient λ includes the influence of geometric characteristics on the total pressure line and the influence of temperature and air pressure. It can be determined by direct ground measuring and the effect of other values of pressure and temperature can be established in a simple way.

Dynamic pressure correction is then given by the expression:

$$\delta q = \delta p_O = \lambda \frac{dp_{OR}}{dt} = \lambda \frac{dq_R}{dt} \qquad (7)$$

Instrument errors

Standard deviation of drag coefficient σ_{CD} can be written from the relation (3) as an error of indirect measured value as follows:

$$\frac{\sigma_{CD}}{c_D} = \pm \sqrt{\left(\frac{\sigma\dot{q}}{\dot{q}}\right)^2 + \frac{9}{4}\left(\frac{\sigma q}{q}\right)^2 + \frac{1}{4}\left(\frac{\sigma_p}{p}\right)^2 + \frac{1}{4}\left(\frac{\sigma_T}{T}\right)^2} \qquad (8)$$

where $\dot{q} = \frac{dq}{dt}$

and $\sigma_{\dot{q}}$ means standard deviation

$$\frac{dq}{dt}$$

including the accuracy of instruments, of reading and of maintaining the level constant.

It is obvious that the resulting error depends mainly on $\sigma_{\dot{q}}$, σ_q and is increasing with the speed decrease.

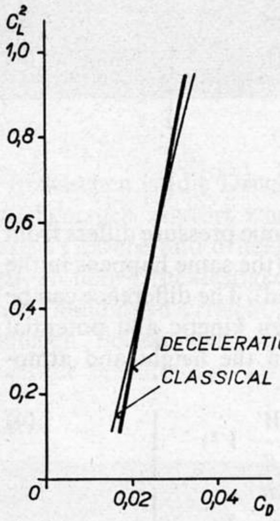

Fig. 3

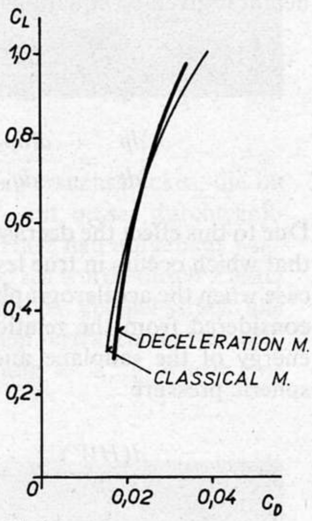

Fig. 4

Influence of meteorological conditions

As known the main sources of errors which occur in sailplane performance measuring are the vertical air movements. Not taking into consideration large-scale air movements, due to convergence or divergence of the air flow, we can assume that the longer the run the greater is the probability that the total sum of upward and downward currents will be nearer zero. Thus the measuring will be more reliable. As by using the "classical method" the measuring run is longer than by the "deceleration method" it is obvious that in this respect the accuracy of the "classical method" will be higher. The advantage of the "deceleration method", consisting in the fact that the nearly complete lift-drag curve is attained from one run—instead of singular points attained by the "classical method"—appears not as valuable as it might be considered at first sight.

Description of measurements carried out

Measuring has been performed with the L-13 Blaník sailplane in September 1956 at the stable atmospheric lapse-rate.

Following instruments were applied:

Recording differential gauge as an airspeed recorder, barograph;

recording statoscope (altered differential gauge);

level indicator.

A total number of 3 flights has been carried out of which the first was devoted to training in piloting technique and to verify the correct functioning of instruments.

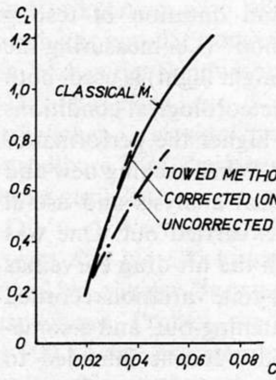

Fig. 5

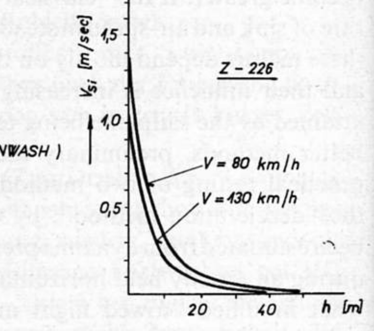

Fig. 6

Analysis of the results

From the results of measurements selected according to the accuracy of maintaining the level constant and from the results obtained by the "classical method" (Fig. 4) it follows that the greatest differences of measurements from different runs exist in the slopes of relation $c^2_L = f(c_D)$ and that the mean effective aspect ratio (given by the slope of the mentioned relation) is greater than the same ascertained by the "classical method".

The meteorological conditions have been assessed as the main cause of the above mentioned differences. However, it does not appear probable (in spite of the small number of runs) that they could result in such a great systematic error in effective aspect ratio determination. It seems that the source of this error is to be found in unsteady flight conditions when the vortex path behind the wing, the inertia of air flow and possibly the inertia influence upon the boundary layer development have a certain affect.

As even a rough technical analysis of this problem could not be found in the literature available, it appears difficult to judge whether the above mentioned phenomena could perceptibly affect the results obtained.

Even the quality of the measurements carried out and the impossibility of the elimination of other factors do not make even a rough analysis possible. Finally it is to be mentioned that the finish of the measured sailplane surfaces was worse than that measured by the "classical method" which could cause an increase in friction drag.

Conclusions

Compared with the "classical method" the following experiences can be summarized:

a) The accuracy of measuring is lower due to the higher influence of the meteorological conditions, even with carefully provided instrumentation. In the range of lower airspeeds the accuracy is so small that it makes measuring virtually impossible;

b) The measurements require a substantially more complicated instrumentation and its servicing, higher standard piloting technique and evaluation of results;

c) the results obtained by this method imply systematic errors due to the unsteady flight conditions during the testing.

Generally speaking it is possible to say that the estimated results did not meet the expectations and that even more careful measuring with better instrumentation would not give substantial advantages when compared with the "classical method".

Towed flight method

It is known that using this method enables one to shorten the testing time considerably. The measurements can be made during one flight (the range of measuring is, however, limited by tug performance—especially by minimum airspeed[1] and the test level can be selected. The latter is a great advantage because of the influence of meteorological conditions. (In practice there are often meteorological conditions where all measuring is impossible up to the height e.g. of 1500 m while at the height of 2000 m the conditions may be nearly ideal.) The downwash behind the tub and the difficulties in piloting technique represent the main disadvantages, which has made this method hardly practicable. Therefore an attempt has been made in Czechoslovakia to overcome these disadvantages by applying a weight to the towing cable. It was expected that the use of the weight would result in such a vertical separation of the tug over the towed sailplane, without unfavourable effect upon its trim, that the downwash effect would be negligible and steady flight conditions easier to maintain.

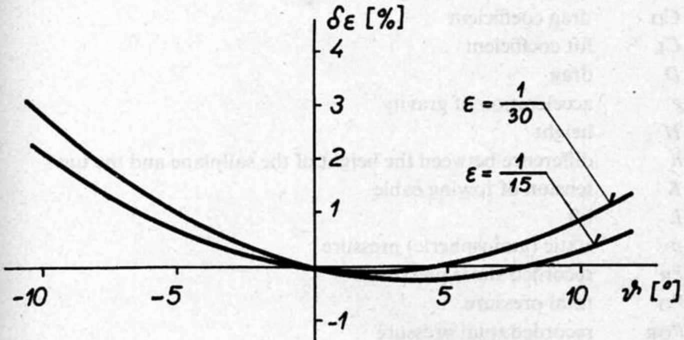

Fig. 7

Theoretical considerations

Provided the angle of the sailplane flight path γ is small the gliding ratio ε can be expressed from the equilibrium equations (9)

$$\left.\begin{aligned} D + W\sin\gamma - K\cos\theta &= \varnothing \\ L - W\cos\gamma + K\sin\theta &= \varnothing \end{aligned}\right\} \qquad (9)$$

in the following manner:

$$\varepsilon = \frac{c_D}{c_L} = \frac{\overline{K}\cos\theta - \Delta\overline{H}}{1 - \overline{K}\sin\theta} \qquad (10)$$

$\overline{K} = \dfrac{K}{W}$ K – tension of the cable

$\Delta\overline{H} = \dfrac{\Delta H}{\Delta L}$ ΔL – distance of the run

ΔH – change of the height during the run

θ – angle between the cable tension and the flight path of sailplane

Supposing testing under such conditions[2] that $\Delta\overline{H} = \theta = \varnothing$, we obtain:

$$\varepsilon = \overline{K} \qquad (11)$$

$$\left.\begin{aligned} c_D &= \overline{K}\,\frac{W}{Sq} \\ c_L &= \frac{W}{Sq} \end{aligned}\right\} \qquad (12)$$

Errors

Results determined from the relations (11) and (12) will be affected by errors caused by the downwash effect behind the tug and by the accuracy maintaining the conditions of $\Delta\overline{H} = \theta = 0$. The analysis of other errors—as of a position error and so on—has been omitted.

Effect of the downwash behind the tug

The results of the measurements carried out in the Netherlands have shown that the substitution of the tug influence by a simple horseshoe vortex approximates to the real situation. This substitution, however, does not appear sufficient for measurement corrections—degree of accuracy of results being considered—as the influence of viscosity cannot be precisely accounted for, neither can the position of the sailplane relative to the vortex be exactly determined.

These difficulties can be avoided if a sufficient vertical separation of the tub over the sailplane is achieved. This is shown in figure 6 plotting the rate of sink (due to the downwash behind the tug) against the vertical distance between both aircraft. Considering the influence of air viscosity, the downwash effect can be apparently neglected if the vertical distance is greater than 50 m.

Accuracy of maintaining level flight

The accuracy of maintaining the level constant depends chiefly on the instrumentation being used. In order to reach the gliding ratio accuracy required by equation (10) the following condition must be fulfilled:

$$\Delta L > \frac{100\sigma_H}{P\varepsilon}$$

where σ_H represents the standard deviation from level flight during the run.

Should the condition $\Delta H = \varnothing$ not be realized it would be necessary to measure the height and the temperature. Thus the measurements would become more complicated and less accurate, the errors of the barograph being greater than those of the level flight indicators (recorders).

Effect of the cable tension direction

During the testing the assumption that the direction of cable tension is identical with the flight path angle of the sailplane

[1] It is possible to extend the measuring range by means of artificially increased sailplane weight. However, the effect of Reynold's Number and structure efficiency of the sailplane must be considered.

[2] Even when maintaining these conditions approximately a considerable simplification of the measuring is reached, errors caused by this simplification will be considered further on.

can be realized only approximately. It is responsible for the error in gliding ratio $\delta\varepsilon$ which can be expressed from the relations (10) and (11) as follows:

$$\delta\varepsilon = \frac{1 - \bar{K}\sin\theta}{\cos\theta} - 1 \qquad (14)$$

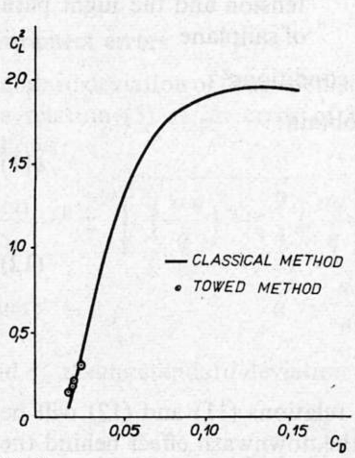

Fig. 8

The graph of $\delta\varepsilon$ against θ is given in figure 8.

It appears that for a relatively wide range of angles θ the effect of the tension direction is small and therefore, the condition $\theta = \varnothing$ being roughly accomplished, it is not necessary to measure the direction of the cable tension.

A moment caused by cable tension can result in a change of the sailplane drag (due to loads on the tail). However, a simple analysis shows that this effect is negligible if θ is small.

Influence of meteorological conditions

As already mentioned this method appears to be favourable as far as the meteorological conditions are concerned. The chosen height of measuring gives the opportunity to use conditions which with other methods could not be used and in addition it gives less important errors by longer measuring runs.

Description of the measurements carried out:

The testing has been carried out with the Mü 13 sailplane, the "Storch" aeroplane serving as a tug.

Following instruments were applied:

Special tension recorder;

recording differential pressure gauge as an airspeed recorder, barograph;

recording statoscope (altered differential pressure gauge); level indicator.

On the steel towing cable a weight (of about 15 kg) was hung, intended to permit both the maintenance of the condition $\theta = \varnothing$ (even when the vertical distance between the tug and the sailplane is greater) and the facilitation of the piloting technique (to minimize possible "jerking"). A simple warning equipment indicates to the sailplane pilot if the permissible deviation of θ has been exceeded. After take-off by means of a short towing cable (20–50 m) the latter is unrolled to the full length (280 m) and after the measuring has been carried out, the cable is rolled up completely. The arrangement diagram is shown in figure 9.

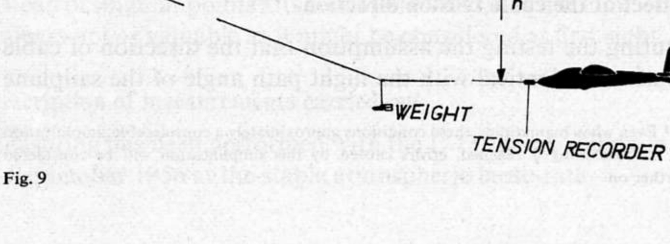

Fig. 9

The measuring, however, has unfortunately not been completed due to an insignificant accident during which a special tension cable recorder was destroyed. Only 4 flights altogether have been performed mostly devoted to the training of sailplane piloting technique. Valuable results have been obtained from a part of one flight only.

Experiences gained by measuring

The main difficulties have been revealed in piloting technique. A certain improvement has been obtained when placing the weight nearer to the sailplane (to about 20 m) and when the pilot had mastered the best way of flying. Placing the weight close to the sailplane has appeared very promising. Owing to the above mentioned accident this method of weight placing could not be proved. As to the influence of the tug it can be said that a few of the measured points (Fig. 10) prove that with a sufficient vertical distance between the tug and the sailplane the effect of downwash behind the tug can be neglected. However, in order to establish the definite conclusion it is necessary to carry out the measuring at lower airspeeds when a greater tug effect would be experienced.

Conclusions

Provided that additional testing will finally solve the piloting-technique problem and prove the possibility of neglecting the tug effect even at lower airspeeds, it will be possible to introduce this method into current practice and thus ensure quicker and more efficient measuring of the sailplane lift-drag curve.

List of symbols

b	semi-span of the tug
C_D	drag coefficient
C_L	lift coefficient
D	drag
g	acceleration of gravity
H	height
h	difference between the height of the sailplane and the tug
K	tension of towing cable
L	lift
p	static (atmospheric) pressure
p_R	recorded static pressure
p_O	total pressure
p_{OR}	recorded total pressure
q	dynamic pressure
q_R	recorded dynamic pressure
S	wing area
T	temperature
V	true airspeed
V_{si}	rate of sink induced by the tug
W	total weight of the sailplane
W_t	total weight of the tug
γ	flight path angle with respect to horizon
δp_a	static pressure error due to the position error
ε	gliding ratio
θ	angle between cable tension and flight path
φ	air density

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