Type Certification Test Results utilized to improve the Design Concept

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1. Introduction

When working on a glider prototype the designer looks for the newest concepts of technical progress to meet the requirements of users of today and tomorrow.

Every new concept in the technical progress appears in two steps:

- formation of the theoretical basis of the concept,
- application of the concept in practice.

The theoretical aspect of the problem depends on a logical or mathematical description of the concept itself as well as the benefits of its application. The analysis, in most cases, is supported with some tests; these seldom go beyond the laboratory, but must be of as wide a range as necessary to ensure that the theory conforms with the real conditions existing in the current production.

The above-mentioned tests concern the new design concepts, those which smooth the way of technical progress. In addition however, many tests are performed on a prototype, to find its characteristics, to prove that the requirements are satisfied and to show that the features defined in the technical documentation are achieved. These tests, apart from Authority satisfaction, can yield much interesting information for the designer by extending the programme only slightly. This information may indicate modifications which ought to be introduced to improve the sailplane's characteristics.

The design problems to be solved can be considered normally under two headings:

- original design,
- modification of an existing type, i.e. development.

It is difficult to find precisely the line dividing these two. In almost every prototype there are components adopted from previous types, as well as many standard or typical parts. So, we can say that no purely original design exists. Modification of an existing type is always more or less extensive. Sometimes it comprises many small changes to improve the operational characteristics; sometimes the modification is so extended that nearly a new prototype appears as a result.

2. Test Classification

In the glider technics two basic groups of tests are carried out:

(1) tests for stimulation of technical progress,
(2) tests for verification of the type characteristics.

The detailed classification of the tests are shown in table I. The tests for stimulation of the technical progress are rather difficult ones in respect to:

(1) no precedence and no pattern in testing a new and therefore unknown technical problem, and
(2) difficulties in financial support for the tests.

This kind of test concerns:

(a) recognizing the new materials, their characteristics and the method of application to the glider structure, technological method, etc.,
(b) practical support for the concept suitability,
(c) experiments with new aerodynamics, discovering of gains, disadvantages or unexpected problems.

The tests for stimulating the progress are carried out in advance, to enable the application of the results in the design of the prototype under consideration or to help in taking the decisions on generating the solution of the problem.

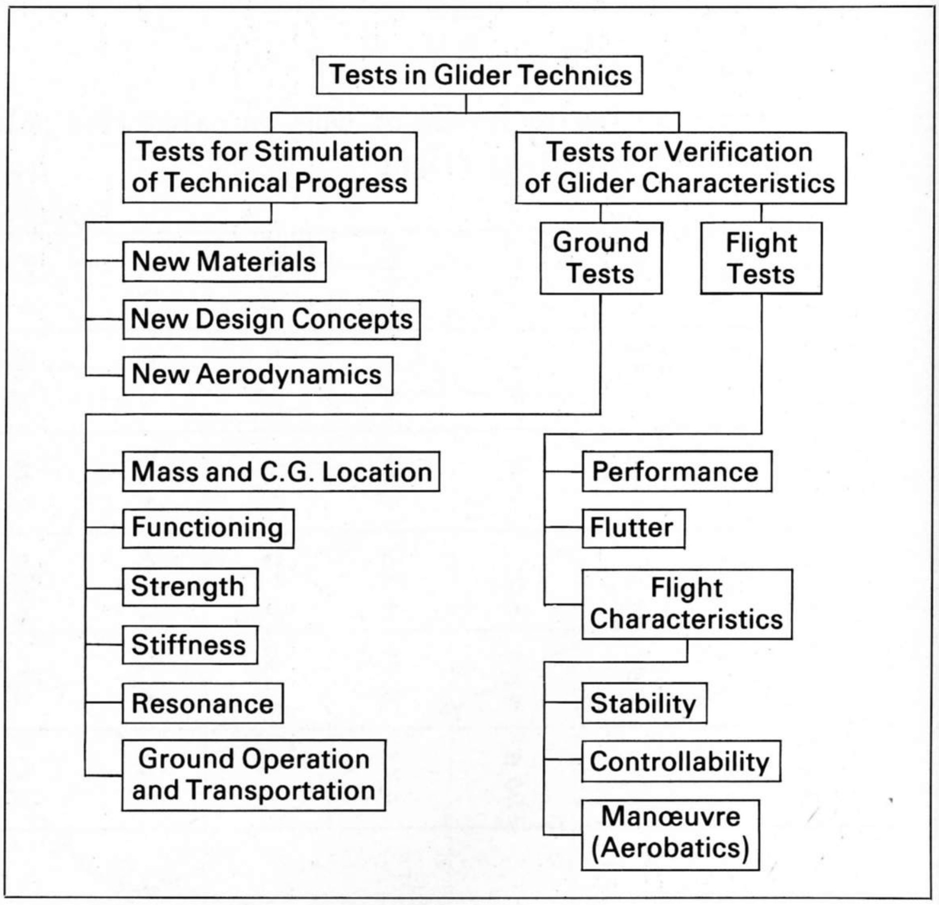

Table 1 Tests in glider techniques

Kind of test		**Possible change to be introduced**
Ground tests	Measurement of mass and c.g. location	Modified c.g. range or mass balast incorporated, recalculation of flight characteristics (stability, controlability, etc.), recalculation of performance and loadings due to actual weight-to-area ratio
	Strenght tests	Alterations in the primary structure (too low or too high safety factor)
	Stiffness tests	Alterations in the structural elements, recalculation of flutter criteria, changes in mass balancing of control surfaces.
	Resonance tests	Data for flutter calculations, changes in balancing mass distribution on the control surfaces or structure elements.
	Test of ground operation and transportation	Changes in the structure to facilitate the ground operation, provision for road transportation of glider
	Functioning tests	Improvements in stiffness or mechanical operation of the systems and details
Flight tests	Measurement of performances	Recalculation of performances on base of measured speed polar and circling characteristics
	Measurement of flight characteristics	Alteration in structure elements and changes in adjustments (control surface deflections, control system corrections, tailplane incidence, etc.)
	Flutter tests	Structural changes to improve the stiffness characteristics, changes in mass distribution on control surfaces

Table 2 Ground and flight tests in glider techniques.

The verification tests start when the prototype (or a component for testing) is ready to be tested. The ground tests, of course, precede the flight tests since they must provide the data which permit flying with the required margin of safety. The ground tests carried out for certification purposes must cover at least the following problems:

- measurements of the glider mass and c.g. location for all operationally possible loading conditions,
- correct stiffness of the structure elements in respect of flutter criteria,
- resonance characteristics of the structure (ground vibration tests),
- operation of all the mechanisms and systems,
- strength of the glider structure,
- easy ground handling (assembling, disassembling, hangaring, etc.) and transportation (trailer facilities).

The flight tests provide the following characteristics:

- measured sailplane performance,
- flight characteristics (stability, controlability, manœuvres, etc.),
- flutter freedom in the whole airspeed range within the allowed flight limitations.

3. Utilization of Test Results

The utilization of the test results in case of tests carried out for stimulation of the technical progress is obvious and need not to be discussed.

The verification tests are carried out to prove that the prototype behaviour is as assumed in the project. The manner of utilization of these tests requires closer discussion. It is obvious that all the test results enhance the statistical data utilized in the design procedure. The verification test results, however, are generally used as a directive for eventual small changes or corrections of the glider structure intended to:

- satisfy the requirements according to which the glider has been designed,
- improve the performance or operational characteristics.

This last item is very important to smooth the way to the market for our product. The more detailed the verification tests are, the better are the information obtained.

Before the serial production of the glider type is undertaken, a period of time is occupied in completing all the tests, documents and any structural modifications for certification purposes. During this time intense activity on the part of the designer is required, but, because of time and financial limitations, usually the only changes introduced are those which modify the glider characteristics in a distinct manner or which are needed to satisfy the Authority requirements.

4. Conjunction of Test Results and Design Modification

The designer, when sizing the structural elements, tends always towards the minimization of dimensions to keep the total structure mass as low as possible for the following reasons:

- the lower the structure mass the wider the range of cockpit load variation or increased water ballast quantity,
- the lower the structure mass the lower the cost of the material used,
- the calculation models used for dimensioning the details of the structure are always the «safe» ones; that means that in the calculations the elevated safety margin is taken into account, because the elements are isolated from the structure as a whole and the influence of structure support is neglected.

This tendency toward dimension minimizing is verified by the test in which the real operation conditions are simulated. On the other hand the test can also show an excess of material which should be reduced in the final product. The most valuable information is supplied by the flight tests. The flight-measured characteristics permit the correction of behaviour by means of structural modifications or rigging adjustments e. g. tailplane to wing incidence, wing to fuselage incidence, etc. The conjunctions between the kinds of test and possible change to be introduced, as met in practice, are listed in table II.

5. Examples of Application

The possible changes to be introduced into the structure, listed in table II, are the general ones. The particular application of test data requires the more detailed analysis, examples of which are given below.

5.1 Measurement of wing torsional stiffness

The glider in calculation is assumed to be a body of finite stiffness. The calculated elastic properties of the structure are based on an ideal model and the values computed are different from those found by measurement. Therefore the confrontation of calculated and measured values is necessary. The corrected value of wing torsional stiffness as a result of measurement should be used for the recalculation of wing loadings.

The torsional distortion of the wing is the function of torque moment and torsional stiffness versus span. The twist angle in station "y" is equal to:

$$\varphi(y) = \int_{y_d}^{y} \frac{M_r(y)}{C(y)} dy \qquad (1)$$

and produces the incidence increment
$\Delta\alpha(y) = -\varphi(y)$
as well as the lift coefficient increment:

$$\Delta C_L(y) = a(y)\,\Delta\alpha(y) \qquad (2)$$

where: y_d station at wing tip
$M_T(y)$ torque moment at station "y"
$C(y)$ torsional stiffness of wing box at station "y"
$a(y)$ slope of lift coefficient versus incidence curve for the station "y".

This increment would affect the longitudinal trim, so the tailplane lift must be changed to maintain the initial flight condition and to introduce the redistribution of incidence. The "zero-lift" incidence for the twisted wing is:

$$\Delta\alpha_0 = \frac{\int_{y_0}^{b/2} \varphi(y)\,a(y)\,l(y)\cdot dy}{\int_{y_0}^{b/2} l(y)\,a(y)\cdot dy} \qquad (3)$$

where:
y_0 - station at wing root
$b/2$ - semispan of the wing
$l(y)$ - chord of wing at «y» station

Redistributed wing incidence:

$$\Delta\alpha_{red}(y) = \Delta\alpha(y) - \Delta\alpha_0 \qquad (4)$$

Local lift coefficient on the torsional distorted wing is:

$$C_L(y) = [C_L(y)]_{\text{stiff wing}} + a(y)\,\Delta\alpha_{red}(y) \qquad (5)$$

For the above lift coefficient redistribution as a consequence of using the measured data the recalculation of loadings should be performed and strength test program corrected.

5.2 Measurement of glider mass and c.g. location

To weigh the glider two balances are required (Fig. 1).
The total glider mass is:
$M = A + B$
C.g. location is given by:

$$x = \frac{B\cdot L}{A+B} - a \qquad (6)$$

according to notation for A, B, L, a and x in Fig. 1.

The value "x" concerns the particular magnitude and dislocation of component masses for the glider condition under weighing. It is the normal user's practice to fit into the glider some additional masses (instruments other than standard ones, radio, oxygen equipment, etc.) which are located in instrument panel, luggage compartment or in other places provided. These additional masses change the all-up mass of the glider and c.g. location. To find this new c.g. location and new all-up mass of equipped glider it is necessary to repeat the weighing procedure. To avoid the repeated weighing in every case of fitting the other equipment as standard one it is possible to procede in two ways:

- to measure the distance of the particular additional mass items in respect to the support (front or rear balance),
- to find the mass increment on the front "A" or rear "B" support as a consequence of 1 kg mass placed on its provided location (for each item of additional mass).

The first way seems to be of a little profit, since it is rather difficult to measure the distance of particular mass in respect to the support on a real glider resting on balances. For the better result the second way is recommended. In every place provided for the extra equipment mass the pattern mass of 1 kg should be placed (for better result the mass of 10 kg is recommended as a pattern one). The support value increment should be found i.e. ΔA for front and ΔB for rear support. This should be repeated for every item of additional equipment placed in its particular location.

For example it has been found the increment for:

- instrument panel additional mass: ΔA_1 and ΔB_1,
- cockpit pocket mass: ΔA_2 and ΔB_2,
- luggage compartment mass: ΔA_3 and ΔB_3, etc.

When into the instrument panel the additional mass of $K_p \cdot 1$ kg and into luggage compartment the additional mass of $K_L \cdot 1$ kg is installed, the new c.g. location is quickly found as:

$$x = \frac{(B+K_p\Delta B_1+K_L\Delta B_3)\cdot L}{A+B+K_p(\Delta A_1+\Delta B_1)+K_L(\Delta A_3+\Delta B)} - \alpha \qquad (7)$$

This result permits avoiding the repeated weighing of the glider equipped with the additional mass items placed in the appropriate locations.

5.3 Measurement of elevator angle for trim

The elevator angle for trim is calculated on the basis of the no-tail moment coefficient (Fig. 2):

$$C_{m_{TL}} = C_{m_{FUS}} + C_{m_w} - C_n\frac{t_0}{l_0} - C_t\frac{n_0}{l_0} - C_{t_H}\frac{n_H}{l_0} \qquad (8)$$

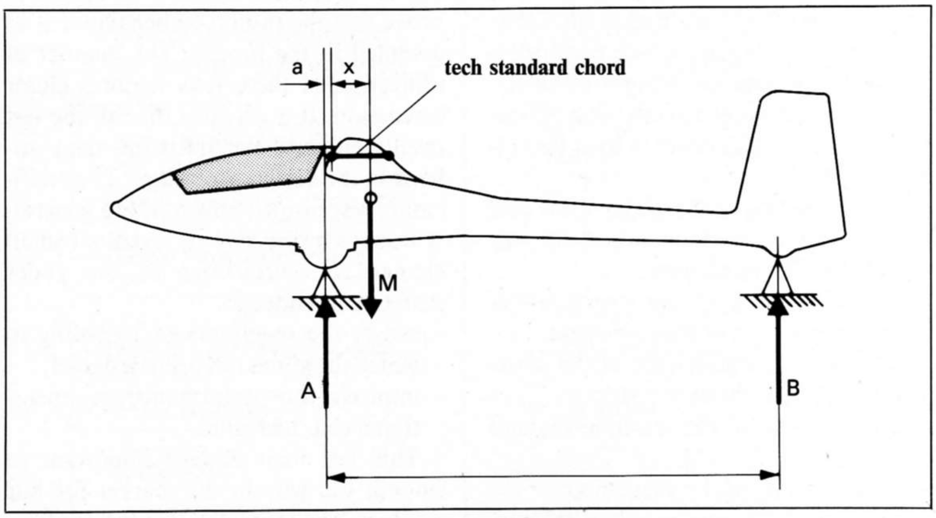

Fig. 1 Model of balances of the glider

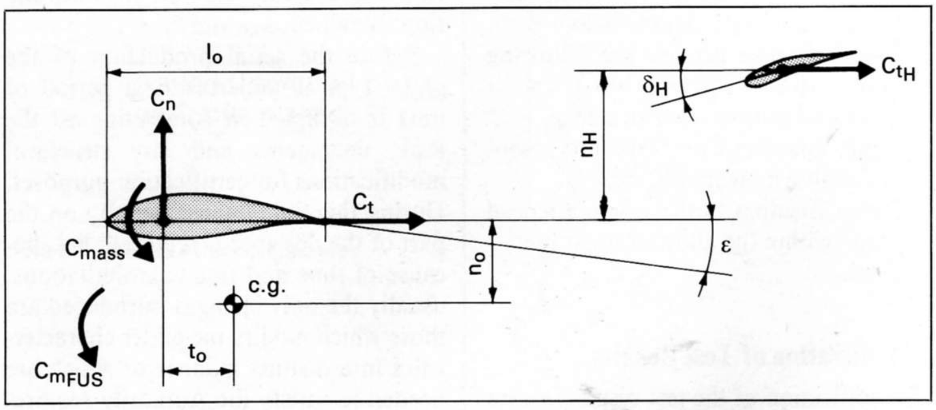

Fig. 2 Calculation of the elevator angle based on no-tail moment coefficient

where:

C_{mFUS}	fuselage moment coefficient
C_{mw}	wing moment coefficient (in respect to 25 per cent of Mean Standard Chord)
C_n	normal force coefficient
C_t	tangential force coefficient
C_{tH}	tailplane tangential force coefficient
t_0	normal force arm with respect to c.g.
n_0	tangent force arm with respect to c.g.
n_H	tailplane tangent force arm with respect to c.g. (in case of "T"-tail arrangement this value cannot be neglected).
l_0	Standard Mean Chord

The fuselage moment coefficient is:

$$C_{m_{FUS}} = C_{m_{0FUS}} - C_n \frac{\Delta t_0}{l_0} \qquad (9)$$

where:

C_{MoFUS}	fuselage moment coefficient (constant part)
Δt_0	normal force arm increment due to fuselage influence.

From (8) and (9):

$$C_{m_{TL}} = C_{m_{0FUS}} + C_{m_w} - C_n \frac{t_0 + \Delta t_0}{l_0} - $$
$$- C_t \frac{n_0}{l_0} - C_{t_H} \frac{n_H}{l_0} \qquad (10)$$

The values of C_{mw}, C_n, C_t and C_{tH} are defined with adequate accuracy by the wind tunnel aerofoil characteristics and formulae for the wing of finite aspect ratio. Some difficulties arise in establishing the value of fuselage moment data since experimental data for modern sailplane fuselage shapes are poor.

On the other hand the correct value of the no-tail moment coefficient determines the value of tailforce for trim and the other tailplane loadings which depend on the initial glider trimmed conditions.

Installation of even a simple instrument measuring the elevator angular deflection "β_H" versus airspeed "V" permits finding the function:

$\beta_H = f(V)$

Using the relation of airspeed "V" versus wing incidence "α":

$V = f(\alpha)$

the relation of elevator angle for trim versus incidence is obtained:

$\beta_H = f(\alpha)$

In the trimmed flight condition the no-tail moment and horizontal tailplane moment must be in equilibrium:

$$M_{TL} + M_H = 0$$

$$C_{m_{TL}} \cdot S \cdot l_0 \cdot q + C_{L_H} \cdot S_H \cdot L_H \cdot q_H = 0 \qquad (11)$$

where:

S	wing area
q	dynamic pressure near wing
C_{LH}	lift coefficient on the horizontal tailplane
S_H	horizontal tailplane area
L_H	tailforce arm in respect to glider c.g.
q_H	dynamic pressure near tailplane ($q_H \approx q$ is assumed).

The no-tail moment coefficient is:

$$C_{m_{TL}} = - C_{L_H} \frac{S_H \cdot L_H}{S \cdot l_0} \qquad (12)$$

On the other hand:

$$C_{L_H} = a_H (\alpha - \varepsilon + \sigma_H + \varphi_F + \varphi_H + \alpha_{\beta_H}) \qquad (13)$$

where:

a_H	slope of tailplane lift coefficient curve versus tailplane incidence
α	wing incidence
ε	wing downwash angle near horizontal tailplane
δ_H	tailplane to wing incidence
φ_F	angle of bending distortion of fuselage near tailplane
φ_H	torsional distortion of horizontal tailplane
$\alpha_{\beta H}$	tailplane incidence incriment due to elevator deflection angle.

Using the notation:

$$\kappa_H = \frac{S_H \cdot L_H}{S \cdot l_0} \qquad (14)$$

From (12), (13), and (14) is follows

$$C_{m_{TL}} = - \kappa_H a_H (\alpha - \varepsilon + \sigma_H + \varphi_F + \varphi_H + \alpha_{\beta_H}) \qquad (15)$$

In the above formula the values of "φ_F" and "φ_H" can be recalculated on the basis of fuselage and tailplane stiffness measurement data. The value of tailplane incidence increment du to elevator angular deflection is defined by:

$$\alpha_{\beta_H} = b_H \cdot \beta_H \qquad (16)$$

where:

b_H	slope of tailplane incidence increment curve versus elevator angular deflection "β_H".

From (15) and (16):

$$C_{m_{TL}} = - \kappa_H a_H (\alpha - \varepsilon + \sigma_H + \varphi_F + \varphi_H + b_H \cdot \beta_H) \qquad (17)$$

where the elevator deflection angle "β_H" is measured in flight. The formula (17) allows for the recalculation of the no-tail moment coefficient on the basis of the measured values.

6. Conclusions

The above presented examples of utilization of test results for the improvement of design concepts permits performing the calculations with an accuracy better reflecting the real conditions.

Generally the tests provide the following gains:

- statistical data on the main glider characteristics (aerodynamics, structure, materials),
- measurement of various characteristics enabling the decisions to be made for modifications, and
- measurement of all the data necessary for Type Certification.

Many of the tests, intended to be of the verification nature only, when only slightly modified, can be utilized in the design process as the progress stimulating one without extra cost or time.

Zusammenfassung

Die Nutzung der Testergebnisse von Typenzulassungen zur Verbesserung von Neuentwürfen

Die Entwürfe von Segelflugzeugen erfolgen normalerweise auf zwei Wegen, nämlich: 1. völlig neuer Entwurf, 2. Änderung bzw. Verbesserung eines bereits existierenden Typs.

Selten sind beide Wege völlig getrennt. In fast jedem Prototyp sind Komponenten eines Vorgängertyps enthalten, entweder als Standardbauteile oder als typenspezifische Bauteile. Selten entsteht ein in allen Teilen neuer Entwurf. Bei reinen Typenmodifikationen werden Vorläufermerkmale teilweise oder vollständig übernommen. Manchmal bedarf es nur kleiner Änderungen, um wesentliche Betriebsverbesserungen zu erzielen, manchmal sind die Änderungen so umfangreich, dass das Ergebnis zu einem fast neuen Muster führt.

Anhand von Beispielen wird nun gezeigt, dass die Testergebnisse, die zur Zulassung eines bestimmten Segelflugzeugtyps durchgeführt wurden, sehr gut auch als Ausgangsmaterial von Folge- bzw. Neuentwürfen mit sehr realistischen Annahmen und Randbedingungen herangezogen werden können. Es stehen dann im allgemeinen folgende Daten zur Bearbeitung zur Verfügung oder können daraus abgeleitet werden:

- statistische Daten der wesentlichen Segelflugzeugcharakteristiken für Aerodynamik, Struktur und Material
- Messungen verschiedener spezifischer Charakteristika zur Durchführung der Modifikationen
- Messungen aller zur Zulassung notwendigen Zusatzdaten

Viele der Tests, die nur als Nachweis notwendig sind, können bei Neuentwürfen ohne Extrakosten und -zeit zur Simulation herangezogen werden, wenn nur begrenzte Änderungen gegenüber dem Vormuster vorgesehen sind.

Die Absicht dieses Artikels ist es, dazu einige einprägsame Beispiele zu geben.