AUTOMATIC CONTROL OF CAMBER-CHANGING FLAPS ON HIGH-PERFORMANCE SAILPLANES*

by

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INTRODUCTION

Preliminary research on camber-changing flap automatic control mechanisms led to the conclusion that recent airfoil developments (Wortmann FX67-K-150 and -170) which theoretically require only two flap positions to maintain optimal airfoil configuration throughout the flight regime, do not, in practice, adequately reduce pilot work load to a desirable level.

Two flap positions are sufficient only if there is uniform sink between two areas of lift. This ideal case seldom occurs. In reality, there is a distinct distribution of lift and sink between those areas of strong lift which make thermaling worthwhile. This requires a pilot who wishes to fly at MacCready speeds to change speed constantly. This will reach V_{ne} for high-performance sailplanes in areas of strong sink. On the other hand, while crossing areas of weak lift in which thermaling is not worthwhile, the pilot should fly at minimum-sink speed. While flying between thermals he will pass several times through his whole speed range, and thus, should adjust the flaps during interthermal flight. The newer Wortmann profiles are better than the older ones inasmuch as they do not require as many flap positions. Nevertheless, at least three positions are still necessary: One for minimum sink; another for best L/D; and yet another for high-speed flight. Frequent adjustment of the flaps is still necessary.

Considering that the pilot, especially during contests, is busy with many additional tasks, (such as navigation, weather observation, collision avoidance, etc), it is important to relieve him where possible of things which have nothing to do with the mere mechanical operation of the sailplane. The more he can concentrate on his surroundings, the better for safety and for his flying performance.

This report discusses an automatic flap positioning system designed with these goals in mind.

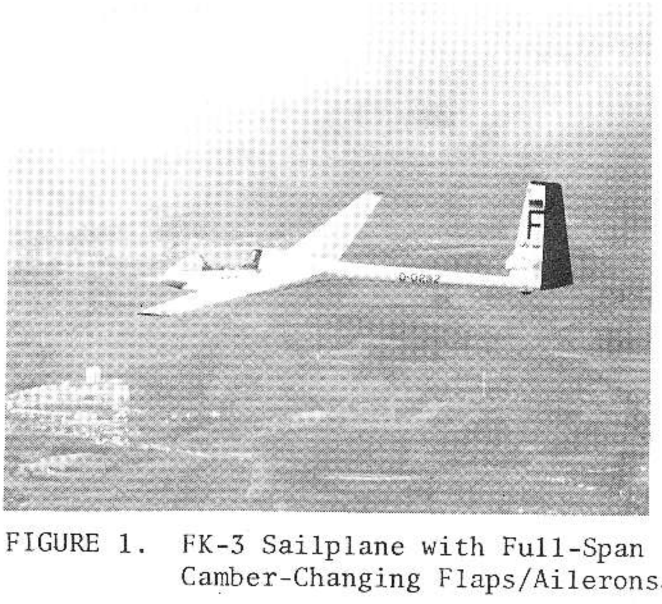

FIGURE 1. FK-3 Sailplane with Full-Span Camber-Changing Flaps/Ailerons.

*Translated from "Automatisch Geregelte Verstellung der Wölbklappen von Leistungssegelflugzeugen", Aero Revue, May 1975, by W. and E. Schuemann; edited for length and style by J. L. Nash-Webber. Published with permission.

AUTOMATIC CONTROL SYSTEM

Considerations of dynamic stability of the sailplane mitigate against the possibility of controlling the flap angle η automatically as a function of speed, acceleration and variometer indication, and in favor of regulating η as a function of the angle of attack α.

The effective angle of attack of an aircraft cannot be measured in isolation. However, the angle of the airflow at the fuselage resulting from the effective wing angle of attack, the flap angle and the transverse airflow during sideslip is a measurable quantity.

Flight tests of an FK-3 sailplane (Fig. 1) using wool tufts on the fuselage side showed that of the 24 positions tried, 5 were suitable for measuring the effective angle of attack. The error due to sideslip stays within acceptable limits. In Fig. 2, the local flow angle at Station 7 is plotted against the optimal speed V_{opt} and flap angle η. This may be sufficiently well approximated by two straight lines, as shown in Fig. 3.

Angle-of-Attack Transducer

We have developed a low-friction, noncontacting transducer. This consists of a wedge-shaped vane in the airstream near the fuselage side which rotates the shaft of a variable-reluctance angular position transducer.

Another electrical signal proportional to flap angle is obtained using a simple potentiometer connected to the flap drive shaft.

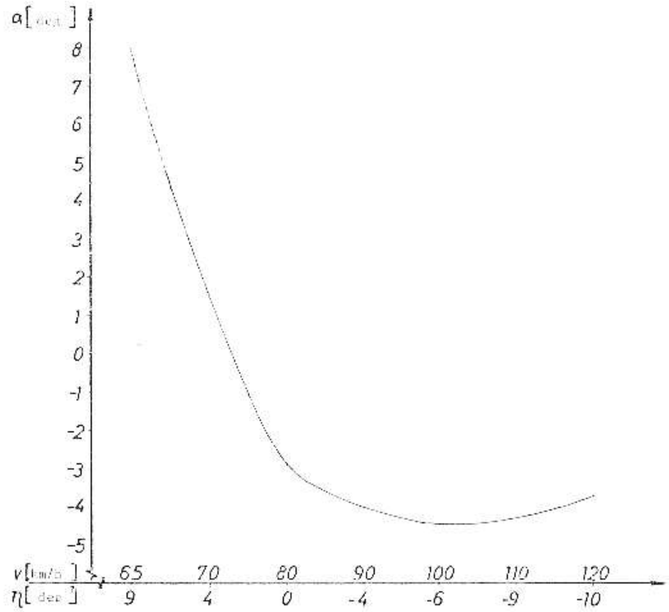

FIGURE 2. Indicated Angle-of-Attack as a Function of Airspeed and Flap Angle as Measured Using Wool Tuft at Station 7.

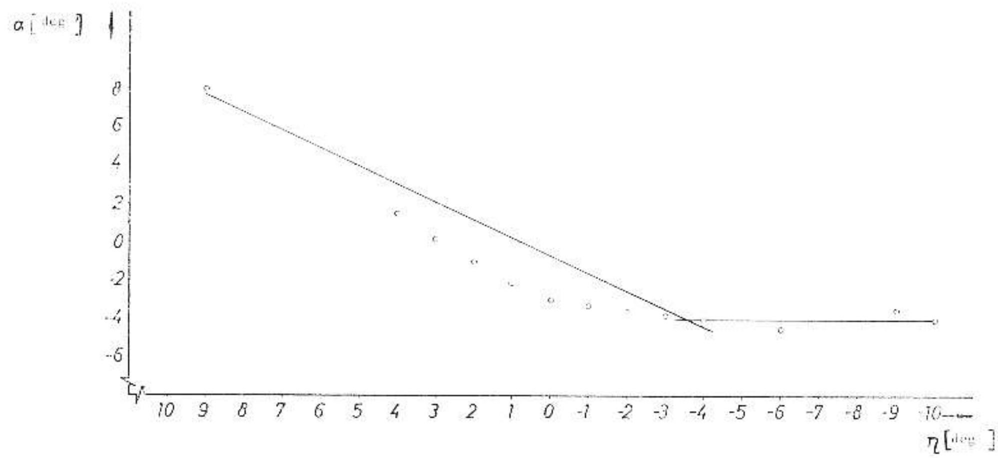

FIGURE 3. Approximation to the Relation Between Optimum Flap Angle and Angle-of-Attack Using Two Straight Lines.

Controller

Fig. 4 shows a block diagram of the controller. The instantaneous value of the flap-angle signal is fed to a function generator having the "knee-function" characteristic of Fig. 3, yielding an instantaneous value of α_{opt}. This is compared with the instantaneous value of α as measured by the vane, and, if the difference is sufficiently great, a hydraulic flap drive mechanism is activated to drive the flaps up or down as needed to reduce the value of the α difference.

The dead-band of this "bang-bang" control system may be adjusted so as to give the requisite damping to the system.

Hydraulic Actuator

We discarded our originally-planned electric drive on grounds of insufficient space being available in the FK-3. Instead, we used a hydraulic actuator to drive the flaps. This has the advantage of good controllability, and the system may also be configured as several separate sub-assemblies, which makes it easier to install in the spaces available. The mechanical requirements for this control function are relatively small, and the actuation speeds can be regulated easily. Very small, light components are commercially available.

The hydraulic system forms a closed circuit, as shown in Fig. 5. Sub-assembly (1) is a hydraulic pump system driven by a 12 VDC motor. An accumulator (2) is used for storing pressurized oil. This makes a sufficiently large volume of pressurized oil available such that the pump does not have to start running for every flap angle alteration. It also helps us to dampen pressure pulses and oscillations.

A pressure gauge (3) is mounted on the instrument panel as a monitoring instrument. Another, more accurate, instrument having limit-switches turns the pump on and off as required to maintain the accumulator pressure.

Sub-assembly (4) contains a high-pressure filter, an adjustable pressure regulator, an adjustable throttle valve, a 4/3-way valve with electromagnetic actuation, and a 4/2-way valve with manual actuation.

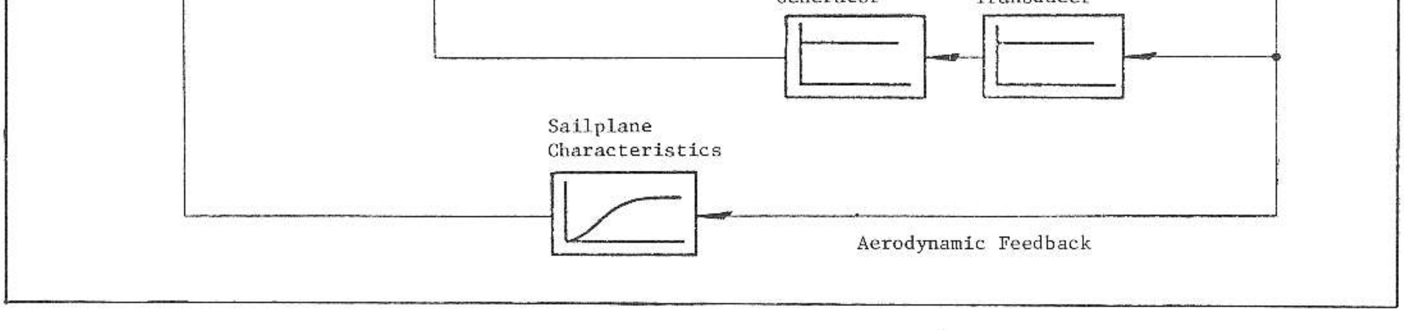

FIGURE 4. Block Diagram of Automatic Flap Control System

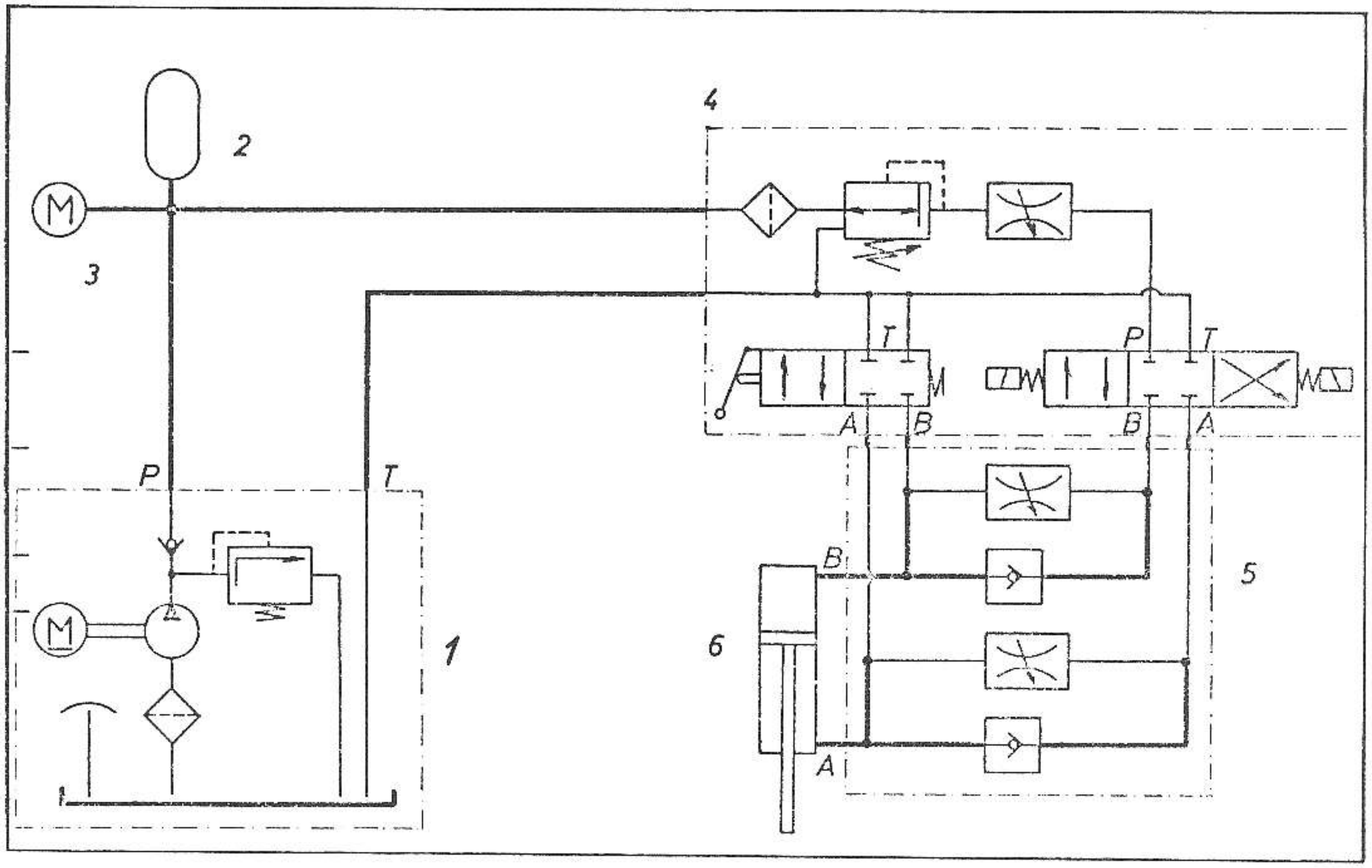

FIGURE 5. Block Diagram of the Hydraulic System

Sub assembly (5) consists of two each throttle and recoil-valves. These serve to regulate the hydraulic drive cylinders (6). The 4/3-way valve is actuated by the 3-way switch of the control circuit. The 4/2-way valve allows, when opened, for manual adjustment of the hydraulic cylinders, and locks the system when closed.

The working pressure of the system varies between 55 and 100 bar, but the pressure at the hydraulic cylinders is limited by the pressure regulator. The control power should not be any greater than that required for reliable actuation.

Installation for Flight Testing

As shown in Fig. 6, the angle-of-attack transducer is mounted on the side of the cockpit under the letters "FK-3". This position does not interfere with the pilot. This measurement point shows little effect due to the changed fuselage airflow during sideslip. The electronic controller was mounted under the seat. Thus, only the seat has to be removed to make adjustments.

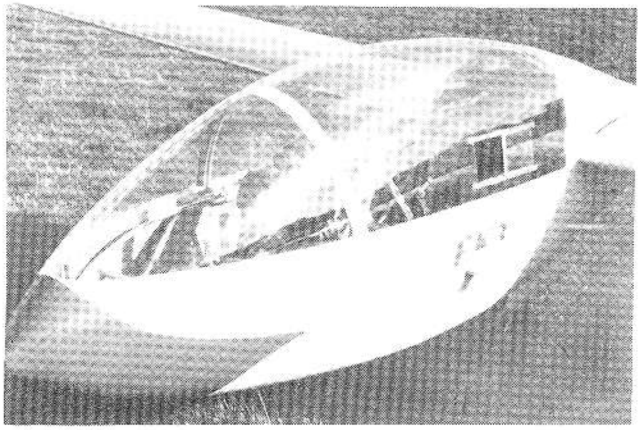

FIGURE 6. Angle-of-Attack Measuring Vane Installed on Side of Cockpit.

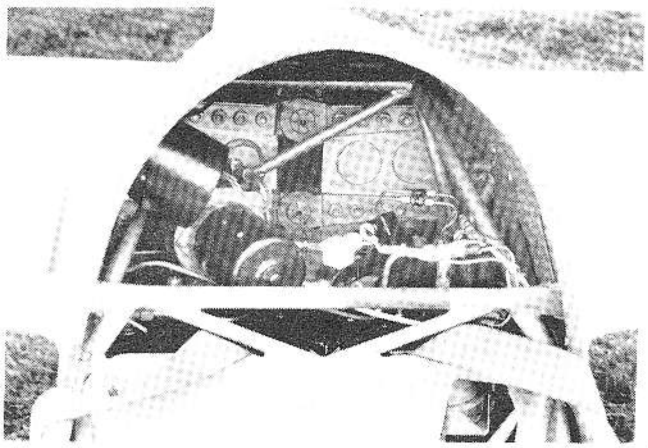

FIGURE 7. Installation of Hydraulic System Monitor and Controls.

As shown in Fig. 7, the "baggage" space behind the pilots' head offers just enough space for the hydraulic system. All parts are mounted on an aluminum plate which is made in two sections configured so as to give access to the wing root fittings for normal assembly and inspection. The components which are rigidly mounted on the plates are connected by rigid metal pipes. Only the connections to the hydraulic cylinders and to the monitoring pressure gauge in the instrument panel are made using flexible high-pressure hoses.

The main electrical switch and the selector for manual or automatic control of the hydraulic flap drive are located on the cockpit LHS near the α transducer. This switchboard also serves to protect the rather vunerable transducer assembly. The main switch for the hydraulic system is located at the bottom of the instrument panel as shown in Fig. 8. Above this, there is a battery-monitoring instrument.

The energy source, a 12 V, 20 A-hr gelled accumulator, is mounted solidly at the junction of the fuselage pod and boom.

The prototype system weighs approximately 20 kg, complete with all parts and the battery. Discussions with several manufacturers of hydraulic components have shown that there is necessarily a compromise between extreme weight reduction and cost. For an open-class sailplane, the extra weight should not make any difference.

System Calibration

A calibration of the angle-of-attack transducer amplified output voltage $U = f(\alpha)$ should yield a curve similar to the wool-tuft results. However, it

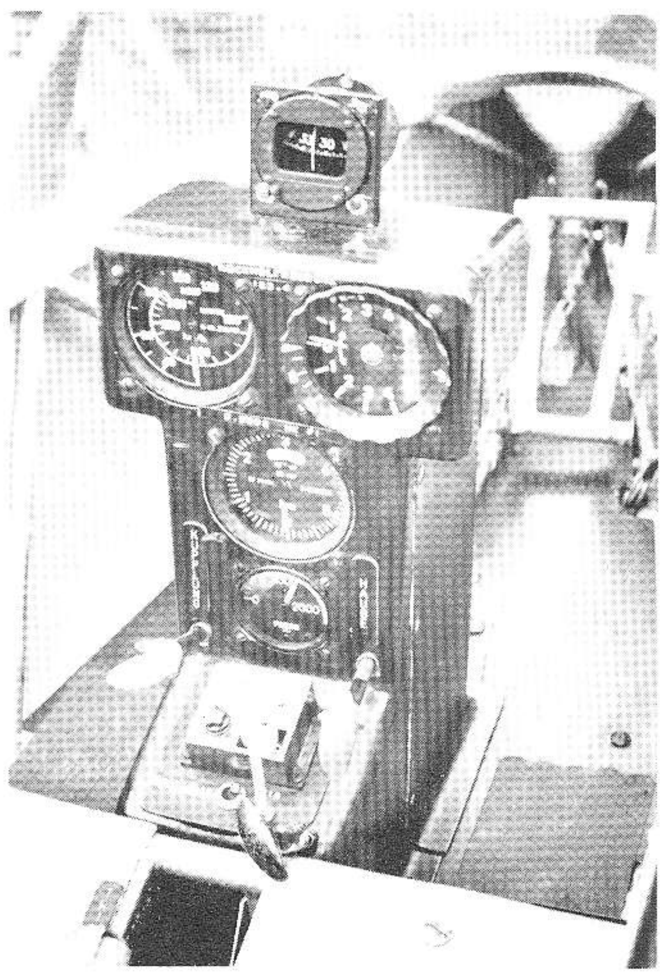

FIGURE 8. Hydraulic System Installation in "Baggage Space."

was found that the different degree of penetration of these two devices into the fuselage boundary layer gave somewhat different, though equally useful results, in that the α vs (η_{opt}) function could again be adequately approximated by a straight-line "knee function".

At this point, we should consider whether a changed wing loading G/F requires a different function $\alpha = f(\eta_{opt})$. Now,

$$\alpha = f(Re, V, \eta, \frac{G}{F}) \qquad (1)$$

Neglecting the effect of Reynolds number and using the relations

$$C_L = \frac{G}{Fq} \text{ and } q = (\frac{\rho}{2})\ V^2 \qquad (2)$$

we find

$$\alpha = f(\eta, C_L) \qquad (3)$$

It follows that for a constant value of C_L flow angle depends only on the flap angle η, and further, that with constant η and the same C_L but, for example, a lower wing loading, the airspeed will be lower. On studying the section polars of the wing profile of the FK-3, it becomes clear that for any useable flap angle, the laminar low-drag bucket extends over a range of at least $\Delta C_L = 0.4$. This means that for changes of C_L less than 0.2, the profile drag will not increase significantly. This limit should not be exceeded if the glide performance is to remain nearly optimal. Thus, a practical range for a control system would be

$$C_L = C_{L_{opt}} \pm 0.1 \qquad (4)$$

To determine a suitable knee function for these limits, the flow angles have to be measured in flight.

The $C_{L_{opt}}$ values for each flap setting are found from the appropriate section polars. The speeds which should be flown for any given wing loading are calculated using the relations given above.

The knee function is set on the controller as follows: the threshold values are selected to give a maximum steady η deviation corresponding to approximately half the allowable C_L deviation. The flap handle is moved to the full positive or negative position before choosing the threshold values. With the flow angle α fixed, the automatic system is carefully adjusted. The flap position is then changed until the desired threshold value is reached. The condition required is that during optimum flight at a particular value of η the deviation of α is approximately $\pm 1^\circ$ without actuation of the hydraulic drive by the automatic control system.

Following the initial flights for which the controller was set inaccurately, the correct values were determined from the test results. Thereafter, the predetermined deviation tolerances were maintained.

FLIGHT TESTS

Pitch Response

With the flap angle η fixed, the aircraft exhibits a divergent oscillation in pitch, which ends with a steep dive from a fully stalled condition if there is no control input by the pilot. However, when the automatic flap control is activated, the oscillations are damped, as shown in Fig. 9. Note that the stated velocities in the region below 70 km/h are quite unreliable due to flowfield distortion at the nose pitot. Note also that the automatic system acts on the stick-force characteristic in the manner of a trim system.

Spin Tests

The normal fixed-flap spin characteristics are that only a half turn of a true spin is possible for all flap positions except $\eta = -10^\circ$. For this extreme position, a fully-developed spin is obtained, with recovery in approximately three-

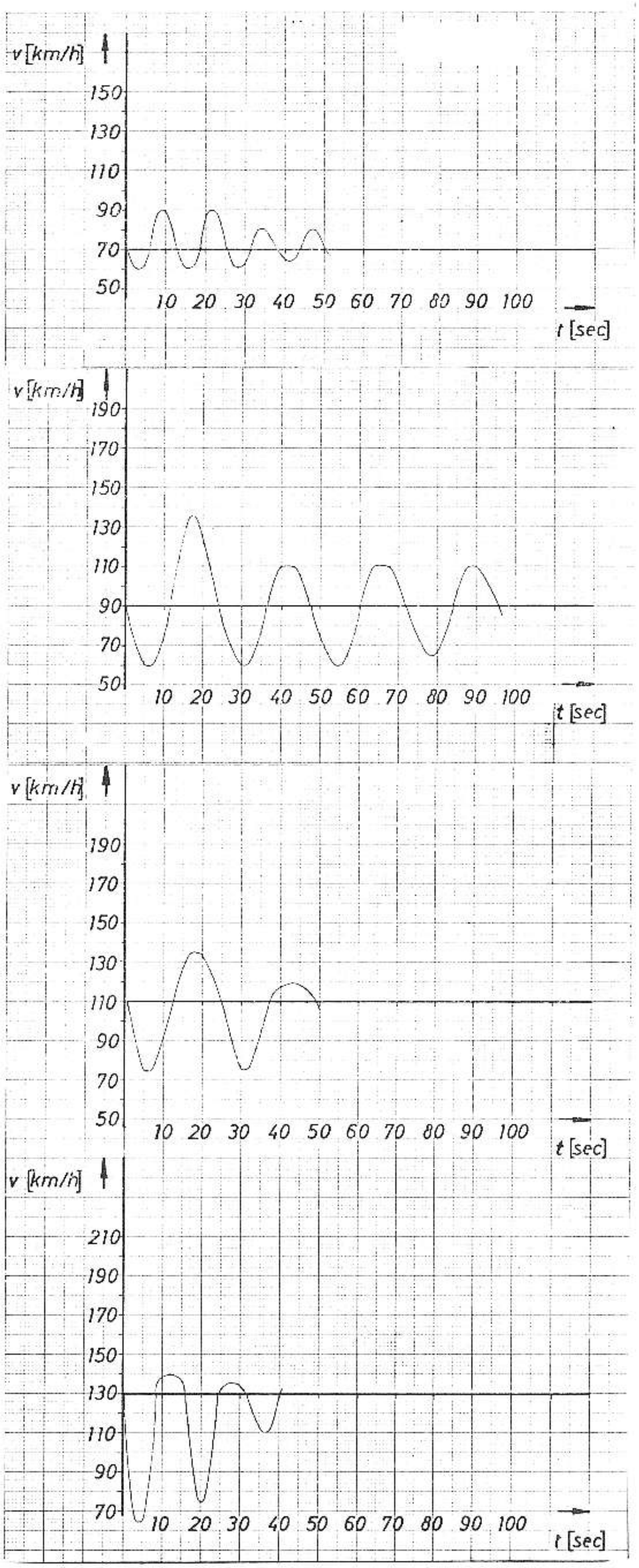

FIGURE 9. Stick-Fixed Speed/Pitch Characteristics of Sailplane under Automatic Flap Control

quarters of a turn. With the automatic system turned on, the most that can be accomplished is half a turn using full rudder. The automatic flap deflection damps the initial nose/wingtip dropping phase. During a stall, the flap deflects fully positive and after the resulting nosedive to -10°. The speed goes to 130 km/h.

Cross-Country Flying

The automatic system shows up especially well during cross-country flying using MacCready speed techniques. Also, when circling in smooth thermals, the flaps are set automatically to their optimum positions. In choppy and rough thermals, the system was too sensitive according to first impressions of the pilots. It also reacted too fast when the stick was moved suddenly. Since then, this problem has been alleviated by incorporating a variable damping control which has the effect of allowing reaction only to long-period disturbances in bumpy conditions.

CONCLUSIONS

The flight tests show that the goals of this development program have been attained. The predetermined tolerances for deviations from optimal conditions have been maintained. In straight flight and in circling, the optimum flight performance is retained. The automatic system stabilizes the sailplane. Pitch oscillations are damped and the spin behavior becomes more docile. Thus, we believe that this development represents a step in the right direction.

Approximately 150 hours of flight testing have been completed with the automatic system thus far, all without the slightest trouble. The some 30 different pilots who have flown with it so far have been convinced, without exception, that extraordinary progress has been made towards the optimization of flight performance.

First steps have been made to test the automatic flap system on other types of sailplanes. Flight tests with wool tufts on the Nimbus II—a high performance open-class sailplane, designed by Klaus Holighaus/Schempp-Hirth—and on the PIK 20—high performance standard class sailplane from Finland—have been performed. Tests with the 19m—and 17m—Kestrel "(from Glasflugel") will be made in the near future. Soon a more compact and "long living" hydraulic system will be available and also a modified electronic controller, which makes it easier to adapt the system to different characteristics of other sailplanes.