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EXPLORATORY TESTS OF A SIMPLE AERO-MECHANICAL
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LOADED AIRCRAFT

By Donald E. Hewes and Eric C. Stewart

February 14, 1974



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16. Abstract Some exploratory wind tunnel and radio-controlled free-flight tests were made with a small high-wing airplane model (1.23m wing span) to study the concept of a simple aero mechanical system intended to alleviate gust loads and improve ride comfort of lightly loaded aircraft. The system consisted essentially of the outer portions of each wing being hinged in the chordwise direction and connected directly to the wing flaps using internal counter weights to provide neutral mass balance. When the wing experienced a change in velocity or angle of attack, the movable wing panels, acting as sensors and flap actuators, deflected in response to the changes in lift on the wing. The corresponding movements of the interconnected flaps tended to reduce the changes in the wing lift.					
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INTRODUCTION

Aircraft with a relatively low wing loading, such as most general aviation and short takeoff and landing (STOL) types, are particularly responsive to gusts. This responsiveness often creates passenger ride discomfort, induces extra pilot workload, and requires the reduction of normal cruising speeds to prevent overstressing the aircraft. Several years ago, a French engineer, René Hirsch, developed and flight tested a unique, small twin-engine airplane which he equipped with an aero-mechanical system designed to reduce the effects of gust disturbances as reported in reference 1. A sketch showing some of the details of the airplane system is shown in figure 1. The specific objective of this system was to permit the airplane to be designed for lower load factors thereby reducing the overall weight of the airplane structure; however, the functioning of this system also had a favorable impact on passenger ride comfort and pilot workload during some limited flight tests. Unfortunately, the system is very complex, both aerodynamically and mechanically, and therefore does not appear to lend itself easily to applications in general aviation and short-haul STOL fields.

The purpose of this paper is to describe a simplified system based generally on the principles of the Hirsch concept and to present the results of some exploratory tests performed with a small radio-controlled airplane model equipped with one version of this simple system. The model, shown in the photograph of figure 2, corresponds approximately to a 1/8 dynamically-scaled model of a popular high-wing light plane. A limited series of static and dynamic tests were made in the Langley 12-Foot Low Speed Tunnel using the wing by itself to measure the variation of lift with angle-of-attack changes and to demonstrate the stability of the flap-sensor system and its effectiveness in reducing responsiveness to gusts. The model was flown in free flight to demonstrate the ability to control the airplane through the simple gust-alleviating system and to evaluate qualitatively the general dynamic behavior of the system and the airplane.

SYSTEM CONCEPTS

The Hirsch system was intended to alleviate both longitudinal and lateral gusts. To accomplish longitudinal alleviation the horizontal tail was hinged in the chordwise direction at the root so that the up-down flapping action of the tail surfaces, induced by longitudinal gust components, was transferred to a set of compound wing flaps through a series of pushrod-bellcrank linkages. The flap deflections were in a direction which tended to cancel the normal lift effects of the gusts on the wing. In a somewhat similar manner, special wingtip panels hinged in the chordwise direction were linked to the ailerons to produce compensating effects for the lateral gust components that tended to roll the airplane. The elevator and aileron systems were linked with the conventional pilot's control so as to give him control authority over the airplane with the system active. In order to compensate for reduced stability of the airplane caused by the gust-alleviation system, two gyro sensors and actuators driven by ram air were also linked into the control system.

In the present simplified approach, which was proposed by Mr. W. H. Phillips of the Langley Research Center, the system is intended to alleviate only longitudinal gust responses. This approach is a compromise between system simplicity and operational effectiveness, based on the assumption that it is reasonable to reduce the normal accelerations due to gusts with this system, and to reduce the effects of lateral gusts with a wing-leveling system. Wing-leveling systems are currently available in relatively simple forms at fairly reasonable costs. A further consideration in this approach is the location of the sensing surfaces much closer to the flaps than in the Hirsch design. This location should minimize linkage flexure problems and also facilitate some of the manufacturing and operational factors involved in a practical application. The final consideration is that the basic airplane configuration should be selected such that the pitching moment due to flap deflection is small. This characteristic will minimize the effect of the gust-alleviation system on the longitudinal stability of the airplane and will minimize or eliminate mechanical linkage between the flaps and the elevator controls.

Operation of Model System

The installation of the simplified gust-alleviation system on the radio controlled model shown in figures 2 and 3 represents one possible configuration. Of course, there are other configurations such as fuselage-mounted sensor surfaces, but this discussion is limited to this particular arrangement, which was used partly to facilitate construction of the model. The outer 10 percent of each wing panel (the sensor surface) is hinged in the chordwise direction so that the surfaces can deflect up and down with respect to the chord plane of each wing panel. The main portion of each wing panel is equipped with a simple, 25 percent chord, full-span flap which is interconnected directly with the other flap and with the wing-tip sensor. As the

sensor is deflected upward it deflects the flap in the same direction. A counterweight is used to balance the flaps and sensors about their respective hinge lines.

Each sensor is equipped with a half-span tab control surface connected to the pilot control actuator in the fuselage through a pushrod-bellcrank linkage. This linkage is displaced vertically from the sensor hinge line by a small amount such that, as the sensor moves up, the control tab also moves up, and vice versa. This action is used to regulate the response of the surface to changes in angle of attack. An adjustable spring located in the fuselage is connected to the flap system through a control horn or crank arm to provide an adjustable hinge moment for trimming the system to a given weight condition of the model. A counterweight attached to the sensor surface on the opposite side of the chordwise hinge line and inside the main wing is used to achieve a mass balance for the complete system.

In operation, the flap spring holds the sensors and flaps in their full-down position until the combination of airspeed and angle of attack is reached where the wing lift is nearly equal to the airplane's weight. At this point, the lift forces acting on the sensor panel and flaps start to overcome the hinge moment of the flap spring. The panels then come off the lower travel stop, thereby raising the inter-connected flaps. This action in turn reduces the portion of the total wing lift. The amount of lift reduction for a given change in angle of attack and airspeed is determined primarily by the geometry of the sensor-to-flap and sensor-to-tab linkages, and the sizes of the sensors, control tabs, and flaps. Other factors such as flap hinge moments and the force gradient of the flap spring must also be considered. Also, there are other features, such as servo-tabs or ram-air actuators, that could be incorporated into the system to augment or replace the basic sensor-linkage elements discussed, but such modifications are beyond the intent of this paper.

The sensor-flap can be trimmed to its neutral position by either the flap spring or the control tab. Normally the center position of the control tab was set and the spring was adjusted to bring the system to its neutral point at the airplane's trimmed airspeed and angle of attack. It is observed that, in this steady condition, the sensors are generating a part of the total lift of the airplane and increase the effective aspect ratio of the basic wing. (The hinge gap must be properly sealed to minimize lift losses and reduce drag).

When the combination of angle of attack and airspeed is altered, as in the case of a gust, the lift of the sensors as well as the rest of the wing is altered. Since the ratio of inertia-to-lift of the sensor flap system is purposely kept much lower than the complete airplane, the sensors will respond to the lift change faster than the airplane and consequently will deflect either up or down relative to the airplane. This action will reduce the change in the lift of the wing by some amount depending on the various geometric characteristics of the system. In an ideal case, the system would be sized so that the lift increment caused by the disturbance would be

exactly canceled by the lift decrement of the flap. Although it is doubtful that this ideal case could be approached very closely, especially for both velocity and angle of attack changes, it is hoped that the effects of the gusts can be reduced more than 50 percent.

The overall effect of this system is to cause the wing to act as a nearly constant lift device over the operating limits of the sensors and flaps. This contrasts with the normal response of a wing in which the lift varies directly with angle of attack and the square of airspeed. With the wing acting essentially as a constant lift device, the response of the airplane to the pilot's elevator control inputs will be markedly different from normal. In fact, in the ideal case just discussed, the elevator control would merely serve to change the attitude of the fuselage without perceptible influence on the flight path of the airplane. In the practical case with less than 100% alleviation, the flight path would be altered, but to a much lesser extent than for the case with the system not functioning. In other words, the stick-fixed maneuvering stability (stick deflection per g) will be increased. The stick-free maneuvering stability (stick force per g) would probably be increased also. The effect of the system on the static stability is more complicated and depends on the ratio of the pitching moment due to flap deflection per se and the pitching moment due to flap downwash on the tail. The impact of these changes on the overall handling qualities will have to be investigated. For example, auxiliary controls of the flap may be required, or the elevator may be interconnected with the flap system. The former approach was taken in the case of the radio-controlled model flight tests.

It is evident that the inherent longitudinal stability characteristics of the airplane will be altered by this system inasmuch as an important portion of the damping of the longitudinal motions is generated by the tail. The effect of the system is to reduce this damping. One of the reasons for performing the radio-controlled model tests was to obtain a preliminary evaluation of this specific problem.

DESCRIPTION OF TEST EQUIPMENT

The 1.23 m - wingspan radio controlled model employed in these tests was an original design used for sport flying and had a mass of 1.8 kg. The model when modified had several mass and geometric characteristics which were close to those for a 1/8 - dynamically scaled model of a popular high wing light-plane. Reasonably realistic characteristics, particularly those pertaining to wing loading and wing-horizontal tail relative positions, were considered desirable for these exploratory tests. A comparison of some of these characteristics is given in table 1.

For reference, the curve given in figure 4 shows the variation of lift coefficients with airspeed and dynamic pressure of the model for standard atmospheric conditions. The lift coefficients corresponding to the various phases of flight for the full scale airplane are also indicated in this figure.

The original wing was replaced with a new wing equipped with the system as described in the previous section. The wing was built with about 4 degrees geometric dihedral to provide effective lateral control by means of the rudder control only. The aileron system was eliminated for the model to simplify construction, and the flaps were extended to the full span of the basic wing so as to ensure adequate flap-lift attenuation capability. The sensor area and travel, the sensor-flap travel ratio, and the sensor control flap configuration were selected primarily on the basis of judgements as to what appeared reasonable for a full-scale airplane application and for the model design and fabrication effort. Some estimates of the flap effectiveness and appropriate sensor-flap travel ratio were based on aerodynamic data available for a somewhat similar lightplane configuration tested in the Langley Full-Scale Wind Tunnel (reference 2).

The model was equipped with a multichannel proportional radio control system that permitted operation of the elevator, rudder, engine and sensor-flap controls through a transmitter (shown in figure 2) held in the hands of the pilot located on the ground. The normal control functions correspond to those of a full-scale airplane except that for these tests the rudder was used for lateral or roll control in lieu of the normal aileron system. This exception is considered to be insignificant insofar as the objectives and results were concerned. The sensor control flap was operated by an auxiliary trim lever that had 100 percent authority. With this control system the pilot was able to trim the model to any desired flight condition, apply a specific control input to disturb the model and then remove his hands to observe the model's response characteristics for the control-fixed condition. No flight-data instrumentation was installed on the model.

The model pilot has over twenty years experience in flying radio controlled models and is active as a private pilot of lightplanes. His background represents 27 years as a research engineer in stability and control of aircraft and space vehicles with a speciality in flight testing dynamically scaled models using the radio control techniques.

For the wind tunnel tests, the wing was removed from the model and fitted with a mounting bracket for the three component force measuring strain-gage unit on the bottom surface at the center section. This unit, which was 5.08 cm square and about 12.7 cm in length, was mounted in the chordwise direction beneath the wing. The tests were performed in the Langley 12-Foot Low-Speed Tunnel whose normal operating conditions cover the usual flight speeds of the model. The tunnel has a closed test section that is sufficiently larger than the model so that the tunnel correction factors can be neglected for this type of exploratory testing.

TESTS AND RESULTS

The wing-alone wind tunnel tests were made primarily at a dynamic pressure of about 144 N/m^2 which corresponds approximately to that for which

most of the free-flight tests were made. Some tunnel tests were also made at 96 and 192 N/m², but the results are not discussed inasmuch as they were generally similar to those that are discussed. Zero reference for angle of attack was arbitrary but the range of angle from slightly below zero lift to above the stall was covered generally in 2 degree increments. The tunnel tests were actually performed after numerous successful flights of the model had been obtained. However, the tunnel results will be discussed first.

Wind Tunnel Results

Results for tests of the complete wing conducted at a dynamic pressure of 144 N/m² are given in figure 5. This figure shows the variation of lift coefficient (C_L) with angle of attack (α) for various conditions of sensor-flap system. With the system fixed at zero deflection of all surfaces, the wing functioned essentially as a rigid wing with a lift curve slope ($C_{L\alpha}$) of 0.070 per degree and maximum C_L of slightly over 1.10 as determined for the curve with circular symbols. This is consistent with higher Reynolds number tests (reference 2) of a full scale lightplane with a tapered and somewhat higher aspect ratio wing. The corresponding values for the full scale tests are 0.086 and a range of about 1.40 to 1.60 depending on tail surface settings. The slightly higher $C_{L\alpha}$ value is attributed primarily to the differences in taper and aspect ratios whereas the C_{Lmax} differences are attributed to Reynolds number effects and lack of a fuselage and tail on the model. A slight anomaly in the model data curve near maximum lift suggests that premature stalling of one wing panel, probably induced by some model asymmetry, is quite likely involved. However, these differences are not considered significant insofar as the purpose and results of the exploratory test are concerned.

The second curve, designated by the square symbols, shows variation of lift with α with the sensor-flap system active using the linkage condition similar to those for the free-flight tests. At low angles of attack, the flaps were down against their lower stops so that additional lift, when compared with the previous data, was produced. As α was increased, the lift acting on the sensors overcame the effects of the preloaded flap springs and the sensors caused the flaps to raise uniformly to their upper limits. The active α range for the sensors is generally between -2° and $+6^\circ$ and the midpoint of this range at a C_L of about 0.35. Notice that the lift curve slope below and above the active α range is essentially the same as that for the previous fixed-system data. The value of the effective $C_{L\alpha}$ for the active α range is about 0.023 per degree corresponding to a reduction to one-third of that for the inactive case. The implication of this effect is that the influences of a gust could be reduced by something approaching this amount with this system, although the exact amount would, of course, depend on many other factors.

The influence of the flap hinge-moment spring is demonstrated by the third curve, designated by the diamond symbol. Here the spring has been removed and the primary effect has been to lower the active α range of the

sensor with a mid-point at a C_L of about 0.18 with no significant change on the effective $C_{L\alpha}$.

The influence of the sensor control tab as a feedback device is seen in the comparison of the fourth curve with the triangular symbols and the previous curve. For the fourth condition, the control tab linkage was removed and the sensor control surfaces were taped in their neutral positions on the sensors. There were two effects: first the crossover point was shifted downward slightly and, second, the effective lift curve slope was reduced essentially to zero as was expected. Both effects are directly attributed to the control effectiveness of these small tabs on the sensors. The crossover point is governed by the position of the control tab at zero flap deflection, and the effective slope is governed by the change in tab position with a given change in sensor position. This serves to demonstrate that these tabs can be used both for pilot control of the system and adjusting the degree of gust alleviation provided by a given system.

Simulated gust dynamics. - A few simple tests of the system were made with the wing mounted on the force measuring unit in the tunnel to demonstrate the dynamic response of the system to some airstream disturbances. The disturbances were created in two ways. In the first case, they were generated by a person standing beside the wing in the test section and striking the sensor to deflect it momentarily a few degrees. In the second case, the person held a .3m square flat plate parallel to the airstream about 1 meter directly in front of one sensor panel and oscillated the plate to create a steady oscillating airstream with a frequency of about 1 Hz.

The results of these tests are shown in figure 6 in which the oscillographic traces of the normal force outputs from the strain gage measuring system are presented. The traces consist of three pairs, with each pair corresponding to wind off (zero lift) and wind on (with an average lift value of about 6.7 newtons). The tests were run at a reduced dynamic pressure primarily out of consideration for the comfort of the person standing in the test section. The sensor control flap feedback linkage was active for these particular tests.

The bottom trace (b) of the top pair demonstrates that the sensor-flap system was stable and that the disturbance damped in about 2 cycles at a frequency of 4 Hz. For another test (not shown) with the sensor control tab feedback linkage inactive, the system damped in about the same time but the frequency was lower. The lower trace (d) of the middle set of traces in figure 4, shows response of the wing with the active sensors and flaps to the oscillating airstream. Notice that there is little evidence of the 4 Hz natural frequency of the sensor-flap system in the trace for the active case. This trace should be contrasted with the lowest trace (f) in the figure, for the flap-fixed condition, to see the influence of the active system. However, it should be remembered that the gusts were not necessarily the same for these two traces nor was the gust uniform across the entire wing span for either trace. The force fluctuations for the active case appear to be less than half of those for the inactive case. This result is generally consistent with the

static force data in which the effective lift curve slope of the wing was reduced to about one-third by the sensor-flap system.

Free Flight Tests

Inasmuch as there was no flight test instrumentation installed in the model, the results of these tests can only be reported in a qualitative manner by discussing the pilot's observations.

Prior to installing the modified wing, the model was flown several times with the original wing to establish the general flying characteristics of the model with particular reference to longitudinal responses to elevator control inputs and to maintaining steady level flight conditions with various throttle settings. Also the original full-span ailerons were rerigged as flaps and flight checks were made to ensure that the effects of flap deflection on longitudinal trim did not require interconnection between the flaps and elevators. The model was kept in continuous flight within less than one hundred meters of the pilot by following a race track-type of flight pattern.

These tests showed that the model was longitudinally stable and quite responsive to elevator. As the elevator was pulsed up and down slowly about the trimmed position, the flight path would noticeably vary in altitude. The takeoff distance on a fairly smooth hard surface was generally 15 to 18 meters into a moderate headwind. Based on dynamic scaling relationships, this corresponds roughly to that required for a full scale airplane under similar conditions. This indicates that a comparable power loading was being used. Estimates of the maximum speed obtained in level flight with full throttle indicate that lift coefficients comparable to cruise conditions for full scale airplane were obtained based on the relationship given in figure 4.

With the sensor-flap system locked on the modified wing, the model flew very much like the original model. With the system unlocked, takeoff was made by adjusting the sensor control tab such that the flaps remained in either their full up or full down positions so that the model could be controlled longitudinally in the normal manner with the elevator. With the flaps full up, difficulty was encountered with a severe lateral oscillation that is attributed to the resulting extreme nose high attitude of the fuselage, the dihedral effect of the upturned sensor panels and some differential flexing between the two flaps. Once the model was fully airborne and had gained some speed there was no further oscillation tendency noted; also there was no tendency evident at any time with flaps full down. In the case of a full scale airplane application, it is assumed that operational considerations will most likely dictate that takeoff maneuvers be performed with the system locked.

After steady level-flight conditions were established with the throttle and elevator the system was brought into play by moving the sensor control until the model was seen to respond. Further adjustments were made with both sensor and elevator controls until the sensors and flaps were observed to be

approximately in their mid positions. The first indication that the system was functioning properly was the feeling of sluggishness in the response of the model to elevator controls when attempting to a just the flight path. It was possible to control the flight path with elevator but large displacements of the control stick were required. This contrasted very sharply with the "crisp" response to elevator, inputs with the system locked¹. This sluggishness is directly attributable to the reduced effective $C_{L\alpha}$ that was obtained in the wind-tunnel tests.

The second indication of the system's effectiveness was in the responses to the slowly pulsed elevator control with excursions of up to 50 percent of total stick travel. In this case, the attitude of the model was seen to oscillate a few degrees in direct response to the elevator inputs, but there were no noticeable corresponding altitude changes. Also, when performing the banked turns to hold the racetrack course about the pilot, a large amount of elevator "back-stick" was required to hold the altitude in comparison with that required with the system locked.

Another indication of the system's functioning was the direct effectiveness of the sensor tab control in adjusting the flight path angle. The pilot found that his control was slightly more effective in controlling the flight path than the elevator for this case. As a matter of fact, several landing approaches were performed using this tab control in place of the elevator. Finally, the sensor panels and flaps could be seen to respond to small disturbances as the model was being flown in moderately windy conditions.

The model was flown with the system active from full-power, high-speed conditions to those approaching a stall without evidence of significant stability or control problems other than the changes in control sensitivity noted. Different center-of-gravity conditions were produced by useage of fuel (located in the nose) and by addition of some lead ballast, but the range of the C. G. positions was not documented.

In some initial flight tests, the system was flown without mass balance to check on the occurrence of flutter. A number of flights were made in this condition without incident; however, the flight speeds were held fairly low. Flutter finally did occur when the model was placed into a shallow dive and the speed increased. The divergence was very rapid and consisted of about three cycles of the sensor-flap motion accompanied by significant vertical motions of

¹In fact, the pilot found that he could tell when the system was trimmed properly and when the flaps and sensors were against one or the other stop merely by the difference in the "feel" of the stick. It was quite surprising to be able to feel the difference inasmuch as there was no force feedback to the pilot other than the fixed spring forces in the control stick. The only feedback of any kind in the complete pilot-to-model system was the pilot's vision of the model motions.

the fuselage. The plastic covering of one wing panel failed and complete loss of control ensued. Following repair of the model, subsequent testing, which was reported above, was performed with the system neutrally mass-balanced, and no such incidents occurred throughout the remaining tests.

It was concluded from these tests that the system itself was stable and tended to reduce changes in lift and that the results for those conditions tested are in direct agreement with the wind-tunnel test. Also, the model could be controlled through the sensor system without encountering severe stability and control problems. Furthermore, it appears that the system could be used for landing as well as for cruising flight. It was evident from this investigation that some special techniques will be required for integrating the system into the pilot's normal control system both from the system design standpoint and from that of the pilot's operational procedures.

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2. Greer, H. D., Shivers, J. P., Fink, M. P.; Wind Tunnel Investigation of Static Longitudinal and Lateral Characteristics of a Full-Scale Mockup of a Light Single-Engine High-Wing Airplane. NASA TN D 7149 May 1973.

Table I

Comparison of Mass and Geometric Characteristics

<u>Item</u>	<u>Test Model</u>	<u>1/8-Scale Airplane</u>
Mass, kg	1.8	2.0
Wing Area, cm ²	2500	2530
Wing Span, m	1.23	1.37
Wing Aspect Ratio	6	7.5
Wing Loading, N/cm ²	.00711	.00791
Wing Tail Length, cm	56	56
Horizontal Tail Area, cm ²	639	600
Center of gravity, percent chord	32.5	16.9 to 36.5
Flap chord, cm	5.1	3.3
Flaps area, cm ²	464	161

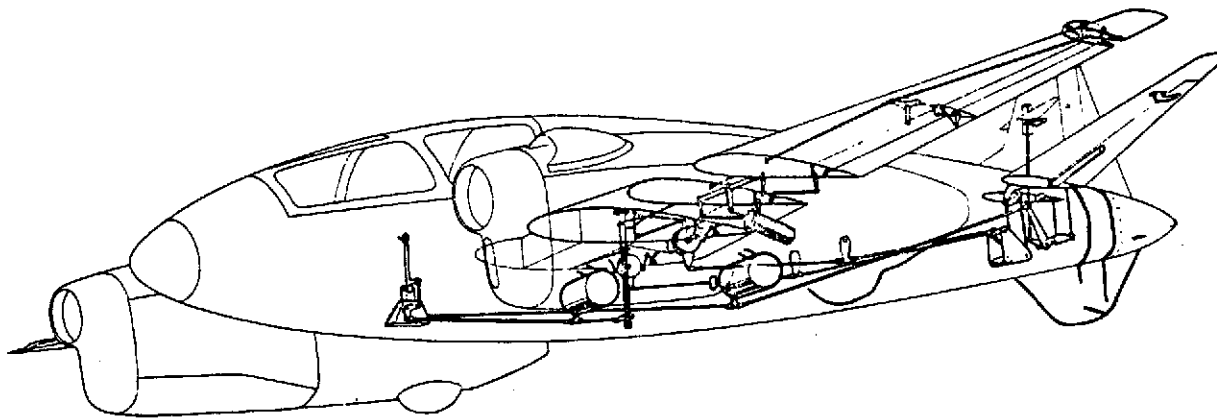


Figure 1. Sketch of gust-alleviation system installed in an experimental airplane designed, built, and flight tested by René Hirsch.

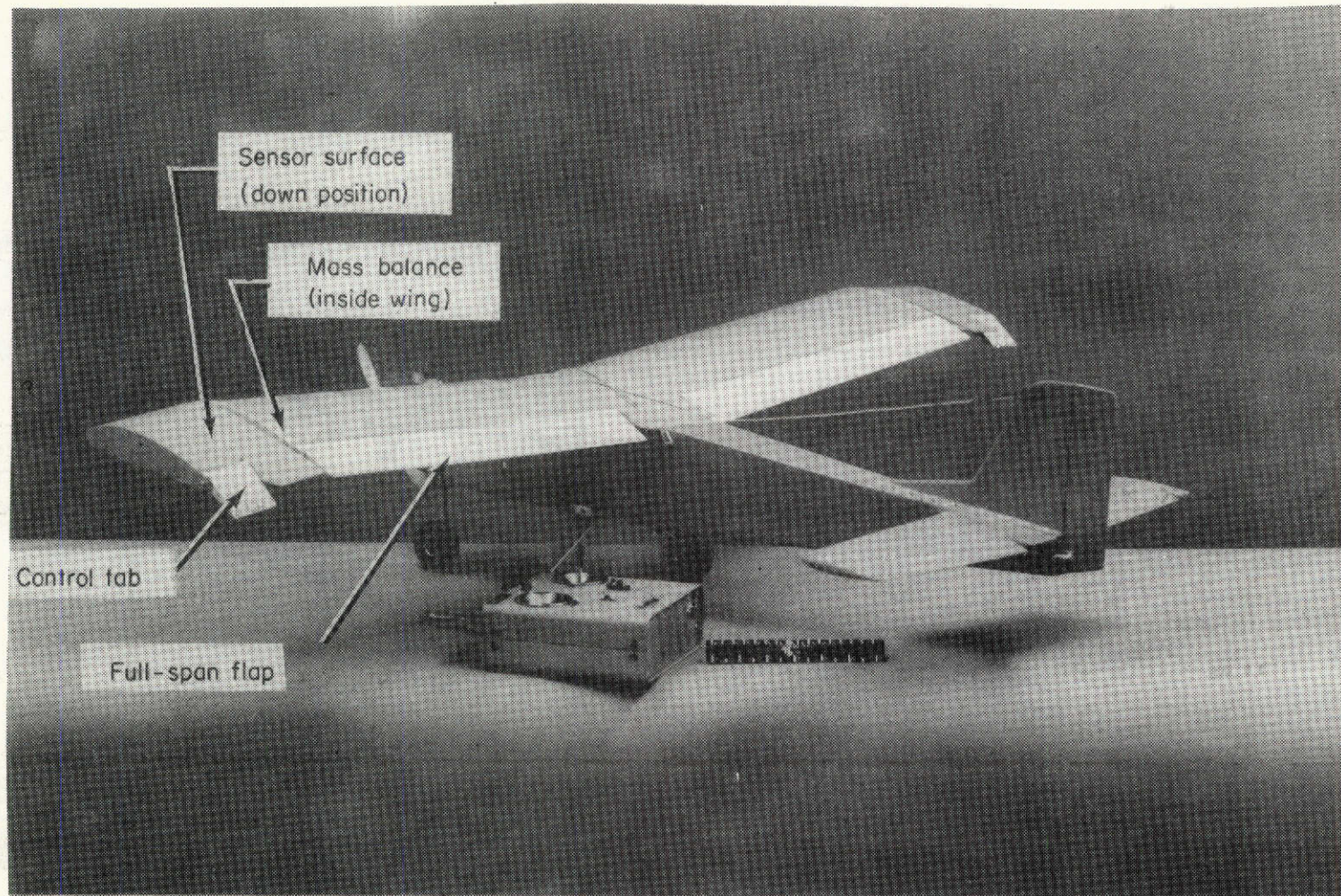


Figure 2. Photograph of 1.23m wingspan radio controlled model equipped with the simplified gust-alleviation system. The sensors and flaps are shown in the full down position. The pilot's control transmitter is shown in the foreground.

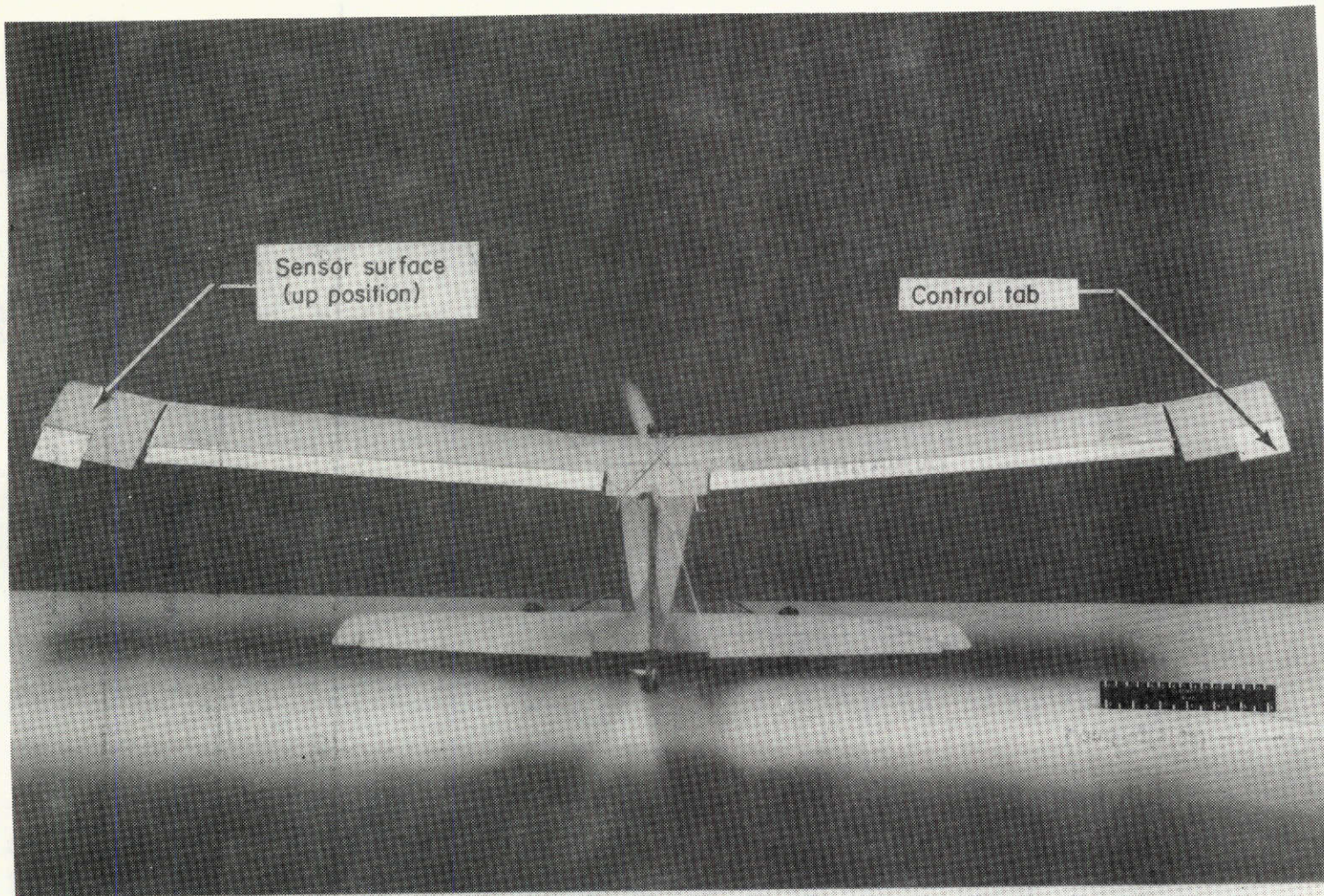


Figure 3. Rear view photograph of model showing sensors and flaps in the full-up position. The sensor control tabs are also shown in their down position which reduces the lift of the wing.

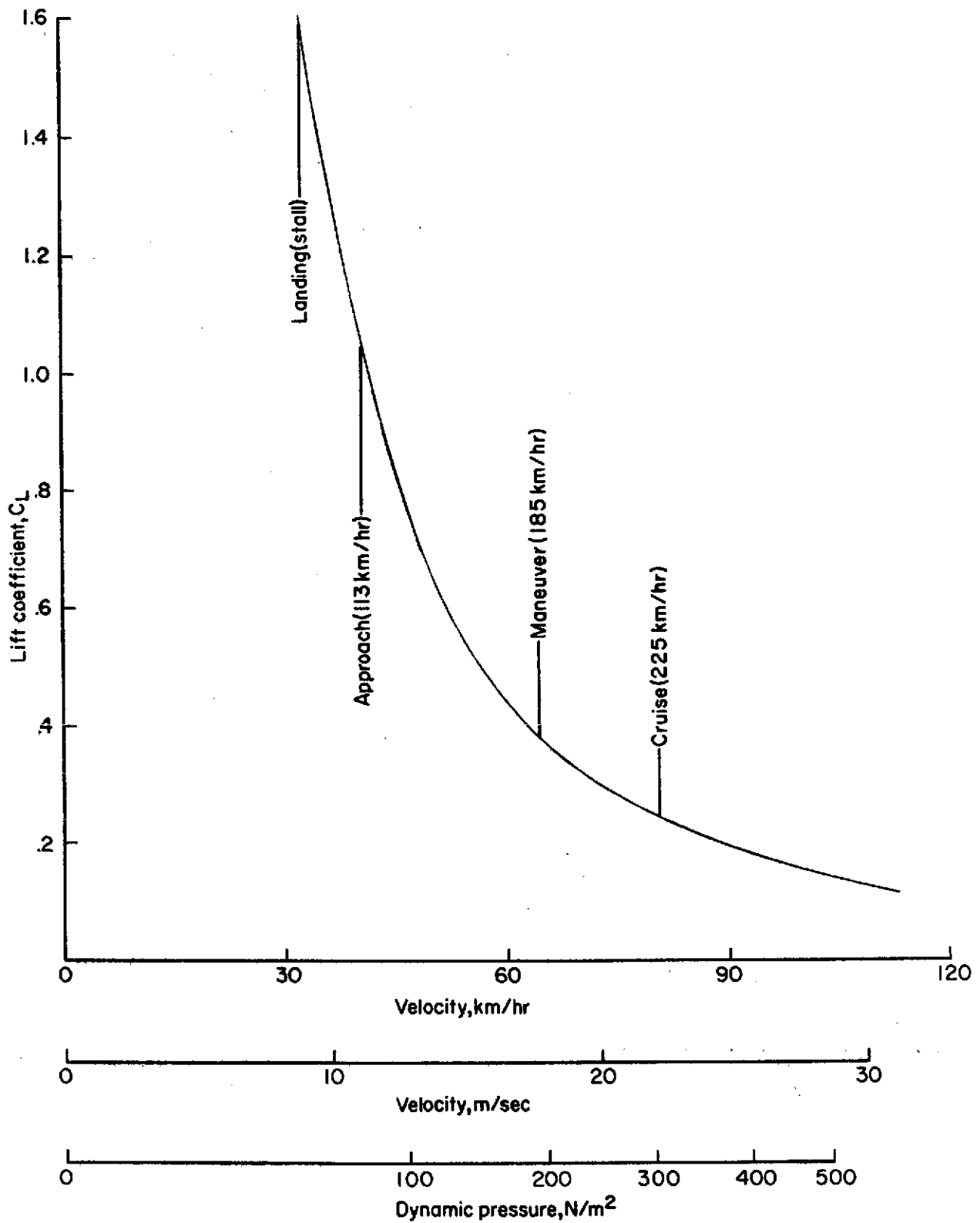


Figure 4. Variation of lift coefficient with airspeed and dynamic pressure for the model on the basis of a wing loading of $71.3N/m^2$ and standard atmospheric conditions. Airspeeds corresponding approximately to full-scale aircraft flight conditions are indicated.

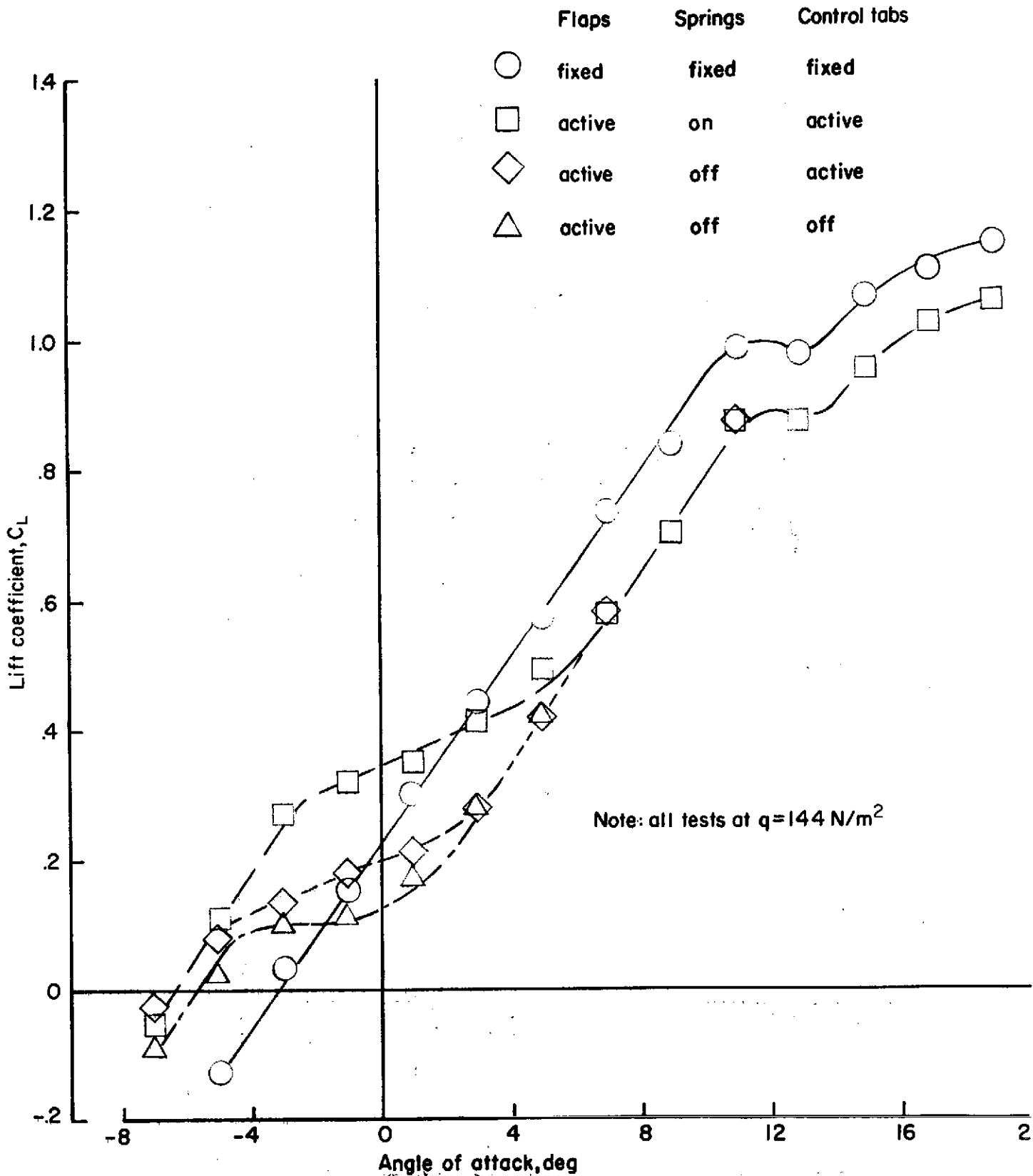
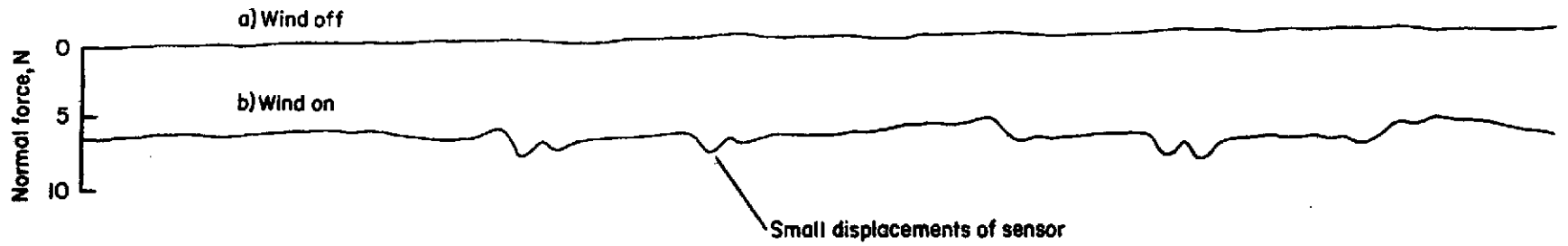


Figure 5. Static wind-tunnel results of wing alone with simple gust-alleviation system showing effects of system components.

Normal force response to small disturbances of sensor



Normal force response to simulated gust inputs

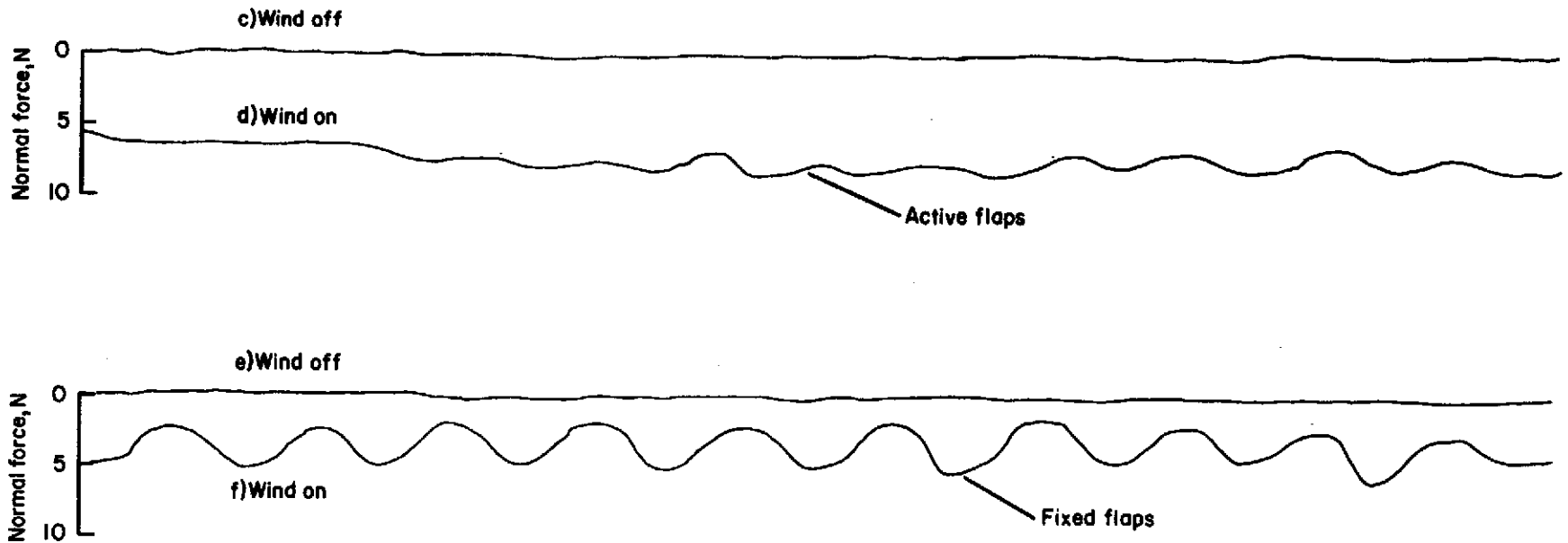


Figure 6. Results of simulated gust tests of wing alone with simple gust-alleviation system. Traces a, c and e are wind off zero reference traces. Trace b is time history of normal force with wind on, and with the sensor disturbed momentarily several times. Trace d and f are time histories with a simulated continuous oscillatory gust with system active and fixed, respectively.