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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 669

THE GERMAN INVESTIGATION OF THE ACCIDENT
AT MEOPHAM (ENGLAND)

By Hermann Blenk, Heinrich Hertel and Karl Thalau

Zeitschrift für Flugtechnik und Motorluftschiffahrt
Vol. 23, No. 3, February 15, 1932
Verlag von R. Oldenbourg, München und Berlin

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THE GERMAN INVESTIGATION OF THE ACCIDENT
AT MEOPHAM (ENGLAND)*

By Hermann Blenk, Heinrich Hertel and Karl Thalau

I. THE ACCIDENT

The commercial airplane G-AAZK (type Junkers F 13 ge) fell to the ground at Meopham, England, on July 21, 1930. The four passengers and the two pilots were killed. Eye witnesses to the accident could only report that the airplane was seen entering a cloud, followed almost immediately by a loud noise and the falling of the fragments to the ground.

The official English accident report (reference 1), published in January, 1931, gives a detailed description of the airplane and its previous history, along with the pilot's history, as well as the evidence of witnesses on the ground.

The airplane was built at the Junkers Works, Dessau, early in 1930, and equipped with a Junkers L 5 engine. The German certificate of airworthiness was dated May 28, 1930. It was, therefore, a new airplane and its total time in the air up to and including the day of the accident, amounted to 101½ hours. The airplane was owned by the Walcot Air Lines, Ltd.

At the time of the accident the plane was piloted by a young pilot, C. D. Shearing, who in 1928 had met with a serious airplane accident in the United States, and was not granted a Class B license in England until February, 1930. In this particular airplane he had flown six times as second pilot, twice as first pilot, and twice as the sole pilot in charge, giving a total of fifteen hours in the air with this airplane.

*"Die deutsche Untersuchung des Unfalls bei Meopham (England). Zeitschrift für Flugtechnik und Motorluftschifffahrt, Feb. 15, 1932, pp. 73-86.

Colonel G. L. P. Henderson, who occupied the second pilot's seat during the accident, was a pilot of very considerable skill and war-time experience.

The weather conditions were particularly bad at the time of the crash. Meteorological experts hold that up-currents at the time and place of the accident, as strong as 10 m/s (30 ft./sec.) are considered possible. One pilot who passed very near at the same time, stated that the bumps were the worst he had ever encountered. The country about Meopham is hilly. The airplane flew at about 300 m (1,000 ft.).

The wreckage was scattered over a considerable distance (up to 2 km (1½ mi.)). The main points of fracture may be seen in Figure 1.

II. ENGLISH INVESTIGATION AND FINDINGS

The investigation of the accident by the Accident Investigation Subcommittee was conducted in a very thorough fashion, covering 92 printed pages with many photographs and diagrams. (See reference 1.) Besides the principal investigation on tail "buffeting," it included various others, such as dropping tests with small models (scale 1:50) shaped to resemble certain fragments (wings, tail, etc.), in order to determine the paths of such fragments.

The English report arrives at the conclusion that the accident was probably due to tail fracture from buffeting as primary cause, and that all other fractures were induced by the former. This conclusion is based upon the experiences gained in England (but biplanes only) that in a break-up in the air the tail either breaks first or else falls to ground undamaged (after a wing fracture), and on model tests in the wind tunnel. As a result of this and the aspect of the break, it was concluded that the horizontal tail unit broke first. It was assumed that a strong gust in normal cruising flight suddenly produced a high incidence on the wing. In this flight attitude (large angle of attack, cruising speed) buffeting sets in on the tail plane. From the results of model tests it is deduced that the amplitude of these buffeting vibrations could become so large as to break the horizontal tail group at speeds within the normal flying range of the airplane.

"Buffeting" is explained as an irregular, more or less violent oscillation of the tail unit, in which the stabilizer bends rapidly up and down and the elevators move in an erratic manner; it is said to be caused by the eddies given off by the wings at large angles of attack. It is quite distinct from "flutter." Flutter, which more frequently is known to appear on the wings, is induced by the aerodynamic coupling of two or more degrees of freedom which, under certain conditions, affords an energy removal from the uniform air stream and thus is apt to initiate forced vibrations.

A number of other theories of the accident (propeller fracture, material defect, etc.) are briefly discussed in this same report but discarded as impossible or very improbable. The most important other explanation adduced is: That due to a too rapid pull-up from a dive out of the cloud, or through a violent gust (by high flying speed) the wing broke first. This is in accordance with an analysis made by the inspector of accidents which, however, as stated before, covers biplanes only.*

III. THE GERMAN ACCIDENT INVESTIGATION

1. Problem and Kinds of Tests

The findings of the English investigation made it incumbent to institute experiments on tail buffeting, its cause, intensity and gravity. Thus, the minister of transportation authorized the D.V.L. to proceed with these tests, which were made by the static test branch (K. Thallau, chief), in collaboration with the flight test section (J. v. Köppen, chief), and the aerodynamic section (Dr. F. Seewald, chief). The program included experimental flights, model tests and tensile strength tests. Incidentally, the

*Against this interpretation of the Meopham accident it is contended that: When, as in most cases, part of a wing of a biplane, or both wings of a monoplane or biplane break at the same time, it is not accompanied by torsional motions about the longitudinal or normal axis. But if, as in this particular case, half a wing of a monoplane breaks almost completely away, it is followed by violent rotating motions about both the longitudinal and the normal airplane axis, as a result of which the tail might give way.

D.V.L. scratch elongation recorder and the D.V.L. optograph found an opportune occasion to prove their usefulness.

Lacking an airplane of the Junkers type F 13 ge, the test flights were made with another type quite similar to it: the D 570 with Junkers F 13 fe, on which slight buffeting vibrations had previously been observed,* and which already had undergone alterations on the trailing edge of the wing near the root and also on the stabilizer and elevators. The different modifications can be seen in Figure 3. On the D 570, the edge is slightly raised, in the F 13 ge, more so, in order to delay the separation of flow in proximity of the fuselage at high angle of attack. The principal differences can be readily seen in Figure 2. The tail area, span, and position of struts are about the same, with exception of the portion of the balanced elevator, which is greater on the F 13 ge. As to internal construction of the stabilizer, the tubular struts of the D 570 are 30 per cent thicker in the overhang. The tail of the F 13 ge (D 570) has the profile of an inverted wing, which is bound up with a timely breakaway of the flow at positive angles of attack, whereas the profile of the F 13 ge is symmetrical. The other discrepancies are of minor significance.

In the wind-tunnel tests with F 13 models, the differences of the two F 13 types (fe and ge) as well as the slipstream effect on buffeting, were investigated.

Observation flights with another F 13 fe, with two airplanes, W33b and F13ke, and with an F13ge were made in addition for comparison.

The D 570 was further used in buffeting tests, made to define the natural vibration frequency. The dynamic and static tests were made on a new F 13 ge and on an older F 13 ge D.V.L. tail.

*Report of H. G. Küssner at the International Congress for Mechanics, Stockholm, 1930.

2. Static and Dynamic Tests on Junkers F 13

Horizontal Tail Units

a) Elasticity tests.— The test program included load tests with deflection and elongation readings on F 13 ge and F 13 fe (D 570) stabilizer and elevator. The ensuing influence lines, together with the deflections and strut stresses measured in free flight, yield an approximate account of the imposed tail loads. (See section 4, page 10.)

The airplanes were so arranged that the landing-gear wheels were rigidly held while the tail skid was supported on a universal ball bearing, thus affording free movement in any direction. The 100 kg (220 lb.) loading was first applied asymmetrical and then symmetrical at both ends of the left and right tip of the stabilizer spars. The result is shown in Figure 4, where the influence lines for deflection of the tips are plotted against the individual load traveling over the stabilizer span for both F 13 ge and F 13 fe (D 570). E is the influence line for the deflection on the loaded side, U that for the deflection on the unloaded side, and B that of the symmetrical individual loads for the final deflections.

b) Static breaking tests.— D.V.L. tail F 13 fe (like D 570). For this test we used the rear fuselage with complete horizontal tail group and bracing system of an F 13 fe hydroplane. The loads applied as symmetrical separate loads on the stabilizer were progressively increased to rupture. The break occurred at the left, in the tension-stressed lower spar tube directly outside of the strut fitting (99 cm (39 in.) from the center section). The same gauge compression flange was slightly buckled on top because of the strain induced by the failure of the tension flange. The bending moment causing breakage was $M_B = 356 \text{ m-kg}$ (2575 ft.-lb.). The failure of the right side also occurred in the tension flange at bending moment $M_B = 388 \text{ m-kg}$ (2800 ft.-lb.). The break of the tension flanges goes through three rivet holes each and is free from any indication of fatigue fracture induced by stresses in flight. The breaking stress corresponding to $M_B = 388 \text{ kg}$ (855 lb.) is 35 kg/mm^2 (49780 lb./sq.in.). The deflection of the left tip amounts to about 12.2 cm (4.8 in.) at breaking stress, that of the right tip only 11.6 cm (4.6 in.) for the same load and 13.1 cm (5.2 in.) at failure.

These tests were continued on a brand new half of an F 13 ge tail. It still supported a load $P = 250$ kg (550 lb.), but signs of yielding showed that failure was imminent. A further 10 kg (22 lb.) resulted in failure by collapse of the top flange 29 cm (11.4 in.) ahead of the strut attachment. (See fig. 10.) The deflection at rupture was 9.1 cm on the stabilizer tip and 12.4 (4.88 in.) on the elevator tip. The breaking stress amounted to 35 kg/mm² (49780 lb./sq.in.). For comparison with subsequently described dynamic breaking tests the bending moment at failure is to be equated with the dynamic section at rupture. (See fig. 10.) For this section $M_B = 310$ m-kg (2240 ft.-lb.).

The most unfavorable section of the stabilizer spar lies outside of the point of application of the struts. The static bending moment at failure was experimentally defined at 310 m-kg (2240 ft.-lb.) (112 cm (44 in.) from center of tail) for F 13 ge and 388 m-kg (2800 ft.-lb.) (100 cm (39.4 in.) from center of tail) for F 13 fe. The difference in the figures is due to the spars of the F 13 fe D.V.L. tail being of slightly heavier gauge than the other (1 mm (.04 in.) instead of 0.8 mm (.03 in.) wall thickness), because the attained breaking stresses of both tails are identical with $\sigma = 35$ kg/mm² (49780 lb./sq.in.).

c) Dynamic breaking tests of F 13 ge tail.— These tests were carried out in order to determine how the tail would react when vibrations conformably to the natural frequency of the tail were excited and permitted to build up. The test specimen was a brand new complete horizontal tail unit of the F 13 ge type, mounted on an iron frame which resembled the rear end of the fuselage. (See figs. 5 and 6.) The lead plates fastened on the substitute framework, together with the iron frame, corresponded to the airplane mass reduced to the center of the tail. The unbalance was installed below the iron frame. (See fig. 6.)

The total set-up was suspended by soft shock-absorber cord from the hangar crane. The rudder lever was joined to a flat spring screwed to the mock-up fuselage. The flexibility of the spring was the same as the experimentally defined elastic yield of the complete control. (See fig. 6.)

Within 7 to 17 Hertz (s^{-1}) the stabilizer manifested a pure vibration in bending, whereas the same bending vibration in the elevator was superposed by a torsional vi-

bration of identical frequency about the elevator axis. The resonance curves in Figure 7 indicate a distinct maximum at $n = 11.8 \text{ s}^{-1}$. The torsional vibration of the elevator shows a second maximum at $n = 7.9 \text{ s}^{-1}$.

In the dynamic breaking tests it was attempted to speed up the amplitudes to failure as quickly as possible. This was accomplished at about 300 vibrations, or about 25 seconds. Upon reaching the double amplitude, measured at the tip of the stabilizer at $a_{\text{max}} = 12.5 \text{ cm}$ (4.92 in.) and $n = 11.8 \text{ s}^{-1}$, the break occurred 22 cm (8.7 in.) away from the strut fitting (112 cm (44 in.) from center of tail) on the bottom flange of the right spar. The break at this point goes through the first rivets of the tube joint. At failure the amplitude died out and the frequency fell off. The breaking process can be followed in Figure 8 on the strut stresses by the sudden drop in stress. The discontinuance of the excitation is characterized by the jump after another 60 vibrations. The whole process was recorded by slow-motion cinematographic camera. These records together with optograph records were the basis upon which the amplitude-elastic curve at failure was computed and plotted in Figure 9. The dynamic load of the oscillating tail is found from the inertia forces of the tail masses.

The maximum force of inertia P (kg) of a partial mass m ($\text{kg cm}^{-1} \text{ s}^2$) which a harmonic vibration with double amplitude a (cm) and velocity v (s^{-1}) develops is, in the inversion point

$$P = - m \frac{a}{2} v^2 \text{ (kg)}$$

The bending moment at failure was defined by means of the amplitude-elastic curve at failure (fig. 9) from the mass forces at $M_B = 255 \text{ m-kg}$ (1840 ft.-lb.). The stresses were resolved by means of the moment of inertia, due account being taken of all stabilizer and elevator longerons. In the mean breaking stress $\sigma_{Br} = 30 \text{ kg/mm}^2$ (42670 lb./sq.in.) the local stress concentrations at the edges of the rivet holes were ignored. The breaking stress after about 300 vibrations accordingly amounts still to 85 per cent of the ultimate stress developed by static breaking tests.

The vibration experiments were continued with the broken tail. The natural frequency had dropped to $n =$

7.6 s^{-1} . Upon reaching a double amplitude $a_{\text{max}} = 18 \text{ cm}$ (7.09 in.) at the spar tip, the break enlarged immediately by destruction of the rear spar, so that the vibration became completely unsymmetrical. (See fig. 9.) After the break the bottom flange of the main spar can only transmit compression. The metal skin covering on the bottom side still acts as tension flange. Hence the upward deflection of the stabilizer is greater than the downward. There also is a marked asymmetry in the left and right amplitude. After the test the corrugated metal skin showed cracks over the spar break on top and bottom, beginning at the rivets.

d) Static breaking tests with dynamically broken tail.-- The tail which had been broken in the dynamic loading tests was then subjected to static tests, even though the tail was only held together by the metal skin. Individual loadings (symmetrical at right and left) were so applied that the damaged spar tube came on the tension side. The stabilizer tips still supported a load $P = 125 \text{ kg}$ (276 lb.) each; a subsequent load increase produced suddenly a yield at the left side. After unloading a pure torque was unsymmetrically applied on the stabilizer tips. It still supported a torque of $M_d = 160 \text{ m-kg}$ (1157 ft.-lb.). The torsions recorded at the broken right side at $\phi_s = 3.3^\circ$ and at the practically undamaged left side at $\phi_B = 2.4^\circ$, are comparatively slightly different. Following this the right side was completely destroyed by applying a load in bending at the nose. The developed load on the stabilizer tip was 150 kg (331 lb.); increased another 25 kg (55 lb.), it induced pronounced yielding on the broken right side and the right boom of the stabilizer bent up 90° .

It is remarkable how the stabilizer with a broken spar on the tension side was still able to carry 60 per cent of the static breaking load of the undamaged tail. Another point is that torsion stiffness and torsion strength are little affected by spar failure.

e) Conclusions.-- The conclusions from these tests are that, if failure is brought about by high dynamic loads (resonance), the natural period of the tail is at once lowered to the point where resonance no longer occurs. As the strength of the tail under static load is still 60 per cent of the original, it is concluded that complete static breakage can only take place under especially unfavorable circumstances.

f) Fatigue tests.— Upon completion of the static breaking tests the left half of the F 13 ge horizontal tail group was completely repaired again and tested in fatigue. The amplitude was so chosen that in the endangered section the bending moment computed from amplitude curve, mass distribution and frequency, amounted to $M_w = \pm 74$ m-kg (535 ft.-lb.), or 24 per cent of the static bending moment at failure. After approximately 700,000 vibrations the metal covering began to crack, indicating that breakage was imminent. Examination revealed the bottom flange broken again on the first rivets of the joint.

3. Vibration Tests with the F 13 fe, D 570 Airplane

in the Hangar

The dynamic properties of the tail and rear fuselage of the D 570 airplane, type F 13 fe, equipped with D.V.L. stabilizer and elevator were determined by vibration tests. The airplane was suspended horizontally from the hangar crane by rubber cords, and a double unbalance excited the body-tail vibrations. Bracing was resorted to in a subsequent test series in order to reduce the stabilizer vibrations. In view of the available possibilities this bracing reached from the tip of the tail fin over the end rib of the stabilizer to the strut attachment point on the fuselage. At the end rib the bracing passed over a pulley in ball bearings, which could be retarded or locked by a brake.

The resonance curves of the right and left side of the unbraced stabilizer by asymmetrical excitation are shown in Figure 11a for horizontal amplitudes, and in Figure 11b for vertical amplitudes. They reveal, within the ambit of frequency investigated, three distinct and two minor resonance points, of the following type, as observed by double mirrors:

$n = 7.45 \text{ s}^{-1}$: torsional vibration of rear fuselage and of horizontal tail group around longitudinal axis of fuselage.

$n = 9.75 \text{ s}^{-1}$: torsional vibration as above and vibration of stabilizer and elevator around normal axis.

$n = 12.1 \text{ s}^{-1}$: vertical symmetrical vibration in bending of stabilizer and elevator.

$n = 13.4 \text{ s}^{-1}$: coupling of bending in horizontal tail unit and bending in fuselage.

$n = 15.3 \text{ s}^{-1}$: vertical vibration in bending of body end.

Figure 11a reveals the marked motion about the normal axis at $n = 9.75 \text{ s}^{-1}$. At this frequency the vibrations are especially severe, because of the contemporary second vertical vibration in resonance (3 nodes) of the wing, at which the wing root vibrates in torsion about the longitudinal axis. The coupling distances between the resonances reveal fairly high amplitudes. This fact proves that the horizontal tail surfaces can impress arbitrary excitation frequencies within a wide range. The amplitudes of the stabilizer spar recorded at the frequencies of torsional and bending vibrations are graphed in Figures 12a to 12d as elastic curves. They manifest that the contribution of the stabilizer in bending to the total amplitude is large even by torsional vibration.

In Figure 11c the resonance curves of the braced tail are given for comparison with Figure 11b. The first two resonances (torsional vibrations) are barely shifted by the bracing, their amplitudes were lowered, slightly in the first resonance, strongly in the second. Figures 12a and 12b show foremost the diminution of purely stabilizer deflections in contrast to the deflections due to body torsion. In these graphs the stabilizer deflections are given for identical body distortions with braced and unbraced tail.

Bracing changes the symmetrical bending vibration in the stabilizer completely, according to Figures 11c and 12c, whereas the bending vibration of the body in Figure 12d is scarcely affected by it. The experiments with loose, damping bracing revealed vibration characteristics which lie between those of the braced and the unbraced tail.

4. Flight Tests with D 570 Airplane, Type F 13 fe

a) Problem.— The purpose of these special flight tests was to determine the behavior of the air flow between wing and tail, the vibrations of the horizontal tail

unit as well as the stresses in the struts of the latter.

b) Preparation (see fig. 13) - First series.- Records with slow-motion cinematograph camera, mounted practically shock-proof on felt and sponge rubber in the passenger cabin and driven from an electric motor and flexible shaft, and taking approximately 80 pictures per second. The angle of focus was adjusted so as to bring the air space between wing trailing edge and horizontal tail unit as well as the left side tip of the stabilizer into one picture. The flight speed was determined by Bruhns type Pitot tube mounted on a 1.6 m mast. The indicator was located in the left cabin window and reflected by a prism into the focus of the camera. To render visible the most important processes of the flow we used red-white braided woolen threads 2 m (6.56 ft.) long, as well as smoke* and aluminum foil. Scattered light shavings, powder, paper, or metal foil promises the best reproduction of the flow pattern and, under certain circumstances, of the local velocity also. The aluminum foil used reflected the sunlight and could therefore be readily photographed. The foil was blown through a pipe to the desired point. The air enters the pipe through a funnel mounted on the fuselage. During stalling compressed air was used.

Second series.- Optograph records (reference 2).- The optograph was so installed in the cabin that with three objectives the test stations (glow lamps) at both tips of the stabilizer, at the left elevator and on the rear fuselage were photographed. The flying speed was also recorded in the optograph. Strut pyramids were attached on both sides of the fuselage, their tips fitted with light, balanced vanes lying in front of the stabilizer in the air stream between wing and tail fin. The vibrations of a glow lamp fastened to the vane were recorded by optograph. (Figs. 13 and 17.)

Simultaneously with these we determined the stresses in the strutting with D.V.L. scratch elongation recorders.** (See fig. 17.)

*Electrically ignited smoke cartridges (4-volt) are also suitable for this special purpose. These are manufactured by the Pyrotechnischen Werken at Malchow.

**Described by W. Pabst in Z.F.M., 1929, No. 46; and D.V.L. Yearbook, 1930, p. 31.

c) Test procedure and results.- The object of the first special flight test was the exploration of gust effects on the air flow in front of the tail and on the tail itself. In the other flights of both series we consistently attempted to develop severe vibrations by assuming unusual, unfavorable flight attitudes. From speed at stalling upward to 210 km/h (130.5 mi./hr.) we flew with and without gas, banked, pulled up, and sideslipped to right and left.

First test series - main flight 1 in strong wind and moderate gusts.- Flight at high speed (between 180 and 160 km/h (112 and 99 mi./hr.) with throttle wide open and throttle closed and filmed at various times. It was found that the present moderate bumps had no visible effect on the direction of the air flow. The tail vibrations, if at all noticeable, were very minute.

First test series - main flight 2.- This flight was primarily devoted to investigating the effect of the slipstream on tail buffeting. Pictures were taken of the following flight attitudes (speed in km/h):

Flight attitude	Throttle setting	
	to cruising	to idling
Stall	85	95
Steep dive	175	-
Rapid pull-up at	125	120
Slow pull-up at	160	160
Right bank*	120	130
Side slip, right*	-	125
Landing	-	90

*The right bank was preferred because then the turbulence emanating from the fuselage was on the left side where the measurements were made.

Subsequent showing of the films and evaluation revealed that the interferences of the flow and thereby the tail vibrations in equal flight attitudes by idling are essentially stronger than by slightly throttled engine, according to which the slipstream diminishes the flow interference considerably. Complete stall was possible only by idling, otherwise the slipstream pushed the stalling angle upward.

In level flight at more than 100 km/h (62 mi./hr.) the threads lie quiet and straight in the air stream. A slight sideslip or bank merely alters the yaw of the threads. Smoke and aluminum foil left a smooth trace parallel to the threads. (See fig. 14, top.) Any flow interference set up by a sudden decrease in angle of attack, stalling, sideslip, or bank at large angle of yaw made the threads sway and undulate and eventually turn into violent whipping motion when the particular attitude was intensified. The ends then pointed toward the leading edge of the tail and somewhat above it. The smoke and the foil indicated a corresponding behavior. (See fig. 14, bottom.)

One sideslip to the right was unexpectedly followed by abnormally severe buffeting, which was audible in the cabin and very much felt on the control stick. The condition lasted only a short time, because the pilot immediately endeavored to regain normal attitude. The camera was quickly started and was able to record part of it. Subsequently it was repeatedly attempted to reproduce the same conditions again without success. From this fact it can be concluded that a very special set of conditions (of speed, slipstream, bumpiness, state of acceleration, yaw) must superimpose one another in a certain way before buffeting can be produced.

Second test series.- After the main flight 2 of the first series had shown conclusively that by slightly throttled engine the slipstream diminishes the flow interferences which cause tail vibration, the subsequent flights of this second series were made with idling engine. The optograph furnished the running record during the flights, while the scratch instruments were operated only for about 3 seconds each at the beginning of every new flight attitude. The behavior of the horizontal tail unit was checked in all flights of the second series by simultaneous observation of both stabilizer tips through the double mirror.

Second test series - main flights 3-5.- The airplane was stalled repeatedly, rapidly pulled up at different speeds and sideslipped right and left, at different speeds (with quick turns). The angles of yaw during sideslipping were greater than in the preceding flights.

d) Test data of principal flights.- Interpretation of slow-motion camera film (1, test series). The method is illustrated in Figure 15. The rotations of the wool threads serving as measure of the flow interference were accurately read on the scales α_1 and α_2 to within 1° . The obtained angles were referred to inclination $\alpha = 15^\circ$ which prevails in level flight.

Figure 16 is such a worked-up film strip, which had been taken during the violent buffeting in a side slip to the right. (See section c, main flight 2.) Maximum and minimum deflections are approximately 10 cm (3.94 in.) apart ("double amplitude"). In this attitude the movements of the wool threads also are strongest. In the first half second there is a distinct dependence of the tail amplitudes on the eddy motion. The time interval between observing an eddy at the test point and its arrival at the stabilizer within approximately 0.05 second is negligible. The probable coordination of the maximum deflections of the threads and the stabilizer has been indicated by connecting lines. The vibration frequency cannot be evaluated with any greater accuracy because of the uncertainty of the time scale (starting of motor driving the camera).

In stalled flight with open and closed throttle the recorded vibrations did not exceed 3.5 cm (1.38 in.) double amplitude. The amplitudes vary rapidly and irregularly, which is suggestive of irregular forces of excitation. This is also seen on the motions of the wool threads, which are neither indicative of constant intensity nor of definite eddy frequency.

Interpretation of optograph record (second test series).- Figures 18, 19, and 20 are small sections of optograms at reduced scale. In these charts the records of right and left stabilizer and air flow vibrations are synchronized and provided with a time scale. Thus the comparison of superposed points of the right and left stabilizer vibration record reveals whether it is a symmetrical vibration in bending or a vibration in torsion. Most vibrations are unsymmetrical or torsional vibrations about the longitudinal axis of the fuselage; still, vibrations in bending are not rare. (Fig. 18, before the 10th second, where the air flow on the right and left sides has become separated.) Only minor differences prevail between the vibration of the left stabilizer and the test point on the elevator (mostly phase displacements). No violent

buffeting on the control stick was noted during the recorded flight attitudes.

The double amplitudes were defined as difference of the maximum and minimum values of adjacent vibrations; 65 mm (2.56 in.) was the maximum double amplitude recorded in the second test series in one side slip prior to landing (unintentional movement).

All optograms of the left stabilizer vibration were examined for the appearance of rows of equally long vibrations (3 at least). For each of these vibration groups the mean frequency was computed by means of the time scale, and then the maximum double amplitude was measured. (See fig. 21.) Save for the omission of several scattered values enveloping curves were drawn on the three distinctly expressed resonance groups which correspond to the course of one resonance line. The three resonances, already familiar from the vibration tests in the hangar (fig. 11), are representative of:

- 1) Torsional vibration about the longitudinal axis (at approximately 7.1 s^{-1} compared to 7.45 s^{-1} in hangar test).
- 2) Torsional vibration about an inclined axis (at approximately 9.5 as against 9.75 s^{-1}).
- 3) Bending vibration of horizontal tail groups (at approximately 11.8 instead of 12.1 s^{-1}).

A control check revealed that the first two resonance groups are wholly unsymmetrical, the last group predominantly symmetrical.

In spite of the different respective flight speeds the complete test values were plotted together in Figure 21. Upon separation of the test values from the flying speeds it was found that the amplitudes increased slowly with speed, but did not reach their maximum at any given speed.

Then it was attempted to define the frequencies of the eddies coordinated to the recorded tail and amplitude frequencies. As Figures 18-20 reveal, the vibrations of the air flow are even more irregular than those of the tail. Consequently, the count of the eddies remains uncertain.

Against the obtained frequencies of the air flow we then plotted the maximum amplitudes of the tail excited at this frequency. (Fig. 12, left, for the first; right, for the third group.) The clusters were separated by a straight line through the utmost points. These straights reveal the rise in amplitude with the approach of the interference frequency to the tail frequency.

Excitation frequencies of less than 6 s^{-1} were not measured; the maximum frequencies ranged as high as 20 s^{-1} . While exploring the flow vibrations, it was found that the proximity of the slipstream exerted a significant effect. In level flight the frequency of the wind vanes on both sides was twice the propeller r.p.m., and during pull-up or sideslip the deflections of the prevalent regular vibrations increased at first by constant period, but later increased the period also by further amplification. As a result thereof the separation of the eddies appears, so long as it is inferior, to be guided by the two vortex trains of the slipstream, and this effect is still perceptible on the secondary vibrations even by great vortex intensity. According to this the propeller r.p.m. is an important requisite of the tests.

The shape of the enveloping curves in Figures 21 and 22 beyond 6 cm double amplitude is not known. Linearly extended, the enveloping curves for the first resonance in Figures 21 and 22 afforded a maximum double amplitude $a_{\text{max}}^I = 9 \text{ cm}$ (3.54 in.) approximately, and a mean resonance $a_{\text{max}}^{III} = 6.5 \text{ cm}$ (2.56 in.). These figures are only rough estimates. The value a_{max}^I was reached once and readily exceeded in flight 2 of the first test series, and was accompanied by unusual, violent buffeting, which could be felt in the cabin and on the control stick.

The scratch-elongation measurements on the stabilizer struts were accurately coordinated to the optographically recorded amplitudes of the stabilizer. (See fig. 20.) The detailed evaluation of the strut force measurements by means of "influence factors" from the static and dynamic tests in the hangar, which aim to approximately define the load distribution incurred during the vibrations, is too voluminous to be included in the present report.

e) Supplementary flights.- For comparison, we further made a number of observation flights with an F 13 fe, with two W 33 b and F 13 ke each and with an F 13 ge. These

airplanes were tested in stalled flight, banking and sideslip at speeds below cruising with different r.p.m. The observations can be summed up as follows:

The F 13 fe type buffets more violently and more readily than the other types when a critical attitude is reached. The effect of the angle of attack, angle of yaw and propeller r.p.m. is fundamentally the same for all types. The W 33 and the two F 13 ke differ very materially from one another. In spite of complete external agreement between the two F 13 ke, it was impossible to stall one like the other or to produce more severe buffeting. Even in other flight attitudes the horizontal tail unit of this airplane remained unusually calm. The vibrations were in all cases predominantly asymmetrical (observed by double mirror).

The amplitudes were simply estimated. By sideslip at 130 km/h (80.8 mi./hr.), the following maximum values were recorded:

F 13 fe	D 570	6-7 cm (2.36-2.76 in.)	} with D.V.L. tail
F 13 fe	D 212	5-6 cm (1.97-2.36 in.)	
F 13 ge	D 1563	3-4 cm (1.18-1.57 in.)	
F 13 ke	D 1850	2-3 cm (.79-1.18 in.)	
F 13 ke	D 1843	3-4 cm (1.18-1.57 in.)	
W 33b L	D 1724	5-6 cm (1.97-2.36 in.)	

When evaluating these figures the uncertainty of the observation as well as the diversity of flight attitudes should be borne in mind.

f) Calculation of stress in horizontal tail group in buffeting. - Most unfavorable stress of the F 13 fe (D 570). - In the following the maximum stresses of the stabilizer spar of the F 13 fe anticipated in level flight attitude are computed for the peak amplitude deduced from the reso-

nance curves of the flight tests. (See section d, page 14.) The static initial loading coordinated to the longitudinal moment equilibrium was disregarded.

Harmonic vibrations occurred rarely and the maximum amplitudes themselves may be forced deflections. For that reason it is essential to examine the two limits between which the true stresses should lie, when calculating the stresses pertaining to the maximum amplitudes:

- α) Removal from mid-position is caused by the acceleration forces of the vibrating tail masses corresponding to a free oscillation.
- β) Removal from mid-position is caused by air loads conformably to a single static load application.

To α) Dynamic loading.

The calculation of the dynamic loads $P = -m \frac{a}{2} v^2$ is carried through with the elastic curves of the dynamic hangar tests (fig. 12) with the following numerical values and the known mass distribution:

	Maximum amplitude a_{\max}	Frequency
Torsional vibration	$\frac{a_{\max}^I}{2} = 45 \text{ mm}$	7.5 s^{-1}
Bending vibration	$\frac{a_{\max}^{III}}{2} = 32.5 \text{ mm}$	11.85 s^{-1}

In the endangered section (0.99 m from center) the following moments, as compared with the static moment at failure $M_{st} = 398 \text{ m-kg}$ (2800 ft.-lb.) are obtained:

Torsional vibration $M_1 = 55 \text{ m-kg} = 0.14 M_{st}$

Bending vibration $M_3 = 105 \text{ m-kg} = 0.27 M_{st}$

To β) Static loading.

From the possible combinations of torsional vibration the investigation was limited to the most abnormal case of a one-sided loading which, moreover, is the most likely. For the bending vibration, symmetrical stress application is assumed.

Not knowing the actual load distribution, the two limiting cases of an isolated load P at the end section and of a uniformly distributed surface load p are examined. The calculation is carried out with the influence lines. (Fig. 4.) With a_{\max} in mm and the influence factors y in mm/kg and mm/kg/m² it affords:

For one-sided loading (torsion)	}	$P_1 = \frac{a_{\max}^I}{2 y_{10}} = \frac{90}{2 \times 0.656} = 68.7 \text{ kg}$
		$p_1 = \frac{a_{\max}^I}{2 y_{20}} = \frac{90}{2 \times 0.735} = 61.3 \text{ kg/m}^2$
For two-sided loading (symmetrical bending)	}	$P_2 = \frac{a_{\max}^{II}}{2 y_{11}} = \frac{65}{2 \times 0.500} = 65.0 \text{ kg}$
		$p_2 = \frac{a_{\max}^{II}}{2 y_{22}} = \frac{65}{2 \times 0.454} = 71.5 \text{ kg/m}^2$

With an area $F = 2.21 \text{ m}^2$ (23.8 sq.ft.) of the overhang and an 0.82 m (2.7 ft.) lever arm for p and a 1.70 m (5.58 ft.) lever arm for P the bending moments in the endangered section are:

For torsion	from	p_1	at	$M_1^I = 111 \text{ mkg}$	}	0.29 MSt
($a_{\max}^I = 90 \text{ mm}$)	"	p_1	"	$M_1^{III} = 117 \text{ "}$		
For bending	"	p_2	"	$M_2^I = 129 \text{ "}$	}	0.31 MSt
($a_{\max}^{II} = 65 \text{ mm}$)	"	p_2	"	$M_2^{III} = 110 \text{ "}$		
				mean	117 mkg	

The assumption of static or dynamic loading for symmetrical deflection thus signifies no essential differences in stress, whereas the stresses in a free torsional vibration are only half as high as in an identical amplitude forced by a one-sided static loading.

Summing up, it can be stated that under violent buffeting developed under the very abnormal conditions up to cruising speed, stresses as high as 30 per cent of the static breaking strength are not improbable on the F 13 fe D 570 stabilizer.

For rough comparison of the F 13 fe D 570 with D.V.L. tail and the F 13 ge, the very unfavorable assumption for

F 13 ge is made: that 0.99 m. away from the median section a 117 mkg bending moment can develop. Close examination shows that the respective tail amplitudes of the F 13 ge are but 80 per cent of those on the F 13 fe with D.V.L. tail. On account of the lighter gauge spar the stresses are nevertheless 10 per cent higher than on the F 13 fe with D.V.L. tail D 570.

In view of the more favorable shape of the new type F 13 ge (thicker chord) with raised trailing edge, longer body and thus improved directional stability and shifting of elevator toward the boundary of the eddy zone, the assumption that the extraneous forces attain the same magnitude as with the F 13 fe, is to be called very unfavorable.

5. Wind-Tunnel Tests

The English wind-tunnel tests* were made in a comparatively small tunnel (about 1.2 m (4 ft.) diameter). Because of the size of the model (scale 1:8.88) its wings had to be clipped. It was not anticipated that this would have any effect on the appearance of tail buffeting, although it would have some effect on the angles of attack at which buffeting begins, because the prevention of the lateral circulation around the wing tips implies, so to say, reestablishment of the plane problem and therewith change in direction of the downwash on the tail. Also, in the English tests the propeller is absent and the conjecture was near at hand that the effect of the slipstream on the appearance of buffeting is considerable. Besides, there is hardly any doubt that at the moment of the accident the propeller speed was that for cruising, if not for full throttle. The English model, which corresponded to the F 13 fe instead of the F 13 ge, did not have the raised trailing edge like the crashed one had (compare figs. 3a and 3c), which was to effect a diminution of tail buffeting.

*See reference 1, appendix 21, page 79: Flutter and Buffeting of a Model Tail of Junkers Monoplane G-AAZK.

b) Test procedure.— These tests were carried out in the wind tunnel of the Zeppelin airship company, Friedrichshafen. The 2.9 m (9.5 ft.) diameter of the experiment section made it possible to mount the 1:10 scale models readily. The following three models were tested:

Model A: Junkers F 13 fe with D.V.L. tail (like the one used in the flight tests).

Model B: Junkers F 13 ge with original wing (like the one used in the English wind-tunnel tests).

Model C: Junkers F 13 ge with modified wing (as in the crashed airplane).

As in the English experiments, the complete tail was elastically similar to the actual tail unit. Bending of overhanging part of stabilizer and torsion of rear fuselage were considered as essential degrees of freedom for tail buffeting. The experimentally defined deflections and vibration frequencies on the actual airplane (see sections 2 and 3) and on the model yielded as model scale for the speed 1:10. As a result the experiments had to be made at very low speeds which, in view of the Reynolds Number, is very regrettable, but the same difficulty existed in the English experiments.

The models were suspended as usual by wires. (See figs. 24 and 25.) The entire suspension was accomplished on the outer parts of the wings, thus precluding any danger of eddies, set up by the suspension, affecting the tail buffeting. The rear fuselage with the tail was filmed by slow-motion cinematographic camera (approximately 80 exposures per second). A very small lamp in the fuselage insured an accurate time record; the lamp flashed regularly every 1/4 second. Each vibration attitude was filmed 3 seconds, in exceptional cases longer. The interpretation comprised ordinarily the middle 240 pictures of each exposure.

Each model was tested at different angles of attack, different speeds, and with and without slipstream. A few experiments were made under altered elastic conditions.

c) Interpretation and results.— The pictures revealed the bending vibration in the overhang of the left horizontal tail unit very accurately, the torsional vibration of the rear fuselage less accurately. Upon examination it

was found that the amplitudes on the right side assume approximately the same magnitude as those on the left, although the motions are in nowise always symmetrical. At many points the pictures are suggestive of beats; this may be due to the mutual interference of the two halves of the tail, whose natural frequencies perhaps exhibit minor discrepancies from one another.

From the 130 interpreted film records contained in the complete report, several are shown in Figure 23. They exhibit the type of buffeting vibrations very similar to those in the flight test. (Compare fig. 16.) One notes how the amplitudes increase with the angle of attack and how the amplitudes fall off because of the slipstream. The latter acts favorably in all cases, and palpably so in the ambit of angle of attack within which it can prevent the separation of flow in the wing center. (Compare figs. 24 and 25.) This result is in accord with the flight tests. (Compare section 4.)

In some tests the buffeting suddenly changed its amplitude at irregular intervals, without leaving a trace as to the cause of this behavior. But inasmuch as this occurred in very few instances and then only at certain angles of attack, it is not to be assumed that it can be explained as wind-tunnel interference.

The discrepancies in the results are not very pronounced for the different models. In model A (F 13 fe) buffeting began at slightly smaller angles than in models B and C (F 13 ge); this is probably where the effect of the shorter body of the F 13 fe comes into play. Still it is surprising that the difference is not large except in the measurements with slipstream. Raising the middle of the trailing edge of the wing is of no advantage in the model test in contrast to the flight tests, as seen when comparing the results on models B and C. Here also is a wide divergence in the measurements with and without slipstream.

A particularly clear view of the test data for models A, B, and C is afforded in Figure 26, which depicts the difference Δy of the maximum positive and maximum negative deflection formed from each vibration curve. These values are entered in a field whose one coordinate denotes the wind velocity and the other the angle of attack. On the plotted curves $\Delta y = \text{constant}$ (and specifically = 5, 9, 13 and 17 mm (.2, .35, .51 and .67 in.)). It is not al-

ways easy to draw the curves unobjectionably through the plotted figures. This applies, in particular, to the points where double measurements with varying results are available. Nevertheless, it is hardly likely that the curves could be plotted any other way. For that reason, it is all the more remarkable that the results of the English tests do not agree at all with the German test data. The English results, conformably to Figure 24 of their report, have been appended in Figure 26 (model B without slipstream). In the range, where consistent violent buffeting occurs according to the English tests, our records revealed altogether very minor amplitudes, or were not photographed at all because of the smallness of the amplitudes.

It is impossible to say summarily to what the difference between the English and German results can be ascribed. It may be that the truncated wing tips in the English tests are responsible for part of it. The English curves are plotted for 0 to 5° angle of yaw, the German curves, without exception, for 0° yaw. At any rate, extreme caution must be exercised when applying these data to the accident. It requires more experiments to clear up these differences. The effect of the Reynolds Number should also be investigated. Besides, it does not appear admissible to us to apply the amplitudes of tail buffeting observed by model test summarily to the full-size airplane as the English report does. Aside from the Reynolds Number, it should be borne in mind that the amplitudes can be materially affected by the elastic damping, which was left out of consideration when the models were made.

The wind-tunnel data without slipstream (see fig. 26) intimate the presence of resonance, and this impression is greatly strengthened when evaluating the tests with changed elastic conditions of the tail. Unfortunately, it was impossible to carry out more than a few isolated experiments in this direction. At angle of attack approaching breakaway and a certain speed, the frequency of the eddies in the wake of the wing probably coincides with the natural frequency of the stabilizer. A cursory estimation of the eddy frequency (conformably to the theory of the Karman vortex street (reference 3) and according to more recent experiments (reference 4) on vortices behind wings) confirms the feasibility of this case. Only one footnote in the English report points out that the amplitudes of tail buffeting could be amplified by resonance. But in the

tests, ostensibly no case of resonance occurred. Here also further experimentation is necessary in order to gain a clear insight into these matters.

To apply the German model tests to the accident, the curves for model C with slipstream (fig. 26) must be substituted for the English curves (model B without slipstream). It becomes apparent from the first glance that the probability of the English explanation of the accident has become very much less.

IV. RECAPITULATION OF GERMAN TEST DATA

Static and Dynamic Tests on F 13 Tail

1. The most unfavorable section of the F 13 stabilizer spars lies outside of the point of application of the strut. The experimental breaking stress of the duralumin spars is 35 kg/mm^2 (49780 lb./sq.in.).

2. The dynamic destruction of the F 13 ge horizontal tail unit occurred at $n = 11.8 \text{ s}^{-1}$ (Hertz) natural frequency and 12.5 cm (4.92 in.) double amplitude at the stabilizer tip after 300 vibrations. The bending moment causing failure is 85 per cent of the static bending moment producing failure.

3. The dynamic destruction test merely led to tension failure in the main spars. The natural frequency of the stabilizer falls off considerably after dynamic failure to the point where resonance no longer occurs.

4. Because of the metal skin the stabilizer is very rugged, the static breaking strength of the stabilizer with broken spar is still 60 per cent of the original.

5. In the fatigue test on an F 13 ge tail, an alternating bending moment of $\pm 74 \text{ m-kg}$ (535 ft.-lb.), or 24 per cent of the static breaking moment produced breakage only after 700,000 stress reversals.

Vibration Tests with D 570 (F 13 fe) Airplane in Hangar

6. The rear fuselage with tail showed a number of resonances ranging from 6 to 16 Hertz. The most significant of these vibrations were:

- a) Torsional vibration about the longitudinal axis at 7.45 Hertz.
- b) Torsional vibration about an oblique axis at 9.75 Hertz.
- c) Symmetrical, vertical vibration in bending at 12.1 Hertz.

7. The bracing between fin tip and stabilizer tip scarcely shifted the first two resonances; at the first resonance the amplitudes fell off slightly, at the second, considerably; the third resonance was practically eliminated by the bracing.

8. Experiments with loose, damping bracing revealed vibration properties midway between those of the free and the rigidly braced tail.

Flight Tests with D 570 (F 13 fe) Airplane

9. At large angles of attack and of side slip the tail is struck by vortices shed by the center section of the wing.

10. The vortices develop at large angles of attack on both sides of the fuselage (but not symmetrical) and by yawing (in sideslip and banking) on the side of the fuselage opposite to the angle of yaw.

11. The vortices grow with angle of attack and yaw, because of the consistent spreading of the interference existing on the top side of the wing close to the body wall.

12. The vortex intensity could not be determined numerically, but the angular changes of the wool threads and wind vanes caused by an eddy attained occasionally the order of magnitude of 90° .

13. The eddy frequency was very irregular; those observed range between 6 and 20 Hertz. No systematic relation with the flying speed could be ascertained.

14. The slipstream lowers the flow interference materially. The two vortex layers of the slipstream guide the eddy separation at the inception of the disturbance and induce at first an eddy frequency equivalent to twice the propeller speed.

15. The multiple dependence of the vortex formation on the angle of attack of the airplane against the air stream, on the flight speed, engine r.p.m., and on the structure of the atmosphere, renders systematic test flights very difficult and contains the possibility of accidental, particularly unfavorable combinations, which do not yield very readily to experimental treatment. Only in one case (main flight 2) were such extremely unfavorable conditions obtainable.

16. Tail buffeting occurs in all flight attitudes in which vortices are shed by the wing roots.

17. The vibrations are irregular in amplitude and frequency. Speeding up to high amplitudes during one series of vibrations is rare, although high amplitudes are frequently to be found as individual vibrations or of almost constant magnitude in a short series.

18. The frequencies lie within the range of the natural vibrations of the first three dynamic tests in the hangar. The frequency of the first torsional vibration is more frequently encountered. Comparison of the vibrations of both stabilizer halves reveals dissymmetry at the frequency of the torsional vibrations, and symmetry at the frequency of bending vibrations.

19. The recorded amplitudes, plotted against the corresponding frequencies, show the three resonances, known from the hangar tests, very clearly.

20. The amplitudes slowly increase with the flight speed; they become maximum at no given speed.

21. The eddy frequency is ordinarily greater than the frequency of the tail vibration excited thereby. The possibility of exciting high amplitudes increases with increasing correspondence of frequencies.

22. Extrapolation from the test data revealed for cruising speed with throttled engine the double amplitudes $a_{\max}^I = 9$ cm (3.54 in.) approximately (torsional vibration) and $a_{\max}^{III} = 6.5$ cm (2.56 in.) (symmetrical vibration in bending) anticipated in the most unfavorable case with the F 13 fe D 570 airplane. These are rough estimates. In one case we recorded a torsional vibration of 10 cm amplitude. This was a limiting case, which subsequent attempts failed to repeat.

23. According to calculation the stress of the stabilizer spar was about 30 per cent of the static breaking strength at the double amplitudes of 9 and 6.5 cm for the F 13 fe.

Comparative Flights with F 13 ge, F 13 ke
and W 33 Airplane

24. The F 13 fe type used in these tests evinced more violent buffeting and greater susceptibility than the other F 13 types, once a critical attitude was reached.

25. A rough comparative calculation revealed stresses of around 34 per cent of the static breaking strength in the F 13 ge tail in the most unfavorable case by equivalent extraneous forces. The amplitudes are approximately 20 per cent lower than for the F 13 fe (D 570) tail.

Wind-Tunnel Experiments

26. At certain angles of attack the models of the F 13 fe and F 13 ge developed tail buffeting, and

27. at somewhat smaller angles on the F 13 fe model than on the F 13 ge (effect of shorter body of the F 13 fe), particularly during the measurements with slipstream.

28. Raising the middle of the trailing edge of the wing has no material effect on the occurrence of tail buffeting.

29. The slipstream acts favorably in all cases. With propeller running (especially at low speeds) tail buffeting is shifted toward higher angles of attack, although this effect varies in the different models and defies explanation. On the other hand, it should be borne in mind that these results as well as those enumerated under paragraphs 26-28, are presumably materially affected by the Reynolds Number and should not, for that reason, be applied to the actual airplane without serious considerations.

30. Resonance between the eddy frequency in the eddies in rear of the wing and the natural frequency of the stabilizer amplifies tail buffeting considerably.

31. Our data here are at variance with the English measurements, and no satisfactory explanation of the dis-

crepancies can be given at this time.

32. For this reason and in view of the low Reynolds Number of the model test it appears advisable to apply the model test data for the present only qualitatively.

33. Allowing for the fact that the propeller was probably running at the time of the accident, it throws considerable doubt on the probability of the English theory of tail buffeting as the primary cause of the crash.

V. CONCLUSION

In connection with the English inquiry into the air crash of the Junkers F 13 at Meopham (reference 1), Germany also made an exhaustive study of this accident. It comprised static and dynamic strength tests, flight tests and wind-tunnel experiments, as elucidated in chapter IV.

Based upon this investigation, the English theory loses much on its probability (stabilizer failure resulting from buffeting as primary cause). In particular, it may be stated in this respect that:

The tail stress, given at the end of chapter III, 4, which cannot cause static failure, must already be looked upon as being extremely rare for normal operation. While this does not mean that a stress of the order of the static breaking load is entirely ruled out as an explanation, its occurrence is possible only by a catastrophic combination of abnormal conditions at high flight speed.

A pull-out at high speed would have to be accompanied by a vertical gust, or a side slip while out of sight of the ground, would have to concur with a lateral gust of such intensity that the angle of stall or yaw is exceeded, at which violent tail buffeting is produced. The appearance of one of these cases or their superposition by high cruising speed need not immediately spell danger; very likely it must be concomitant with an expressed resonance of tail vibrations and eddy frequency in order to speed the amplitudes to breakage. In order to exceed the critical angle of attack so that the flow separates at the wing root, while cruising at 180 km/h (112 mi./hr.), it would necessitate a vertical gust w (whose effect is lowered by a factor η through the time rate of change

of flow) of $\eta w \sim 10$ m/s (32.8 ft./sec.). The requisite effective gust intensity increases about linearly with the speed, but decreases conformably to the setting of the airplane during pull-up. The effective period of the gust would have to be sufficiently long in order to lead to a complete development of vortex separation.

So, while it is still possible that the Meopham air crash was due to such a catastrophic case, in view of the fact that the accident occurred in very bumpy air when flying through a cloud and the airplane was not equipped with blind flying instruments, its occurrence is nevertheless so unlikely that in the present state of the technique it cannot, and need not, be designed for. Moreover, several hundred airplanes of the F 13 type have been in operation for years without any similar mishap.

The other theory advanced, that the wing broke first as the result of a violent gust or a too rapid pull-up out of an unintentional glide and that elevator and stabilizer broke afterward, is just as feasible, particularly since English experiences were confined to biplanes only. Reaching the stalling angle at around 215 km/h (134 mi./hr.), the wing is stressed to breaking limit. The limit up to which the present state of the technique must provide for the occurrence of such wing breakages, was discussed during the last conference of the German Aircraft Committee.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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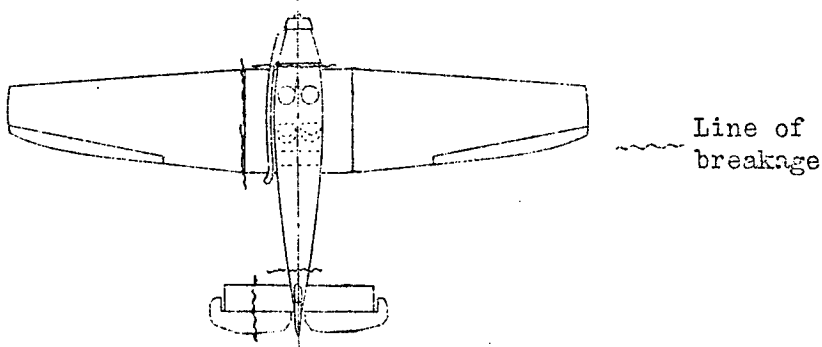


Fig. 1 Principal points of breakage of Junkers F13ge crashed at Meopham.

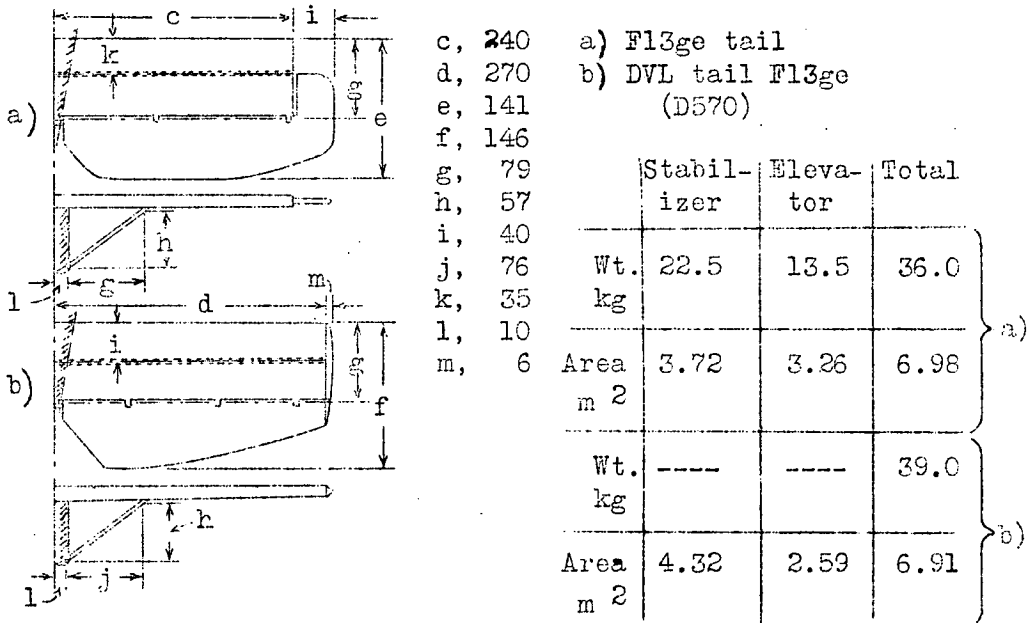


Fig. 2 General dimensions of Junkers F13 tail units.

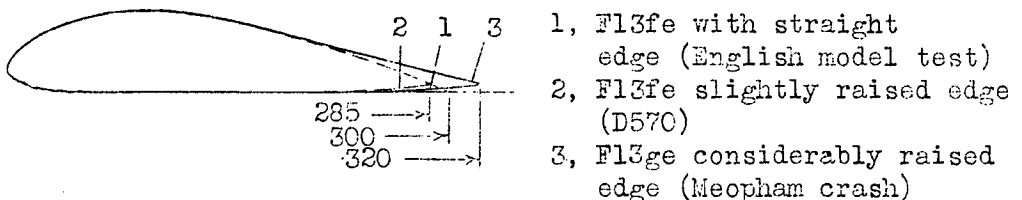


Fig. 3. Wing trailing edge near the fuselage.

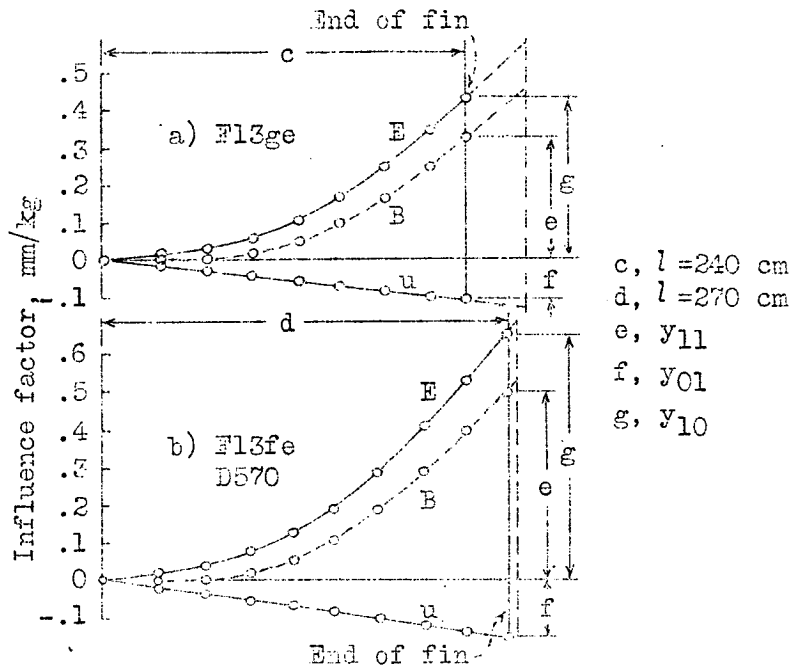


Fig. 4 Elasticity test with horizontal tail units.

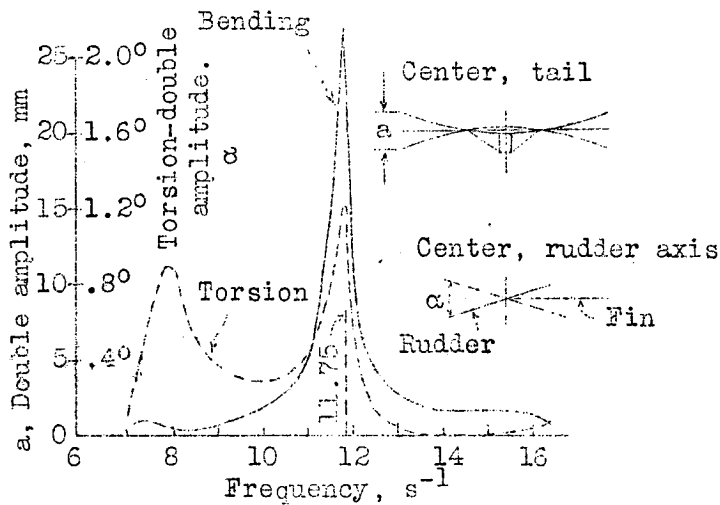


Fig. 7 F13ge horizontal tail group, resonance curve of the stabilizer and elevator vibrations.

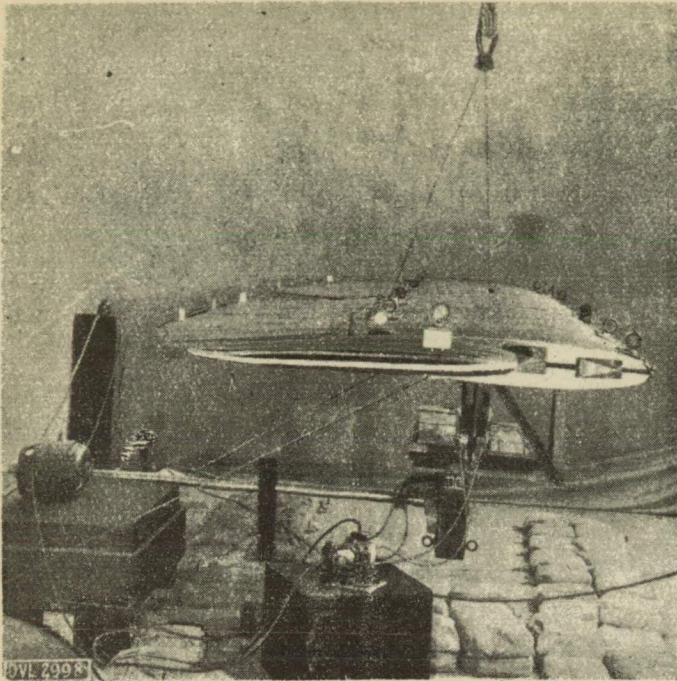


Fig. 5 Dynamic breaking test of F 13ge horizontal tail unit, elastically suspended with double unbalance.

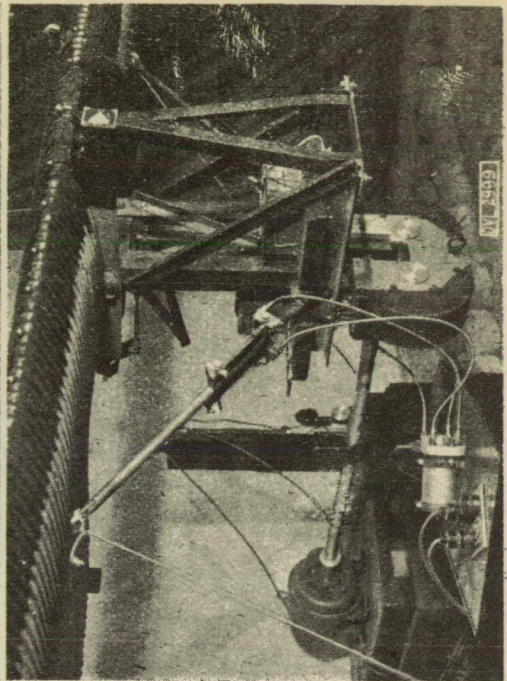


Fig. 6 Dynamic breaking test of F 13ge horizontal tail unit. Fuselage make-up with reduced air-lead plates (reduced air-plane mass). Double unbalance with drive from D.C. motor. Scratch elongation recorder mounted on struts.

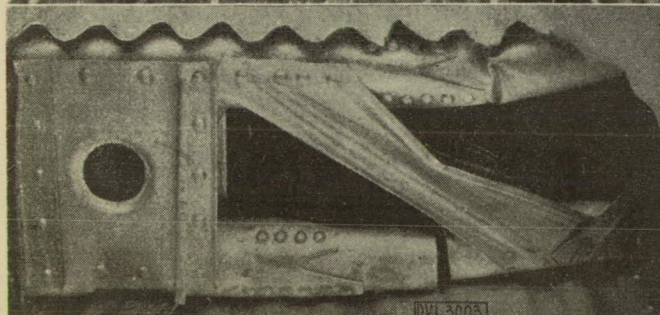
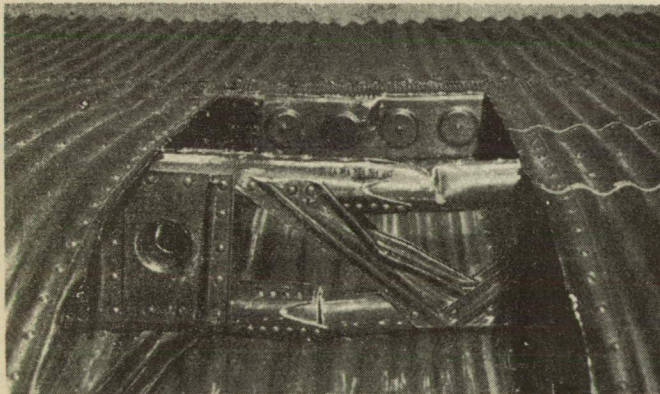


Fig. 10 Spar breakage. Top, dynamic and succeeding static breaking test of F 13ge tail. Bottom, purely static failure.

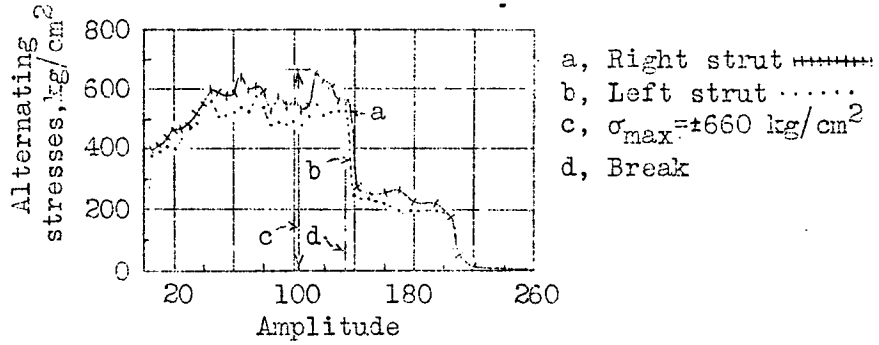


Fig. 8 Dynamic breaking test with Fl3ge tail. Alternating stress recorded in the tail struts.

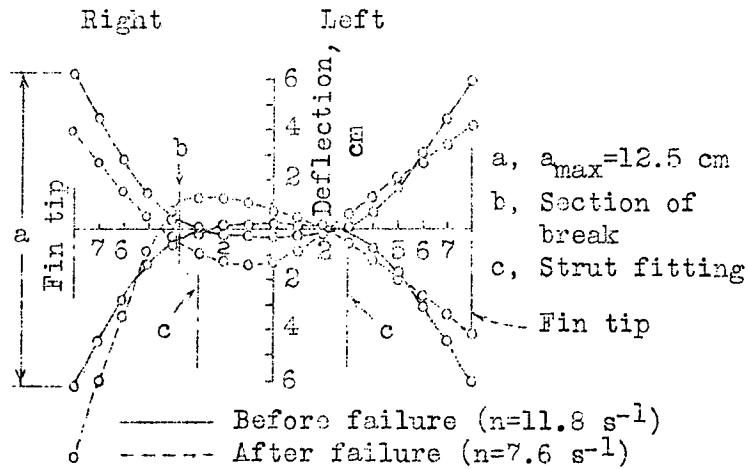
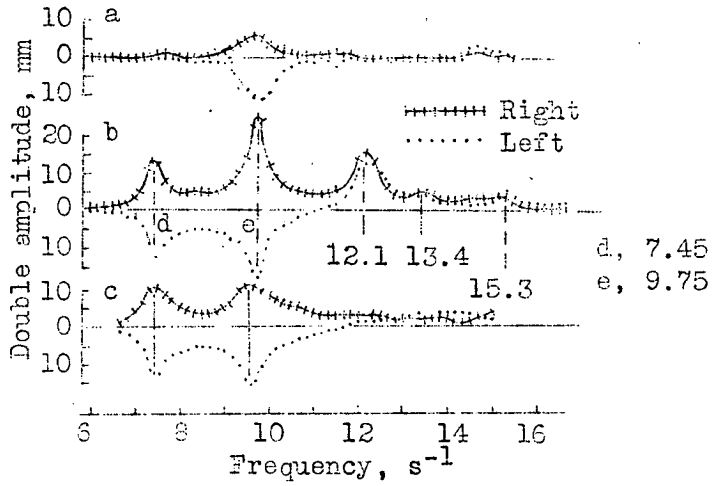


Fig. 9 Dynamic breaking test with Fl3ge tail, dynamic elastic curves before and after failure.



- a, Horizontal vibrations (tail not braced)
- b, Vertical vibrations " " "
- c, " " (bracing between stabilizer and fin.)

Fig. 11 Buffeting test with complete F13fe airplane in hangar; resonance curves for horizontal tail unit recorder at stabilizer tips.

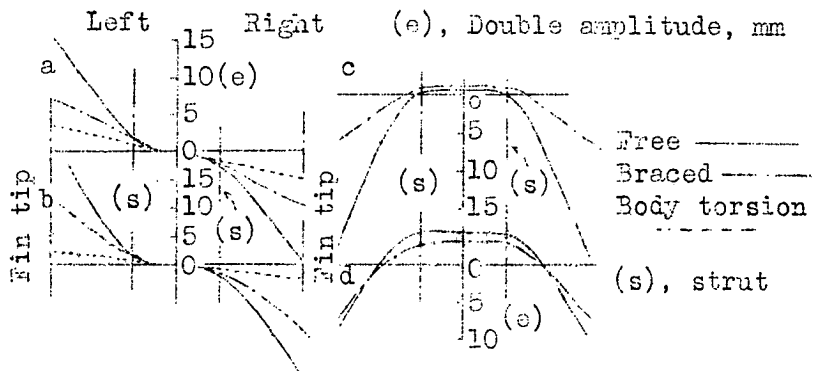
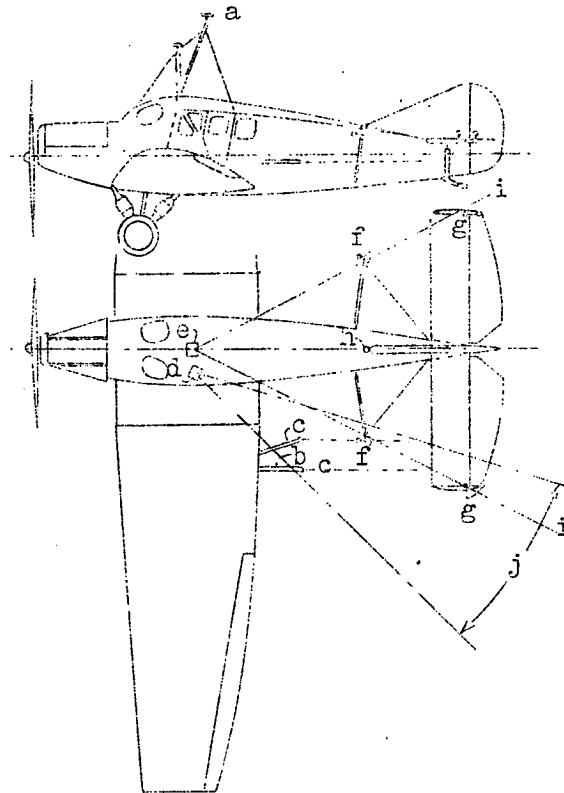


Fig. 12 Buffeting test with complete F13fe airplane in hangar; resonance elastic curves.



I test series

- a, Pitot tube
- b, Spray tube
- c, Woolen threads
- d, Slow-motion camera

II test series

- e, Optograph
- f, Balanced vanes
- g, Lamp
- h, Lamp
- i, Visual rays of optograph
- j, Angle of image of slow motion camera

Fig.13 Set-up for flight tests.

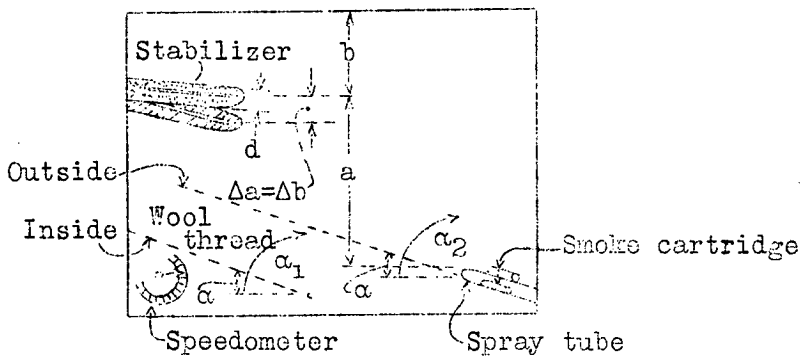


Fig.15 Film record of flow and stabilizer vibration(see fig.14). Sketch for interpreting films.

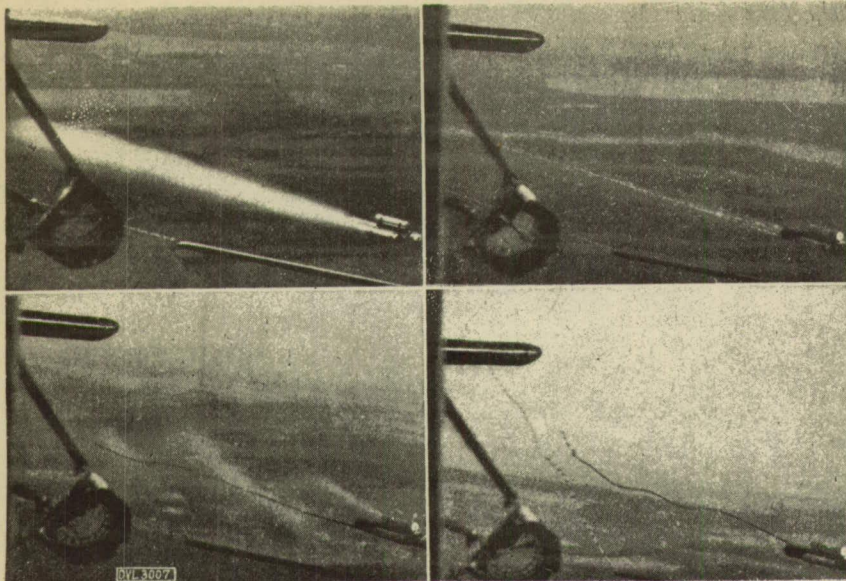


Fig.14

Flow pattern with smoke, wool threads and foil. Top, Undisturbed level flight.

Left, Wool threads and smoke at 140 km/h speed. Bottom, Stall. Left, Stalled glide, speed 90 km/h. Right, Stalled side slip, speed 120 km/h.

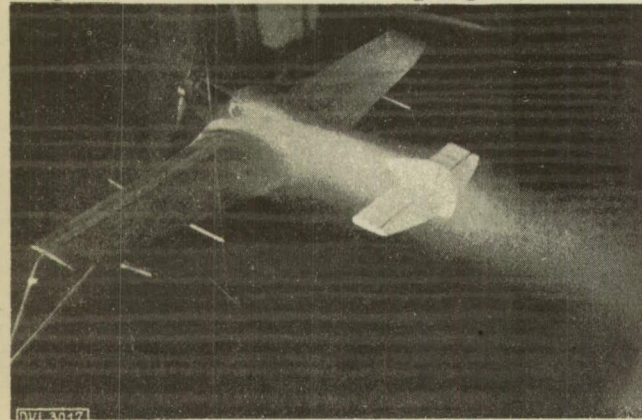


Fig.24

Smoke picture of flow past Model A at 12° angle of attack. The propeller

is not running, the blurred edge of the tail shows that the latter is buffeting.

Fig.25

Model A under identical conditions as in Fig. 24, with propeller running ($n = 1450$ r.p.m.) Now the edge is quiet. Note also the difference in flow. The angle of downwash is greater with propeller running than with propeller locked.

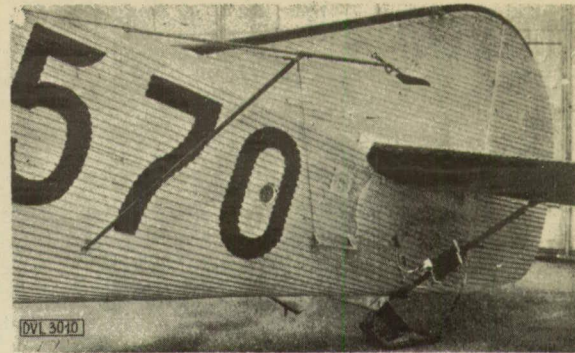
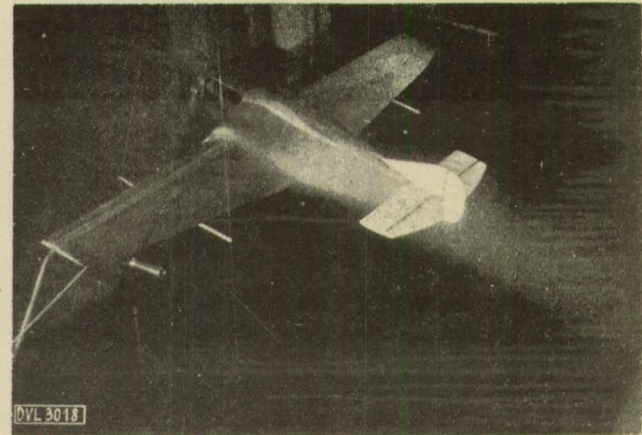


Fig.17 Streamer with lamp at stabilizer struts, recorded by scratch elongation recorder and optograph.

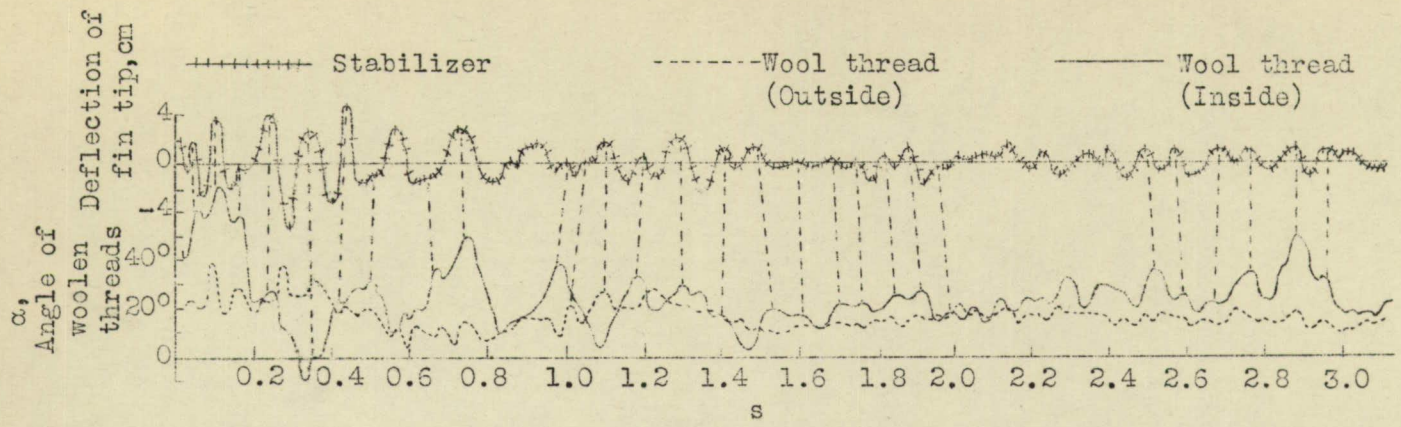


Fig.16 Vibration of stabilizer tip and of the wool threads in side slip; speed 125 km/h . Evaluation of film according to figure 15.

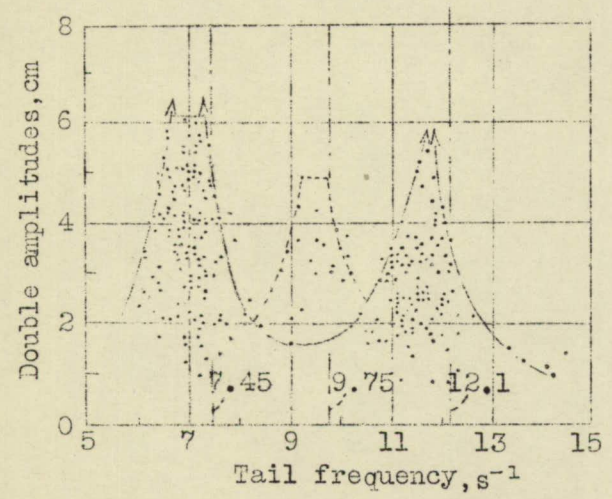


Fig.21 Tail amplitudes plotted against frequency.

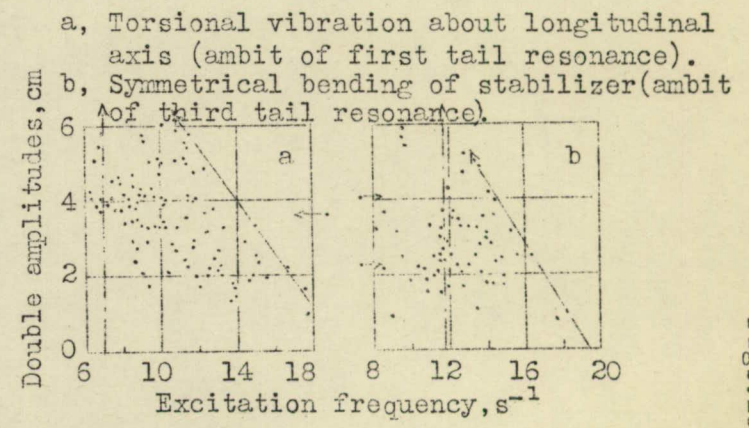


Fig.22 Tail amplitudes plotted against excitation frequency (flow).
 a, Torsional vibration about longitudinal axis (amplitude of first tail resonance).
 b, Symmetrical bending of stabilizer (amplitude of third tail resonance).

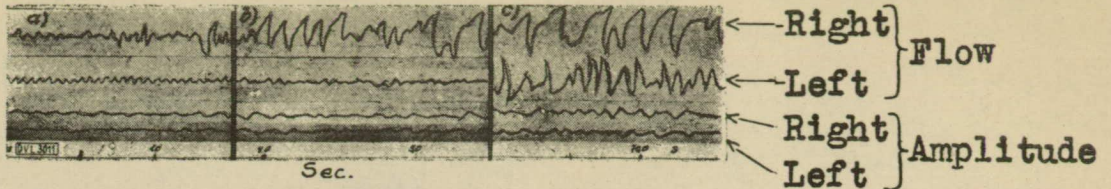


Fig. 18 Optogram of stabilizer and flow vibration. Taken during levelling off prior to landing. (Film section)

Left, flow separates at right side.

Middle, " has separated at right side only.

Right, " " " " " and left side.

Side slip to left, 140 km/h (87 mi./hr.)

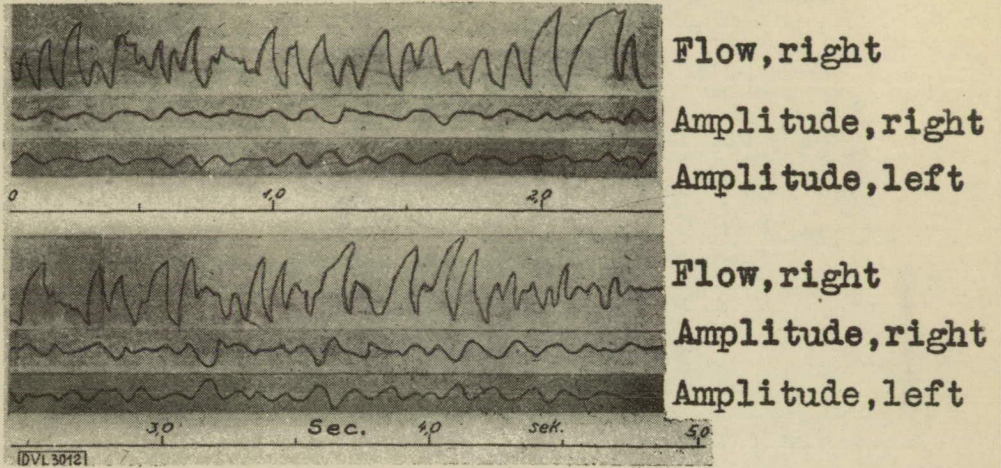


Fig. 19 Optogram of stabilizer vibration and flow. Exposure during side slip to left.

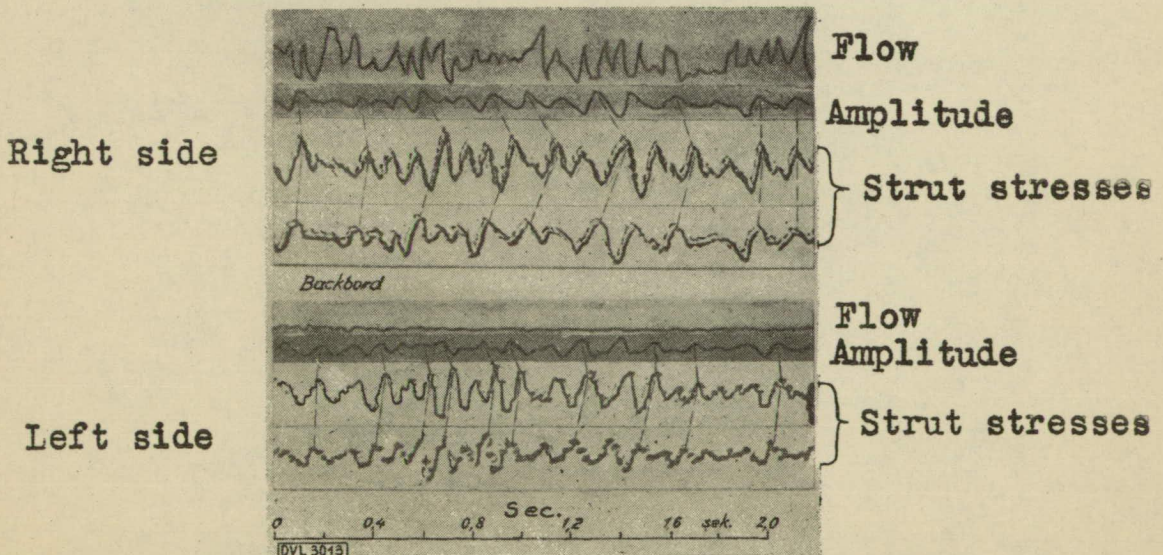


Fig. 20 Synchronization of vibration of stabilizer, air flow and strut stresses from optogram and scratch record.

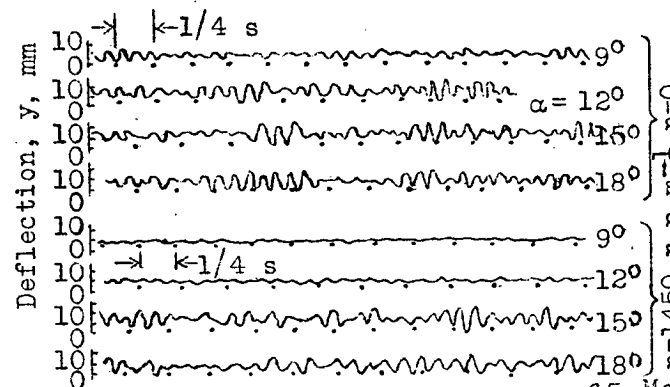


Fig. 23 Vibration curves of edge of model C tail in wind tunnel at different angles of attack, wind velocities 4.1 m/s ($n = \text{r.p.m. of model propeller}$). The dots below the curves denote the flashes of the small bulb in 1/4 second intervals.

----- Consistently severe } English tests.*
 ————— Occasionally " }

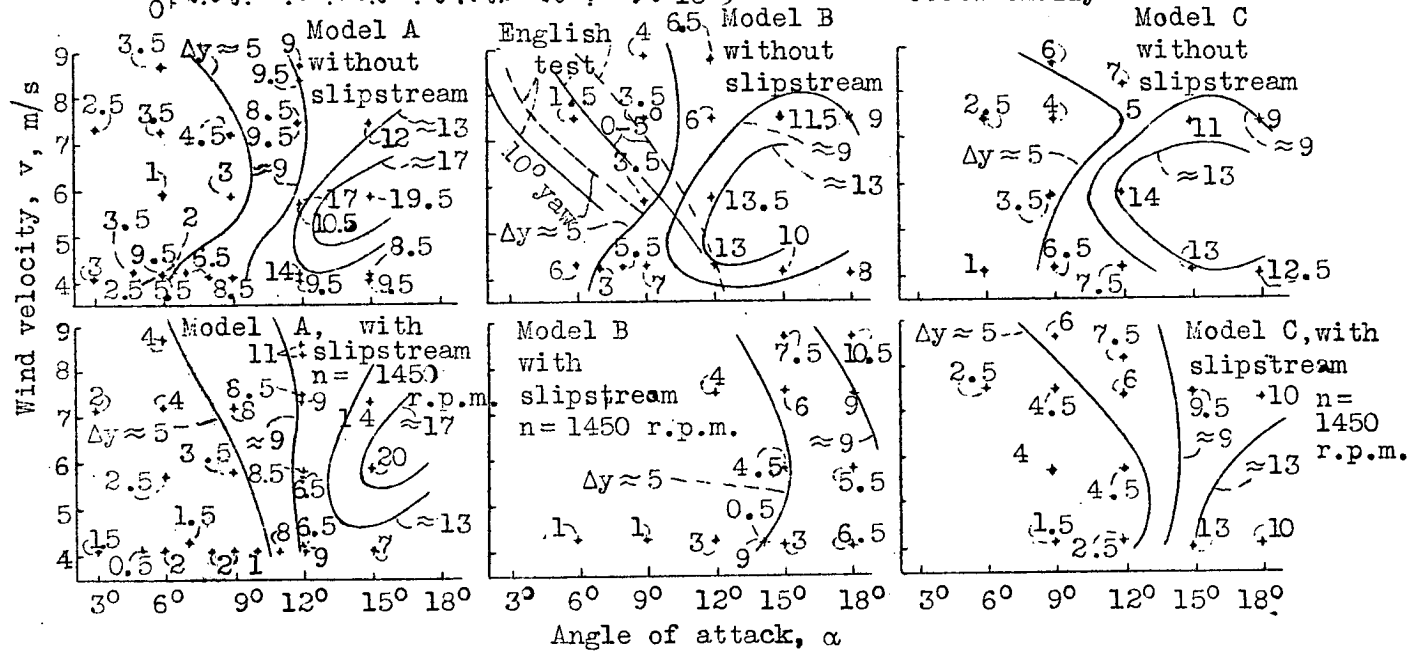


Fig. 26 The Δy (in mm) is plotted at every point in the $v-\alpha$ -field, which corresponds to one measurement. The curves are for $\Delta y = \text{const.}$ (and = 5, 9, 13 and 17 mm). The slipstream effect as well as the discrepancy between the English and German measurement becomes readily apparent. The shape of the curves for the measurements without slipstream are suggestive of falling off of resonance. * 0-5° yaw, English tests, added from Z.F.M. Feb. 15, 1932, p 199.