The L-13SE Motor Glider as a Flying Laboratory

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XXVII OSTIV Congress, Leszno, Poland, 2003

Abstract

This paper deals with the use of a flying laboratory that is based on an L-13SE Vivat motor glider. The ultimate objective of this concept is the measurements of aerodynamic profile characteristic. The theoretical and experimental verification of the basic characteristics of the motor glider are, however, required before it can perform as a laboratory. The computational estimations of the aircraft longitudinal trim are presented here. These results are compared with those obtained in flight tests. The aim was to verify the computational predictions with experimental ones. For this purpose, relatively simple and inexpensive flight measurements were performed with the motor glider used as the flying laboratory. The measurements that are necessary corrections of the pitot-static system were done before the actual measurements of aircraft longitudinal characteristics. The theoretical predictions of the characteristic of the motor glider longitudinal trim were carried out with a minimum of simplifications. The computations of the needed aerodynamic characteristics of the motor glider were performed using standard analytical methods that were modified for this aircraft type.

Notation

a	aircraft lift curve slope, or specified by index (1/rad)
c_A	mean aerodynamic chord length of wing
C_H	elevator hinge moment coefficient
C_L	aircraft lift coefficient
$C_{L\delta}$	aircraft lift coefficient derivative with respect to the elevator deflection (1/rad)
C_m	aircraft pitching-moment coefficient about the C.G.
$C_{m\alpha}$	pitch stiffness (1/rad)
F_H	control-stick forces in pitch (N)
G	aircraft weight (N)
k_H	ratio of dynamic pressure at the horizontal tail to the free stream value
K_H	elevator-gearing ratio (rad/m)
l_H	distance between the aerodynamic center of the horizontal tail and the aircraft neutral point without horizontal tail
l_H^*	distance between the aerodynamic center of the horizontal tail and the aircraft neutral point
S	reference wing area, or specified by index (m^2)
V	velocity of flight (m/s)
$\overline{V}_H$	horizontal-tail volume ratio
$\overline{x}$	non-dimensional distance from the leading edge of the mean aerodynamic chord
α	aircraft angle of attack (relative to x-axis)
δ_e	elevator angle (rad)
ε	downwash angle at horizontal tail
φ_H^*	horizontal-tail incidence angle with respect to the zero-lift-line of wing-body combination
ρ	air density (kg/m^3)

Subscripts

e	elevator
H	horizontal tail
WB	wing-body combination
0	parameters at zero lift, or zero altitude

Superscripts

$()'$	parameters at elevator stick-free stability

Introduction

The aerodynamic characteristics form an essential part in the aircraft-design process. Special attention is paid to the design of wing sections, even in the case of the design of other parts that influence the aircraft external geometry. Thus, it is necessary to know, or at least estimate, many design parameters influencing the total aircraft behaviour during the aircraft designing process. The aerodynamic characteristics cannot, however, always be estimated with sufficient precision based on theory only, and, therefore must be derived experimentally. In particular for the airfoil design, wind-tunnel measurements are often used. A wind tunnel, however, despite being an expensive apparatus, when considering its purchasing and operating cost, supplies measurement results of only limited value. Especially problematic issues are related to Reynolds and Mach number effects, as are surface-roughness influences at models of reduced size. Detrimental influences are, for example, due to elevated turbulence levels, tunnel-wall constraints, and other such effects.

The exact aerodynamic characteristics can usually only be measured with the actual aircraft prototype. Consequently, this is reason to be able to predict the basic aerodynamic characteristics, especially of new wing airfoil designs, correctly using flight tests. A flying airfoil-test bed enables the testing under the influence of the real flight conditions that are daily encountered in real operation. Despite that, however, the usage of the flying laboratories is problematic. It is necessary to correct for the flight conditions of the used aircraft and surrounding atmosphere. The flight regime of a flying laboratory must be monitored to determine exactly the conditions of a measurement. This increases the requirements on the precision of piloting and on the data-acquisition system on board. Limitations include the aircraft operational limits and meteorological conditions.

As there is no flying laboratory available in the Czech Republic for measuring the aerodynamic characteristics of airfoils, a research proposal for developing such a flying laboratory, [1], was designed and approved at the Institute of Aerospace Engineering. This flying laboratory will enable the measuring of the aerodynamic characteristics of airfoils, [2], the influence of the high-lift devices, the influence of the airfoil leading edge impurities, and the influence of simulated icing or production inaccuracies. Besides that, it will be used as a laboratory stand for developing a system for measuring flight performance and researching flight characteristics. Currently, the development for the verification of basic aerodynamic characteristics and flight characteristics is under way. This paper deals with description of the flying laboratory and the analysis of the aircraft longitudinal motion. The objective is to numerically predict the parameters of the longitudinal trim and to compare the accuracy of the prediction with experimental results. For these purposes, relatively simple and inexpensive flight experiments were done with the L-13SE Vivat motor glider, the future flying laboratory. The computations were done using standard methods that were modified for this type of aircraft.

Description of the Flying Laboratory

The L-13SE Vivat motor glider that was produced in the Czech Republic was chosen as a carrier aircraft. It is an all-metal aircraft re-constructed from the L-13 Blanik glider, of which the wings, the tail surfaces and the fuselage tail with its thin-walled stiffened structure were retained. The fuselage central part with the cockpit is a rod structure with a aerodynamically shaped cover. The aircraft is equipped with a Walter-Mikron III engine in the front fuselage and with a simple retraction landing gear with a tail wheel and supporting landing gears at the wing tips. The rod structure of the fuselage central part enables a simple attachment of the test stand. The two-seat design of the glider offers the possibility to position the measuring equipment into the cockpit area. The benefit of accessibility, cost advantages and alternatives for further applications supported the choice of this glider. Several possibilities of attaching the test stand to the motor glider were examined. The influence of the aircraft on the model, structural integrity of the experimental set up, model size, and the precision of the measurements were taken into consideration. In addition, a so-called "measuring sleeve" was considered, in a shape of the tested airfoil put on the wing of the flying laboratory. However, because of technical demands, limited range of the potential models and the flight regimes, this was abandoned.

It was decided to use a more conventional support structure that is located above the motor glider. This configuration has the least influence on the flight characteristics of the flying laboratory, with the test model being located approximately 1.9 meters above centre of gravity of the motor glider (Fig.1). The struts of the test stand form an up-side-down V and are attached to the aircraft near the main wing attachment points. In order to increase the lateral stiffness of the test stand, a slanted stiffening strut is attached to the right wing. Suspended in the test stand, the incidence angle of the airfoil model can be adjusted with respect to the motor glider. In flight, an electro-mechanical drive adjusts the incidence angle. The mechanism is located at the top of the V-strut. The maximum span of the model is 1.2 meter. This allows the testing of the model in the wind tunnel at ARTI in Prague, in order to compare the experimental results. The model has end plates of a circular shape to eliminate the finite wing-effects and ensure two-dimensional conditions during the tests.

The measurements in flight are performed with the engine turned off. The adjustable angle of incidence of the model with respect to the motor glider also enables the measurement of different angles of attack at a constant airspeed, that is, at a constant Reynolds number. The Reynolds-number range is limited by flight performance of the motor glider. In part, it can be influenced by the model size. The Reynolds numbers range approximately from $1.0\text{x}10^6$ to $2.0\text{x}10^6$ for a model with a chord of 0.60 meter. The airfoil characteristics are determined with measured pressure distributions. The measured values of pressures will be converted into electric signals and recorded with a data-acquisition unit located onboard the glider. The unit also records the flight conditions that are necessary for the evaluation of the measured data. This involves angle of attack and sideslip angle, airspeed, flight altitude (pressure), ambient temperature, position of the model, and model flap deflection.

Theoretical Model

The theoretical model is based on basic dependencies in order to determine the angles of the elevator required for each particular trimmed, steady flight condition. In particular, an equilibrium of the aircraft-pitching moments depends on the following relationships:

$$\delta_e = -\frac{C_{m0} C_{L\alpha}}{D} - \frac{C_{m\alpha}}{D} \frac{2}{\rho_0} \left(\frac{G}{S} \right) \frac{1}{V_{EAS}^2} \tag{1}$$

$$C_{m0} = C_{m0,WB} + \frac{a_{WB}}{a} a_H k_H \bar{V}_H (\varphi_H^* - \varepsilon_0) \tag{2}$$

$$D = -C_{L\delta} C_{L\alpha} \frac{l_H^*}{c_A} \tag{3}$$

$$a = a_{WB} + a_H k_H \frac{S_H}{S}\left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right) \tag{4}$$

$$\overline{V}_H = \frac{S_H l_H}{S c_A} \tag{5}$$

The theoretical model of the solution of longitudinal trim that considers the control-stick forces is given as:

$$F_H = F_0 + F_1 \frac{1}{2} \rho V^2 \tag{6}$$

with $$F_0 = K_H k_H S_e c_e \left(\frac{G}{S}\right) \frac{c_{H\delta}\, a'}{D} \left(\overline{x}_{cg} - \overline{x'}_A\right) \tag{7}$$

and $$F_1 = -K_H k_H S_e c_e \left(C_{H0} - C_{m0} \frac{c_{H\delta}\, a'}{D}\right) \tag{8}$$

and $$C_{H0} = C_{H\alpha H}(\varphi_H^* - \varepsilon_0)\left[1 - \frac{a_H}{a}\left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right) k_H \frac{S_H}{S}\right] \tag{9}$$

The aerodynamic derivatives of these relationships are established using theoretical and deterministic methods listed in Refs. [3], [6], and [4], respectively. The determination of these aerodynamic derivations is, however, the weakest part of the theoretical analysis of the longitudinal trim, although some of the data is corrected using Refs. [5] and [7]. Ultimately, the theoretical model describes the dependency of the elevator angles for trimmed flight at various equivalent flight speeds. Similarly, Eqs. 6 through 9 establish the relationship between the control-stick forces and the flight speed.

Experimental results

The experimental results of longitudinal trim require an airspeed correction that takes into account any error due to the pitot-static system of the motor glider. The calibration of the pitot-static system was performed by flying distances of 1 km length with several reversals in order to exclude any wind influence. The results of the calibration are plotted in Fig. 2. This calibration is used to convert the indicated airspeed to an equivalent airspeed at standard, sea-level conditions.

It is essential to set the dependence among the displacement of the control stick in pilot cabin and elevator angle before the determination of elevator balancing angle dependent on airspeed. The real elevator balancing angles based on the direct measurement of the displacement of the control stick dependent on airspeed were identified by the help of this characteristic. Further, K_H – elevator-gearing ratio was determined necessary for the computation of control forces depending on airspeed. Fig. 3 shows the experimentally determined characteristic of elevator gearing ratio.

In order to be able to correlate an elevator deflection with a trim airspeed, the relationship between control-stick position and elevator deflection is needed. This relationship was measured directly on the aircraft and the results are plotted in Fig. 3. The elevator-gearing ratio, K_H, is the slope of the resulting linear curve fit.

Discussion of Results

Theoretical and experimental longitudinal-trim solutions of an L-13 SE Vivat motor glider were acquired using the methods described in the previous section The basic geometric and mass data of the chosen aircraft are as follows:

wing span	$b = 16{,}7$	(m)
wing area	$S = 20{,}2$	(m^2)
mean aerodynamic wing chord	$c_A = 1{,}276$	(m)
wing-aspect ratio	$A = 13{,}8$	(1)
wing sweep	$\Lambda = -5$	(°)
moment arm of horizontal tail surfaces	$l_H = 4{,}965$	(m)
horizontal tail area	$S_H = 2{,}658$	(m^2)
aspect ratio of horizontal tail	$A_H = 4{,}298$	(1)
mean aerodynamic chord of horizontal tail	$c_{AH} = 0.80$	(m)
elevator area (aft of hinge line)	$S_e = 1{,}049$	(m^2)
elevator mean geometric chord (aft of hinge line)	$c_e = 0{,}335$	(m)
takeoff mass of motor glider	$m = 700$	(kg)
centre of gravity location (non-dimensional)	$\overline{x}_{cg} = 0{,}30$	(1).

The experimental relationship between elevator deflection and equivalent airspeed are plotted in Fig.4. The theoretically predicted relationship is also plotted in this figure.

Longitudinal trim with respect to the control stick forces were only determined theoretically. Fig. 5 shows the results of the theoretical prediction of two cases. The first one uses a simplified method that is used during preliminary aircraft design with a constant elevator-gearing ratio. The assumed elevator-gearing ratio is $K_H = 3{,}64$ (rad/m) at a neutral position of the control stick. The second dependence, see the same figure, shows the dependence of control force depending on equivalent airspeed with regard to experimentally obtained variable elevator gearing ratio.

In the second case, an experimentally determined elevator-gearing ratio that varies with equivalent airspeed is used in order to relate the control-stick force to the equivalent airspeed.

Conclusion

This paper discusses the initial development of a flying laboratory for measuring airfoil characteristics in free flight. The planned tasks are partially complicated by the less powerful, motor glider that is available in the Czech Republic. The chosen motor glider, however, is quite suitable for this task, since only a relatively simple modification of the structure is required. Furthermore, the motor glider allows a self-sufficient operation when compared to a glider without an engine. The test stand is designed to be removable in order to ensure a good use of the aircraft, for example for other experiments concerning flight mechanics. Experimental research using the flying laboratory should support the aircraft industry by testing new aerodynamic and flight-mechanical theories. The Institute of Aerospace Engineering of the Faculty of Mechanical Engineering, Brno University of Technology, will extend with the flying laboratory its experimental platform intended for the research and development of small aircraft. At this point, a theoretical model has been developed and experimentally validated that predicts well longitudinal trim based on the elevator deflection. Further parameters related to longitudinal trim are determined solely theoretically. Their experimental verification is the aim of future work that is planned as part of this research when testing the aircraft as a flying laboratory.

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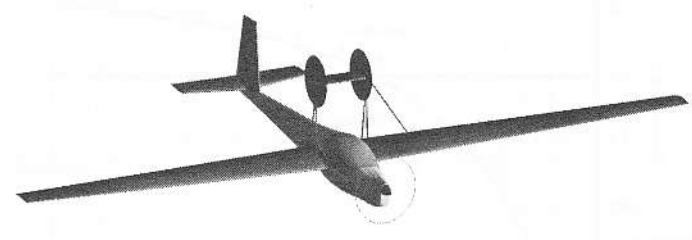

Figure 1 The concept of a flying laboratory built on a motor glider with a test stand for the investigation of aerodynamic airfoil characteristics.

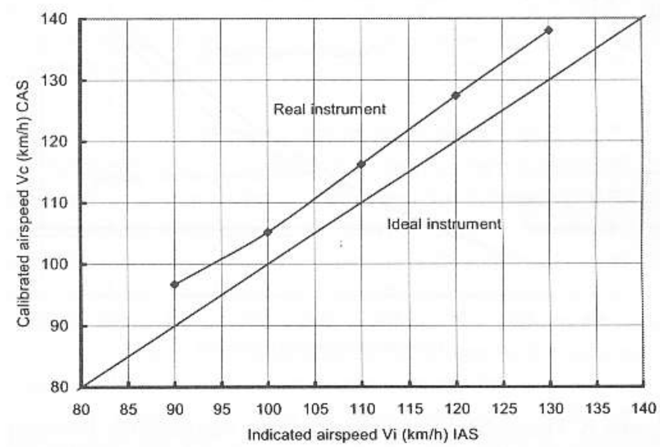

Figure 2 Pitot-static airspeed calibration of the L-13 SE Vivat motor glider.

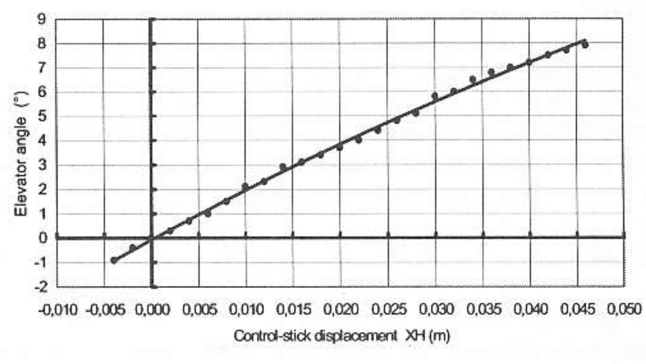

Figure 3 Measured elevator-gearing ratio of the L-13 SE Vivat motor glider.

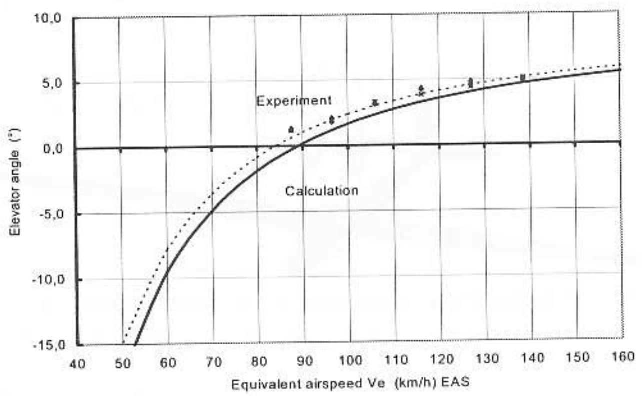

Figure 4 The relationship between the elevator deflection and the equivalent airspeed of the L-13 SE Vivat motor glider.

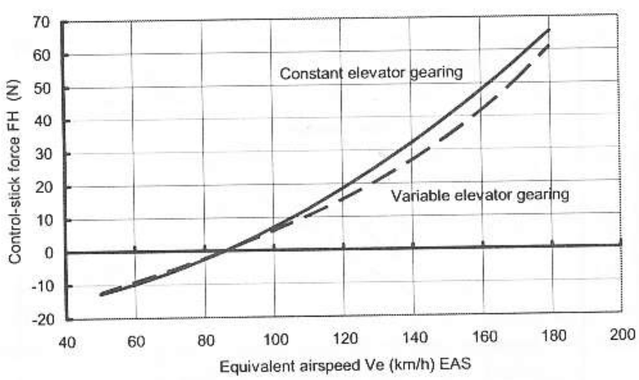

Figure 5 Theoretical prediction of the relationship between control-stick force and equivalent airspeed of the L-13 SE Vivat motor glider.