TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 359

FLIGHT TESTS ON AIRPLANES

By Heinrich Koppe

From "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft fur Luftfahrt," July, 1925

Washington
April, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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FLIGHT TESTS ON AIRPLANES.*

By Heinrich Koppe.

No one nowadays undertakes to build an airplane or airship without careful preliminary calculations and practical tests with models. Unfortunately, experiments seldom have been performed on the finished aircraft themselves, for verifying the results of such preliminary work. This is due partly to a fundamental aversion to such experiments and partly to fear of the difficulties and cost, as also to a certain mistrust of the reliability of results obtained on aircraft.

If I succeed in dissipating some of these apprehensions and prejudices, the object of my lecture will be accomplished. In order, however, not to raise your expectations too high, I should remark in advance that there is nothing fundamentally new about my experiments. I am prompted to make this report to you on the experiments I performed as a coworker with the "Deutsche Versuchsanstalt für Luftfahrt," only by the hope of being able to present methods for making flight tests on airplanes in a new, practical form.

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* From "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt" (A supplement to "Zeitschrift für Flugtechnik und Motorluftschiffahrt"), July, 1925, pp. 38-47.

Referring to the statements of the preceding speaker,* I will first comment briefly on the experiments performed in Copenhagen on the Rohrbach all-metal boat seaplane Ro II 1 (Fig. 1). I do so, because in these experiments, there was such excellent cooperation of theoreticians and practicians, of designers and constructors, and of aviators and scientific observers (or "instrument doctors" as they are sometimes jestingly called) and, furthermore, because the results obtained in the numerous flights furnished the real reason and ground for further practical and theoretical conclusions.

Since the Rohrbach metal airplanes are built on a rather large scale, even as regards the space arrangement, it is allowable for the scientific observer to be bold and demand the best place for himself and his numerous instruments. This is doubtless the front end of the fuselage with the front window (Fig. 2). From this vantage point, the whole airplane can be readily seen and it is easy to communicate with the pilot. This position is also nearest to the undisturbed air flow. With the help of a wooden frame, a "flying laboratory" was installed to fit the available space (Fig. 3). Naturally, everything was measured, observed and plotted, that could be learned from the instruments or by personal observation. Special importance was attached to the determination of flight character-

* Adolf Rohrbach, "Neue Erfahrungen mit Grossflugzeugen," Jahrbuch der W.G.L., 1924, pp. 29-37. See also N.A.C.A. Technical Memorandum No. 353.

istics, a fact which I wish to call attention to, because even in testing new models, the flight characteristics have unfortunately been too much neglected in comparison with pure flight performances.

In the first flights, the rudder deflections were recorded with the aid of a special mechanism which was provided with the rapid works of a talking machine (Fig. 4). The recording levers were connected by rods and lines with the steering controls and adjusted so as to utilize, as nearly as possible, the full width of the available 70 cm (27.6 in.) paper. Of especial importance was the recording of the rudder deflections in flight with shifted vertical tail planes and with only one engine running. Fig. 5 gives the records of two short flights. In all the flights, the starting and landing deflections of the rudders were almost identical.

The measurements included the pressure and temperature of the air (in order to find its density), the dynamic or negative pressure, the flight position, vertical acceleration, flight path, climbing speed and ground speed. Of course, the power plant was under constant observation. Most of the instruments were self-recording, so they needed only to be watched and simply verified. Thus, time was gained for personal observations.

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The results obtained in the 70-odd experimental flights with the Ro II 1 can be reported here only in so far as they are of general interest and have to do with subsequent discussions. Moreover, for lack of time, I must restrict myself to simple flight performances, involving air density, climbing speed, dynamic pressure and angle of attack with the same weight, the same driving gear and wide-open throttle.

Whenever feasible, some experienced aeronautic scientific observer should accompany all experimental flights. He must be familiar with the airplane on the ground and in the air, before beginning the real experiments, and even then, after fifty or a hundred flights, he will learn something new about his airplane. He must let nothing escape his attention regarding the start, landing and flight characteristics of his airplane. The observer can be of little use, however, if he is shut in a cabin where he cannot see much. His location must be such that he can readily observe the airplane and its position in space, install his instruments systematically, that he can communicate easily with the pilot and, if possible, be able to observe the pilot's instruments also. The observer must theoretically pilot the airplane himself, but only theoretically, even if he is actually able or thinks he is able to do it. He may advise, but not act. His advice will be all the more valuable, the better he theoretically pilots the airplane. To accomplish the best results, the pilot and observer must work in perfect harmony, at least during the test flights, because intelligent cooperation between them is the first essential of success.

The instruments should be placed, so far as possible, inside the fuselage, in order to reduce the air resistance, and they should be easily accessible during flight. There should be as many self-recording instruments as possible. The most skillful observer misses details which can thus be recorded and subsequently evaluated at leisure. Rapidly revolving drums are very useful for investigating special flight conditions. In special instances the revolution time of the drum is adapted to the duration of the flight, or even the flight duration to the revolution time. It is very important for all recording instruments to have accurate time marks for the subsequent comparison of corresponding values. It has been found that clockworks often run unevenly under the influence of the vibrations and variations in the temperature and density of the air. A soot-covered drum has proved the best for fine records. I would therefore recommend it for all airplane records. The use of soot is a "black art," which is easily mastered by any one. Soot records have the further advantage of yielding their numerical data only to the informed and of betraying nothing to the uninformed. Lastly, soot records, like photographic films, can be used to make additional copies.

No test flight should be made without previous careful weighing or the possession of the requisite data for an accurate calculation of the flying weight. In this connection, mistakes are easily made, which subsequently appear as very vexatious sins of omission. It is not always possible to weigh an airplane before each flight. It is then advisable to empty the fuel tanks completely and fill them anew. Any calibration of a flat tank for large quantities of fuel is usually very unreliable. There is no use in calculating flight performances to within 2%, when there is an error of 5-10% in the flying weight.

All flight performances and some of the flight characteristics are related to the density of the atmosphere. An air-density recorder was the object of the contest for the Rumpler prize (Koppe, "Ueber den Rumplerpreis," Z.F.M. 1922, p.33 ff). Unfortunately, we do not yet have any simple utilizable instrument of this kind. The air density is, therefore, still computed from the barometric pressure and the temperature of the air.

In most cases, the pressure-gauges can be harmlessly installed inside the fuselage. The effect of the temperature is sufficiently counteracted in good altimeters and barographs. Great care must be taken to avoid pressure disturbances from air eddies inside the fuselage. This danger is especially great in boat seaplanes, due to the one-sided closing of the hull. The pressure disturbance can amount to as much as 2 mm (0.08 in.) of mercury.

A simple and sure means for confirming and eliminating such disturbances is the static sounder (Fig. 6). This is a stable body, towed far below the airplane, which has on the sides of its tubular head, slots or holes like a Pitot tube.

The undisturbed static pressure is transmitted through a rubber tube to the pressure-gauges in the fuselage. The utilization of a static sounder of sufficient weight occasions no difficulty, as it holds perfectly steady during flight. For simple altitude measurements, the static pressure equalization can often be dispensed with. The determination of the pressure difference, however, is important (e.g., in dynamic-pressure measurements with the aid of Venturi tubes, or with a variometer or statoscope). Changes in the angle of attack during flight, which also change the flow about the fuselage, can (e.g.) produce quite large vertical motions, a fact which has hitherto received but little attention in connection with this kind of instruments. The static sounder is, moreover, an excellent instrument for measuring pressure disturbances in and around an airplane.

The determination, on an airplane, of the correct temperature of the atmosphere, presents some difficulties. The direct reading of thermometers in the vicinity of the fuselage easily gives errors of two or more degrees in climbing, on account of the engine being in front. This fact has been confirmed by comparative measurements in gliding flight. The thermometers should also be protected from the sun's rays and from moisture. Excessive inertia manifests itself disagreeably, especially on rapidly climbing airplanes. At the D.V.L. ("Deutsche Versuchsanstalt für Luftfahrt"), in gliding flight, a quick-acting thermometer attached to an antenna weight is suspended beneath an airplane. With the exception of the meteorograph,* none of the recording instruments proved very satisfactory. It should be endeavored to make a distant-indicating or distant-recording instrument.** The latter, in particular, presents a rather difficult relay problem.

Still more important is the determination of the dynamic pressure under different flight conditions. This is done with Pitot or Venturi tubes, which are installed on some undisturbed part of the airplane. I am of the opinion that on any airplane, without any very troublesome changes, a Pitot tube can be so fastened that the pressure disturbances will, in any event, be less than the error limits of the experiment. Satisfactory results can generally be obtained by mounting the Pitot tube far in front of or somewhat above the leading edge of the wing.*** In any event, it is advisable to verify the results with the aid of the static sounder. If necessary, the latter can be used during the test. This precaution is especially advisable when Venturi tubes are used, since the error can then easily amount to 10-20%.

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* Wigand-Koppe, "Ein neuer Flugzeug-Meteorograph," Z.F.M. 1923, p. 106.

** At the suggestion of the writer, a very satisfactory distant-indicating air thermometer has since been made by Hartmann and Braun, Frankfort a.M., Germany.

*** For the Otto Lilienthal prize, the Pitot and Venturi tubes were mounted half the wing width in front of, or two wing thicknesses above, the leading edge of the upper wing.

The pressure is transmitted through tubes to the dial or recording device. These tubes must not be so small as to have any appreciable damping effect. With sensitive Venturi tubes and rapidly revolving drums, very interesting records are obtained of the undamped negative pressures.

As compared with Pitot tubes, the Venturi tubes have the advantage of greater adjustability and they do not get stopped up by rain or moisture so easily as the former. It must be borne in mind, however, that dynamic-pressure measurements with Venturi tubes may give very inaccurate results, if the variable static-pressure disturbances in the vicinity of the recording apparatus are not measured and allowed for in the calculation or (better) directly counteracted. The recording apparatus for Venturi tubes should, therefore, be made airtight and provided with a second connection for the undisturbed pressure counteraction.

The determination of the position of the airplane in space consists principally in finding the longitudinal and lateral inclinations. The angle of attack is then determined from the longitudinal inclination and the angle of climb.

A simple pendulum is all that is necessary for measuring the longitudinal inclinations in unaccelerated flight. A suitable damper is essential. The latter, however, generally has the disadvantage of carrying the pendulum along with it in sudden changes in the longitudinal inclination. It finally becomes a question of finding a compromise as favorable as possible for accuracy, between the errors caused by the effect of the acceleration on the damping device and the vibration period of the pendulum. Very satisfactory results are obtained in this case by a nearly aperiodic damped circular pendulum, which was first successfully employed by Hoff for measuring longitudinal inclinations on airplanes and was calculated by him in its mathematical-physical properties.*

Since my performance tests had to do simply with unaccelerated flight, I employed a damping device whose principal object was to eliminate the very disturbing acceleration forces in the direction of flight. This was satisfactorily accomplished by means of a cylindrical oil damper which worked perpendicularly to the accelerating forces. There was a further slight advantage, namely, that in the event of very strong longitudinal accelerations (but only with these), the damping piston adhered to the cylinder wall and thus, for the first moment, exerted an especially powerful braking effect. Since, moreover, the damper could be located outside the pendulum, structural considerations (which were also affected by its adaptation in the triple recorder to be mentioned later) decided the matter.

The above-described arrangement was found to give the best results in the numerous test flights. The indications

* W. Hoff, "Versuche an Doppeldeckern, Luftfahrt und Wissenschaft," published by J. Sticker, No. 6, p. 18 ff.

of the instrument were found to be accurate.

The measurement of the lateral inclination, the most important question for curving flights, is far more difficult. The best the observer can do is to determine the inclination to the horizon by means of an inclinometer.

Records of the longitudinal and lateral inclinations can also be obtained by means of a rigidly installed kinetic device with a wide angle and the image of the horizon or of the sun or of a shadow point. I have discussed other photogrammetric methods on a previous occasion.* I will mention, however, that the determination of the flight path from the ground is a very valuable supplement to a test flight. I only need here to call attention to the great importance of the dynamometer hub for determining flight performances, which are thereby placed on a much broader foundation.**

Every airplane pilot flies more or less according to feeling. He must, indeed, be able to do so, since otherwise he could not learn to fly an entirely new type of airplane. He feels the flight characteristics, so to speak, in the control stick. This feeling is, however, mostly qualitative, while the indications of the instruments and the calculations of the observer are quantitative. Hence the aviator must learn to supplement his feeling by means of the instruments. Flight

* Koppe, "Verfahren zur Messung der Geschwindigkeitsleistung von Luftfahrzeugen," Z.F.M. 1923, p. 17 ff.
** W. Stieber, "Die Messnabe," Z.F.M. 1924, p. 69 ff.

performances can be made only in this way. This constitutes skilled flight, which should perhaps be ranked higher than stunt flying. The former could be made the object of a contest just as well as the latter. Very large airplanes should be flown chiefly according to the navigation instruments, which seems entirely possible from what has already been learned.

The preceding lecturer* has reported the results of the experiments on the seaplane Ro II 1, so that it only remains for me to explain how they were obtained and to illustrate, by an example, how they were further utilized.

In testing the climbing ability, the aviator was instructed to fly with wide-open throttle and with the same constant dynamic pressure that had previously been found most favorable for climbing. Gusts were to be counteracted as little as possiple by operating the rudders. The records of the longitudinal inclination, dynamic pressure and altitude show that these requirements were largely fulfilled (Fig. 7).

The climbing flight was evaluated according to a very simple process previously employed by the Prussian Technical Section of Aviation (Flugzeugmeisterei), which had proved very successful in practice and which will therefore be briefly explained here. If we designate the altitude by z, the vertical climbing speed by w and the air pressure by p, we then

* Adolf Rohrbach, "Neue Erfahrungen mit Grossflugzeugen," Jahrbuch der W.G.L. 1924, pp. 29-36. Also N.A.C.A. Technical Memorandum No. 353.

have the following

$$w = \frac{dz}{d\tau} = \frac{dz}{dp}\frac{dp}{d\tau} = -\frac{1}{\gamma}\frac{dp}{d\tau} \quad \text{since } \gamma\, d\, z = -\, d\, p.$$

The air density γ is here given in kg/m³ and $\frac{dp}{d\tau}$ in $kgm^{-2} \cdot sec.^{-1}$ and w is thus obtained in m/sec.

The pressure variation is obtained as follows: The air pressure is taken from the altimeter at uniform intervals of $\Delta\tau$ (about every 2 minutes) and determined according to the calibration curve. The mean ΔB_m, of the pressure differences ΔB, multiplied by the specific gravity of mercury, gives the value of Δp with sufficient accuracy.

During the flight, the temperatures are read and the air densities are calculated from the corresponding air pressures. The air densities are then plotted against the air pressures. This gives a definite value of w for every ΔB_m. For the vertical climbing speed in m/sec., we thus obtain

$$w = \frac{13.6}{\Delta\tau}\ \frac{\Delta B_m}{\gamma}$$

For the region where the altimetric curve is flatter, the time intervals $\Delta\tau$ may be made longer. Hence we need only to plot the temperature or air density against the air pressure or time.

The vertical climbing speeds can be conveniently determined from

Table I.

Time min.	Temp. t° in $^{\circ}C$	Air pressure B mm SQ	Difference ΔB	Mean ΔB_m	Air density γ in kg/m³	Climbing speed w in m/s
0	8.8	755.3			1.245	
			36.3	29.6		
2	5.5	719.0			1.198	2.80
			23.0	21.5		
4	2.4	690.0			1.172	2.10
			20.0	18.5		
6	0.6	676.0			1.147	1.85
			17.0	16.5		
8	-0.8	659.0			1.124	1.65
			16.0	16.0		
10	-1.5	643.0			1.100	1.65
			16.0	15.0		
12	-2.0	627.0			1.075	1.60
			14.0	14.0		
14	-2.4	631.0			1.052	1.50

From the air density and the dynamic pressure we determine the air speed according to the formula

$$v = \sqrt{2\ g\ \frac{q}{\gamma}}$$

The air speed, as likewise the vertical climbing speed, was plotted against the air density (Fig. 8, I and II). From both curves, the values of the air speed (or flight-path speed) and vertical speed were found for $\gamma = 1.18$, $\gamma = 1.16$, etc. up to $\gamma = 1.00$ kg/m³. The angle of climb φ, between the flight path and the horizontal plane, is given by the equation $w/v = \sin\varphi$ (Fig. 8, III). By adding to this angle the angle between the wing chord and the top of the fuselage, we obtain the angle between the wing chord and the horizontal. The difference between the latter angle and the measured longitudinal inclination (Fig. 8, IV) is the angle of attack α (Fig. 8, V).

It is obvious that, when q is constant, the angle of attack α also remains constant, within the range of experimental accuracy, thereby demonstrating that a well-executed experimental flight is not necessarily less reliable, in the accuracy of the experimental conditions, than an experiment with a model in a laboratory.

Table II.

Ro II 1 Flight No. 44. Climbing Flight.

No.	Air density γ kg/m³	Air speed v m/sec.	Climbing speed w m/sec.	$\frac{w}{v}$ sinφ	Angle of climb φ°	Long. inclination 3.5°	Angle of attack α°
1	1.18	35.45	2.30	0.0649	3.7	9.7	6.0
2	1.16	35.75	2.15	0.0602	3.45	9.6	6.15
3	1.14	36.05	2.00	0.0555	3.2	9.5	6.3
4	1.12	36.40	1.84	0.0506	2.9	9.35	6.45
5	1.10	36.70	1.68	0.0458	2.6	9.15	6.45
6	1.08	37.10	1.52	0.0410	2.35	8.9	6.55
7	1.06	37.45	1.36	0.0363	2.1	8.7	6.6
8	1.04	37.80	1.19	0.0315	1.8	8.3	6.5
9	1.02	38.20	1.01	0.02645	1.5	7.9	6.4
10	1.00	38.60	0.84	0.02175	1.25	7.35	6.1

$$c_a = \frac{G}{F\,q} = \frac{4910}{71.4 \times 76} = 0.906 \quad \left(\frac{c_w}{c_a}\right)_{mean}$$

$$c_w = 0.0982 \times 0.906 = 0.089$$

Dynamic pressure $q = 76$ kg/m²

Table II (Cont.)

Ro II 1 Flight No. 44. Climbing Flight.

No.	Engine power N_x HP.	c_w/c_a for $\eta = 0.56$	Values of η from			
			No.		No.	
1	676	0.0986	1;2	0.52	1;5	0.55
2	662	0.0983	2;3	0.52	1;6	0.56
3	646	0.0980	3;4	0.58	1;7	0.55
4	632	0.0979	4;5	0.60	2;7	0.56
5	618	0.0984	5;6	0.57	2;6	0.57
6	604	0.0985	6;7	0.52	3;7	0.57
7	588	0.0980	7;8	0.54	8;10	0.61
8	572	0.0979	8;9	0.63	6;10	0.53
9	558	0.0985	9;10	0.56	6;9	0.56
10	542	0.0982	1;4	0.54	5;9	0.56

$$c_a = \frac{G}{F\,q} = \frac{4910}{71.4 \times 76} = 0.906 \quad \left(\frac{c_w}{c_a}\right)_{mean}$$

$$c_w = 0.0982 \times 0.906 = 0.089$$

Dynamic pressure $q = 76$ kg/m²

Mean $\eta = 0.56$

The values thus obtained are given in Table II for air densities from 1.18 to 1.00, along with the corresponding engine powers. The equation

$$\frac{c_w}{c_a} = \frac{75}{G} \frac{N \eta}{v} - \frac{w}{v}$$

represents a relation between c_w/c_a and η, which holds true for all the above values. Ten equations can thus be made up. From each two successive equations, we obtain values for η and c_w/c_a. Since the dynamic pressure and angle of attack are constant, the values of c_w/c_a must agree in all equations. If we combine only two successive values of c_w/c_a, we nevertheless obtain values for η which differ but little from the mean of 0.56.

I will now present another generally applicable method for evaluating airplane performances, which I worked out with Mr. Spieweck.

The motion equations of an airplane read:

$$75\,N - G\,w - c_w\,F\,q\,v = 0 \qquad (1)$$

$$-\,G + c_a\,F\,q = 0 \qquad (2)$$

If the dynamic pressure q is constant in equation (2), then c_a is also constant, i.e., the angle of attack α is constant and consequently c_w is also constant. Since

$$v = \sqrt{\frac{2\,g}{\gamma}\,q},$$

equation (1) can also be written:

$$75\ N\eta - G\ w = c_w\ F\ q \sqrt{\frac{2\ g}{\gamma}\ q}$$

or $$75\ N\eta - G\ w = c_w\ F\ q \sqrt{2g\ q}\ \frac{1}{\sqrt{\gamma}}$$

from which we obtain the vertical climbing speed:

$$w = -\frac{c_w\ Fq}{G} \sqrt{2g\ q}\ \frac{1}{\sqrt{\gamma}} + \frac{75\ N\eta}{G}$$

Now, if the dynamic pressure is constant, then

$$-\ c_w \left(\frac{F}{G}\right) q^{3/2} \sqrt{2g} = K$$

is also constant. If we plot the vertical climbing speeds, obtained at a constant dynamic pressure q_1, against $\frac{1}{\sqrt{\gamma}}$, we obtain the curve q_1 (Fig. 9).

In the example considered, the curve of the climbing speed plotted against the reciprocal of the square root of the air density, at the dynamic pressure q_1, very closely approaches a straight line. Especial note may therefore be made of the fact that this curve does not always conform (or only approximately) to theoretical considerations.

If the power output of the engine did not vary with the air density, the climbing-speed curve would be the straight line

$$w = K'\ \frac{1}{\sqrt{\gamma}} + C_o$$

whereby

$$C_o = \frac{75\ N_o\ \eta}{G}$$

or

$$C_o = \frac{75 \, \gamma_z \, N_{e_o} \eta}{G}$$

This line would cut the w axis at the point $w = C_o$. A second point would be given by the climbing speed w_o at the normal density γ_o and the dynamic pressure q_1.

Since the value of $C_o = \frac{75 \, N_o \eta}{G}$ is generally not known, it can, at first, be arbitrarily assumed. I will show later that the further considerations are really independent of the value of C_o. The straight line I, which thus corresponds to the theoretical vertical climbing speed of an airplane with the dynamic pressure q_1, at a constant motive force, accordingly passes through w_o and an arbitrarily assumed point C_o. The deviation of the measured curve q_1 from the theoretical straight line I proceeds from a decrease in $N \eta$. It accordingly indicates how much the vertical climbing speed is reduced by the air density. These differences are therefore independent of the dynamic pressure. If, therefore, the vertical climbing speed (at the dynamic pressure q_2 and a given air density) is known and if the difference a (coordinated with this air density), between the measured curve q_1 and the theoretical straight line I, is added to it, a point is thus obtained on the theoretical line II, which can then be drawn through this point and C_o. If the differences between q_1 and I (from II out) are plotted for the different air densities (Fig. 10), (hence $a_1 = a_2$, $b_1 = b_2$, etc.), the curve q_2 can then be drawn through these points. The point of intersection of the curve q_2 with the $\frac{1}{\sqrt{\gamma}}$ axis then gives the ceiling at the dynamic pressure q_2. In this way the practical vertical-climbing-speed curves for the dynamic pressures q_3, q_4, etc., can be constructed, if, for each of these dynamic pressures, even a single climbing-speed value for a given air density is known. We see that the above case has to do only with the construction of similar curves, which is therefore actually independent of the value of C_0. C_0 must simply lie on the w axis and must be the point of intersection of all the straight lines I, II, III, etc.

Lastly, the dynamic pressures do not need to be absolute values. It is only necessary for the pressure gauge to be located at the same point on the airplane. The pressure disturbances about an airplane change principally with the angle of attack. With constant q, the pressure disturbances also have constant values. After we have thus plotted several vertical-climbing-speed curves, we can plot them against the dynamic pressure for different air densities and thus obtain a simple graphic representation (Fig. 11), from which we can determine all practical airplane performances for all air densities (at a given flying weight and with the same engine running at full speed).

I have applied this method for presenting the practical results of tests on various airplane types. The results were very satisfactory, always assuming, of course, good "quantitative flying." On the airplanes tested by this method, which did not have supercharged engines, the decrease in the value of $N\eta$ was nearly proportional to the air density, i.e., the curve of the vertical climbing speeds plotted against the reciprocal of the square root of the air density, for a given dynamic pressure, closely approximated a straight line. The vertical-climbing-speed curves (straight lines) for the various dynamic pressures intersect one another again according to well-known geometrical principles, at a point on the w axis. The construction is, therefore, considerably simplified in this case alone.

The speed test was carried out over a large (nearly equilateral) triangle, in such a way as to utilize, at first, a suitable layer of air, which was as quiet as possible. In this layer, by attentive observation of the altimeter, the dynamic pressure was determined at which the airplane was horizontally flown. The speed test was therefore flown not according to the altimeter, but according to the pressure-gauge. The observer seldom had to make any corrections. The accompanying drawings (Fig. 12) show that the altitude was, in fact, admirably maintained. A very sensitive, undamped recorder (Fahrtschreiber) made by the optical firm of C. P. Goerz, of Friedenau, was used.

The speed test was evaluated according to the well-known method already reported.* The result showed a good agreement between the speed measurement from the ground and the dynamic-pressure record. I will now give a few practical results which relate mainly to the construction of a suitable instrument.

The performances of an airplane can be generally determined from simultaneous measurements of air density, dynamic pressure and longitudinal inclination. In the first tests, separate recording instruments were employed for the atmospheric pressure and temperature, dynamic pressure and longitudinal inclination. During the course of the subsequent tests, I developed a combination instrument, the first form of which I will now describe, since it did good work and the design of the instrument for quantity production has not yet been settled. A separate report on this will be made later.

I combined the available successful instruments into a threefold instrument for recording barometric pressure, dynamic pressure and longitudinal inclination simultaneously on the same drum (Fig. 13). The longitudinal inclination recorder and the dynamic pressure recorder are firmly built into the foundation frame, but the altigraph is the ordinary instrument and is easily exchangeable, so that for each test flight, the altigraph can be used, which is best suited to the altitude to be reached (Fig. 14). Since the altigraph is used with its clock-

* Koppe, "Verfahren zur Messung der Geschwindigkeitsleistung von Luftfahrzeugen," Z.F.M. 1923, p. 17.

work, over whose drum another long drum is slipped, it is possible to make a selection according to the revolution period of the clockwork. There are always available for the test flights sufficient altigraphs of various altitude ranges with exchangeable half-hour, two-hour, four-hour and six-hour clockworks. For the dynamic-pressure determination, a Goerz recorder was used, which was made for the Rumpler prize contest (Koppe, "Ueber den Rumplerpreis," Z.F.M. 1922, p.33 ff). This instrument has given good service. The capsules employed are, however, very flexible and consequently very sensitive to undesired external influences. In the last experiments, therefore, Bruhn tubes, with special capsules made by the Ascania (Bamberg) Works at Friedenau, were used with great advantage. The longitudinal inclination recorder had been used by me as a separate instrument in earlier experiments. It was made from an altigraph and gave good service in its present very simple form. The cylinder of the piston damper was filled with a mixture of oil and kerosene and could be closed for transportation.

The long recording drum could be slipped over the regular drum of an ordinary altigraph. A sufficient supply of prepared drums was always carried, so that no long pauses between the test flights were necessary for removing and treating the soot records and preparing the drums for the next flight. Only a short time was required to exchange the drums. It was, in fact, found advantageous to use half-hour clockworks and make the exchanges during the flight. The marking device on the regular altigraphs was employed for marking the time intervals. The throw-out lever on the altigraph was lengthened, so that all the recording levers could be thrown out simultaneously and the clockwork coupled or uncoupled from the outside.

The housing is made of sheet aluminum with a "cellon" window for the observation of the records during flight. Since this housing could not be made perfectly tight, the pressure disturbances in the vicinity of the instrument had to be especially noted and taken into account in the subsequent evaluations. It was repeatedly found (especially in evaluating the dynamic-pressure measurements) that the variations in the static pressure at the different angles of attack required special attention.

The apparatus was suspended by suitable springs between two fixed points (Fig. 15). The records were made by the soot method, the advantages of which need not be discussed again here. Their fineness and accuracy are sufficiently demonstrated by Figs. 16-17.

The evaluation of such a soot record can be made (as is done daily in the aerological observatory) simply with graduated paper and a pair of dividers. Time marks, which can be made on all the curves by the recording levers themselves, or by separate levers, greatly facilitate the evaluation and coordination of simultaneous points on the different curves.

For shortening the evaluation, I have made the process still more mechanical, as shown in Fig. 18. The soot record, after it has been fixed by spraying with a dilute solution of shellac, is so placed on the drawing board of the apparatus that the base line is parallel to the lower straight edge and is then securely clamped with the latter. The time scale must then be properly adjusted. Since, in spite of careful adjustment, the different clockworks do not run exactly alike, the intervals between whole and multiple minutes must likewise vary. This is effected by moving the time scale and instead of utilizing the division mark directly, its projection on the horizontal line is used. It is thus possible, by the corresponding inclination of the scale, to divide suitably each interval between two time marks. The coordination of simultaneous points in the different curves is accomplished by means of a transparent "cellon" sheet, which has circular arcs near its left edge, corresponding to the paths of the recording styli on the drum at rest and which is shifted, parallel to itself, along the lower straight edge, from time mark to time mark or from division to division. The experimental values are then taken directly from the corresponding graduated sheet. If the latter is transparent enough, it can be laid directly on the "cellon" sheet. In the evaluation of numerous flights made with the same apparatus, it is advisable to draw the scale on the "cellon" sheet itself. This evaluation method has proved very satisfactory and enables quick and reliable results. The coordinated values from the individual drawings can, for example, be transferred every minute to a numerical table.

A good dynamic-pressure gauge is of special importance for all test flights. Care must also be taken to reduce retardation through inertia as much as possible. The tubes should not be too small, although no air is transmitted. Any number of indicating or recording instruments can, with the aid of T-pieces, be connected with the same measuring instrument. In using Venturi tubes, special attention must be given to the static-pressure disturbances. If several indicators are used, care must be taken to have them all under the same static pressure. The task of the airplane pilot is simply to fly according to the dynamic pressure. During a series of tests, he must therefore keep the dynamic pressure constant by a very cautious manipulation of the elevator control. It is entirely indifferent as to how the scale on the indicator is divided, but it is better to indicate the dynamic pressure in millimeters of water column rather than in the often misleading speed scale of kilometers per hour. It is only important for the pilot to determine experimentally at what position of the pointer the airplane climbs best and for him to understand the danger of falling below this value (i.e., of "stalled flight"). It is very helpful to mark this dynamic-pressure value in red. Exceeding an upper limit of the dynamic pressure may also become dangerous. This upper limit, which is determined by the safety factor of the airplane is, however, seldom reached. The pilot may also note at what dynamic pressure (for a given air density) the airplane flies horizontally. The dynamic pressures for horizontal flight at the principal altitudes might be marked on an accompanying scale. It should be remembered that these values apply only to the particular airplane with the same load and the same power plant. The utilization of the dynamic-pressure indicator cannot be urged too strongly on pilots, even of commercial airplanes.

The climbing speed of an airplane is generally determined by the increase in altitude per unit of time. If we only had an instrument which would indicate directly the vertical climbing or sinking speed (i.e., a sensitive variometer), it would be an easy task, first to determine the dynamic pressure for the best climbing flight and then to measure and record the corresponding climbing speeds and dynamic pressures for the different air densities. Unfortunately no variometer has yet been able to meet, even approximately, the requirements for such an instrument. Your attention is called once more to the great sensitiveness of the variometer to the strong external pressure disturbances. I will again describe briefly an airplane-performance test, as best executed in accordance with the above-mentioned methods and practical experience.

Immediately after the factory test flights, the installation of the instruments can be begun, so that the pilot can become familiar with them from the first. The scientific observer will likewise improve every opportunity to study thoroughly the peculiarities of the airplane. Both pilot and observer must mutually take every precaution to be in accord regarding every possible event; in a word, to become perfectly familiar with the airplane itself and with the tasks to be performed. Then only will they be ready to make the real test flights. The instruments must be installed with great care not to damage the airplane and to avoid all unnecessary air resistance. Only the instruments for taking the dynamic and static pressure (static sounder) and a thermometer will be outside the fuselage. The threefold recorder, which requires considerable space, is installed in the fuselage, so as to be easily accessible. The observer must sit as near as possible to the pilot and, in any event, he must have the same view as the latter.

A program must be arranged before every test flight and must be gone over carefully, in all its details, by the pilot and observer, until there is no danger of any misunderstanding. An accurate determination of the flying weight must be made before each flight. This can be done best by actual weighing in a hangar with the doors closed, as the force of the wind may greatly affect the result. The recording instruments are thrown into gear shortly before the start, in order to obtain comparative values for the direct observations, which must be made simultaneously. The temperature and the barometric pressure are taken on the ground. The longitudinal inclination is read on a special inclinometer, firmly secured in the direction of the wing chord. General observations on wind and weather are also noted.

From the very beginning of the flight, the pilot and observer cooperate in the performance of their task, i.e., the observer also flies the airplane theoretically and, when necessary, assists the pilot by signs. He must and can make many more observations than the pilot, even those which simply concern the piloting. He is in a position to verify his observations by the instruments and constantly increase their accuracy. Experience in piloting and scientific education place the observer on the same level with the expert pilot. In all the observations, the constant watching of the instruments and especially the making of time marks at regular intervals must not be neglected. Occasional comparative readings assist and facilitate the subsequent evaluation. The final observations are made after the landing, while the recording instruments are still running. The weight of the airplane must also be found again.

As soon as possible after each flight, the pilot and observer must carefully go over together each individual observation and record and make written notes of all pertinent points. Apparently unimportant items may, in the subsequent evaluation, assume important roles and lead to important conclusions. A concession may here be made to the principal participants, in the interest of accuracy. It is, namely, advisable to have the results of their discussion recorded (in shorthand, if possible) by a third party, since pilot and observer are generally too busy with the airplane and instruments and are often too tired to make written reports with the requisite care.

Since the speed test necessitates a calibration of the dynamic-pressure gauge, it is best to make this at the beginning of the test flights. I have previously made a detailed report on the different methods for determining the speed.* Generally a triangular flight, at not too great an altitude, over marked points, is sufficiently accurate.

If the dynamic-pressure gauge is found to be correct, the climbing tests are made at different dynamic pressures. Hereby the dynamic pressure for the best climb is to be determined. In so far as it can be done without danger to the crew or craft, it is desirable to obtain at least one dynamic-pressure value for stalled flight. This is essential for compiling the flight characteristics. The airplane will then be flown as closely as possible to the best dynamic pressure for climbing to the altitude limit (ceiling).

* Koppe, "Verfahren zur Messung der Geschwindigkeitsleistung von Luftfahrzeugen," Z.F.M. 1923, p. 17 ff.

It generally suffices to make these flights for the determination of all the flight performances according to the above methods. If questions or gaps should be discovered during the evaluation, further test flights must then be made. Care must of course be taken to hold strictly to the same experimental conditions. It is then possible to determine all the theoretical bases for engine flight, at constant throttle, with an accuracy not possible in tests with models.

In conclusion, I will add a few words on the application of this method to soaring-flight research. Unfortunately, I have had no opportunity to test the threefold recorder on a simple soaring airplane or glider. I have, however, repeatedly been able to verify, in flight tests with different airplanes (among others the "Habicht" of Blume-Hentzen), over level ground, quite large vertical motions of large air masses, which, at certain spots, extended to a considerable altitude and seemed, at least, to render static soaring flight, even if not dynamic, entirely possible over level ground. I am sorry that I cannot take you farther into this very promising field of the application of experiments on airplanes.

In full appreciation of aerodynamic theories and of practical experiments on models and their results, I will conclude my remarks on the carrying out of experiments on the airplanes themselves with the words: "Here is another green tree, which bears golden apples. Let us pluck them!"

Translation by Dwight M. Miner,
National Advisory Committee for Aeronautics.

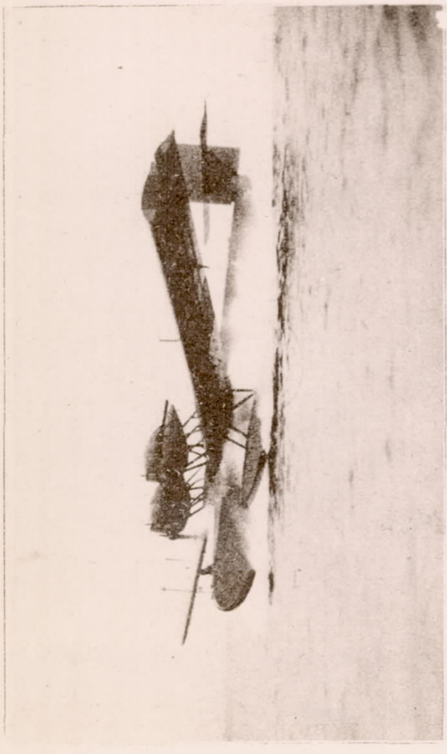


Fig.1

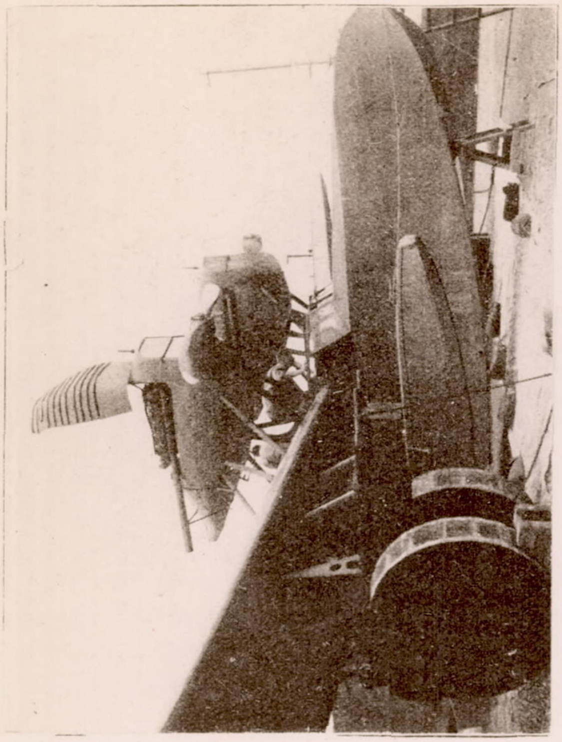


Fig.2

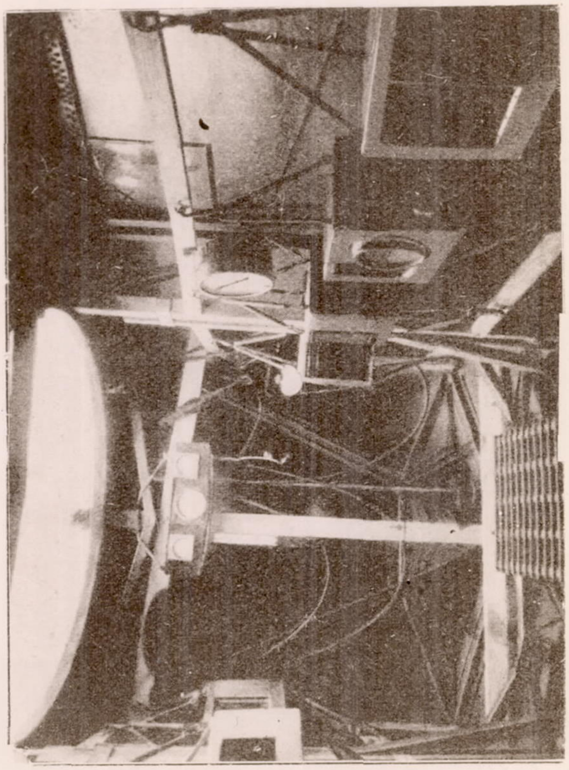


Fig.3

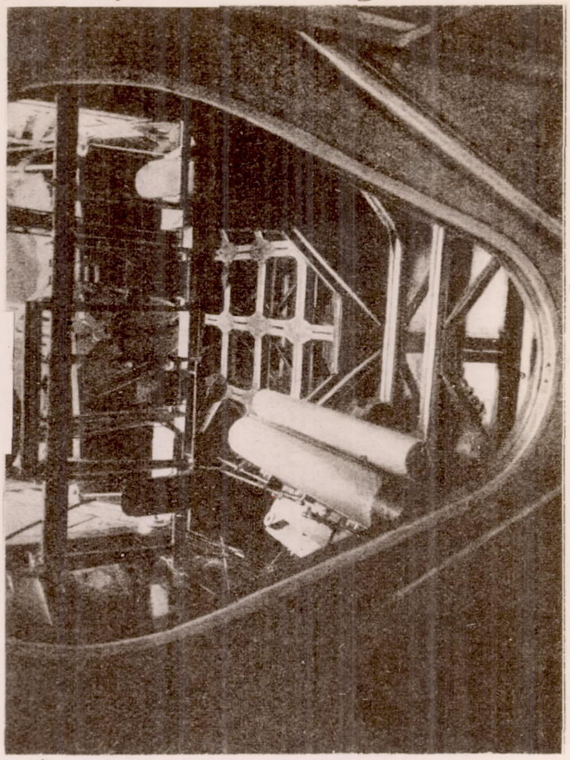


Fig.4

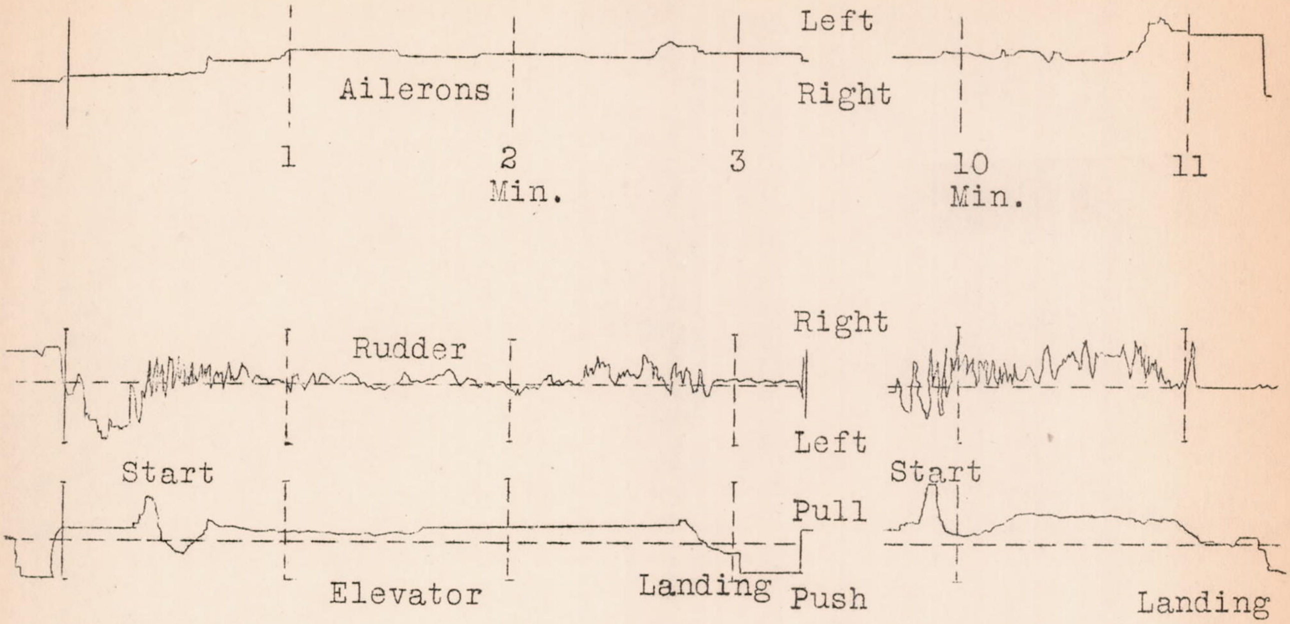


Fig.5

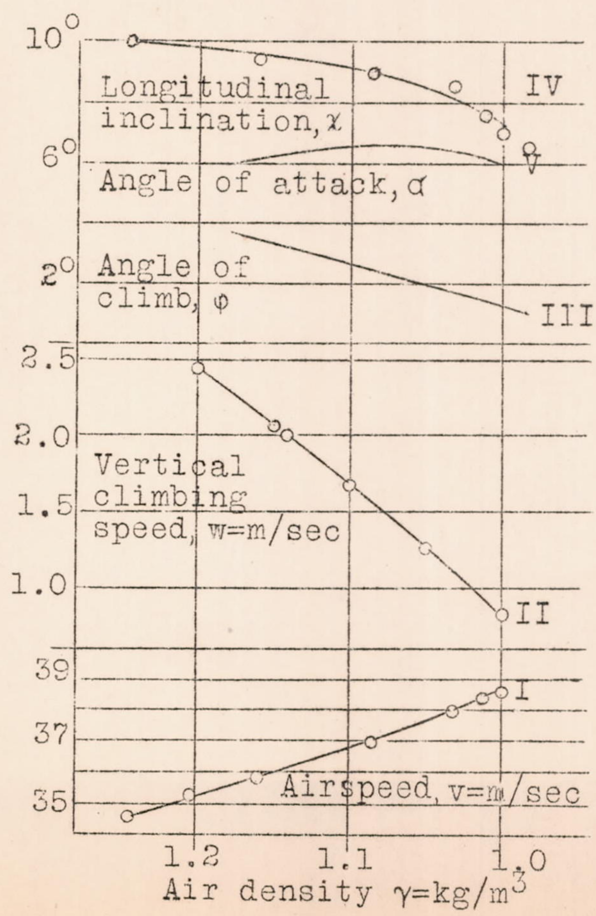


Fig.8 Ro II 1. Climbing flight.

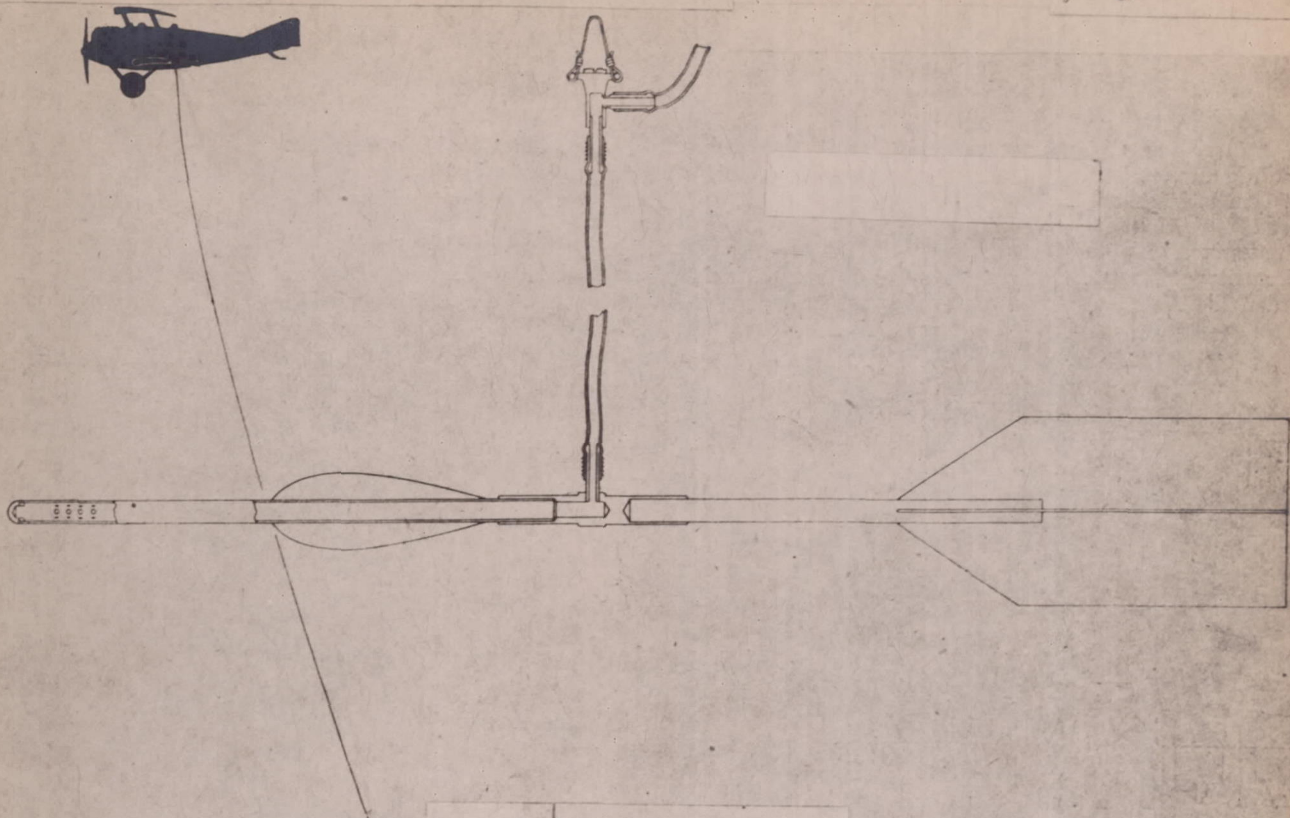


Fig.6 Static sounder

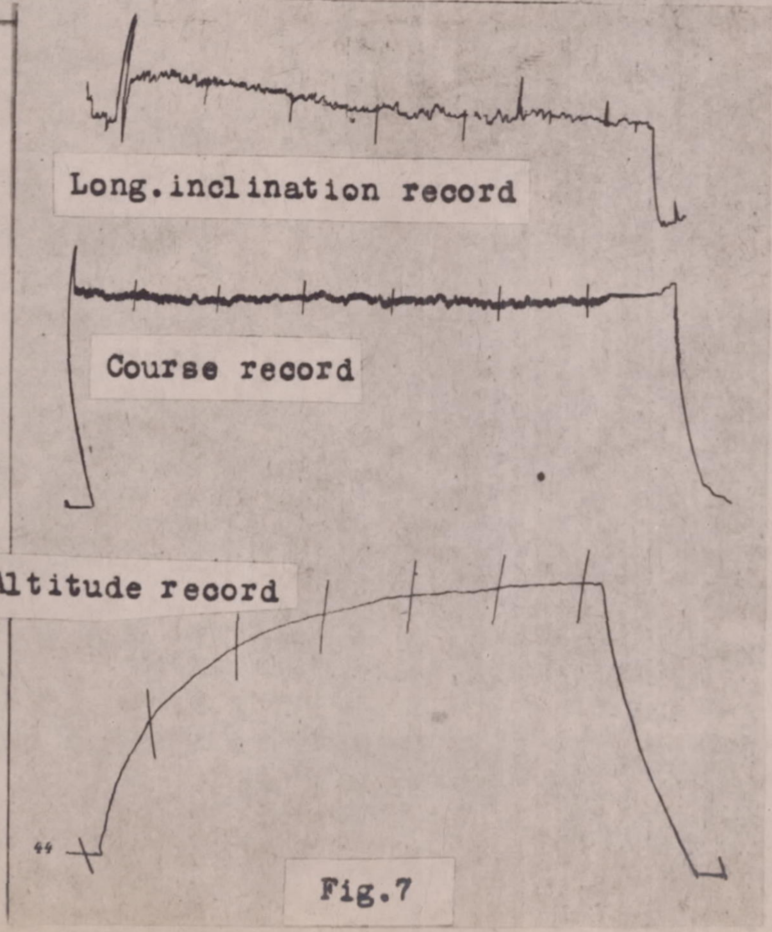


Fig.7

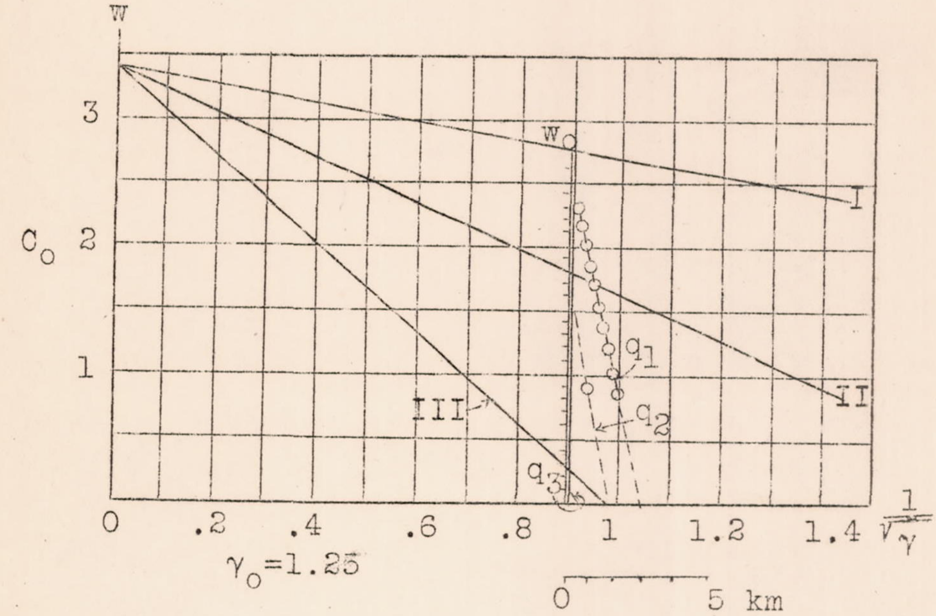


Fig.9

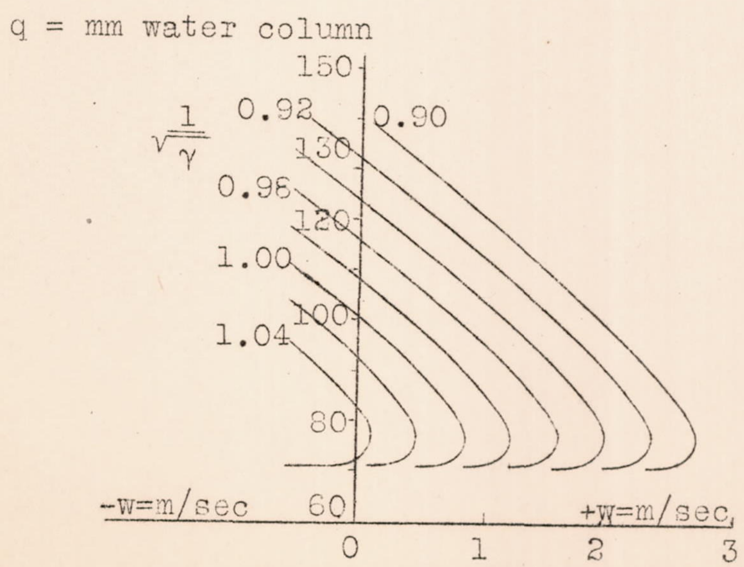


Fig.11 Ro II 1. Climbing flight.

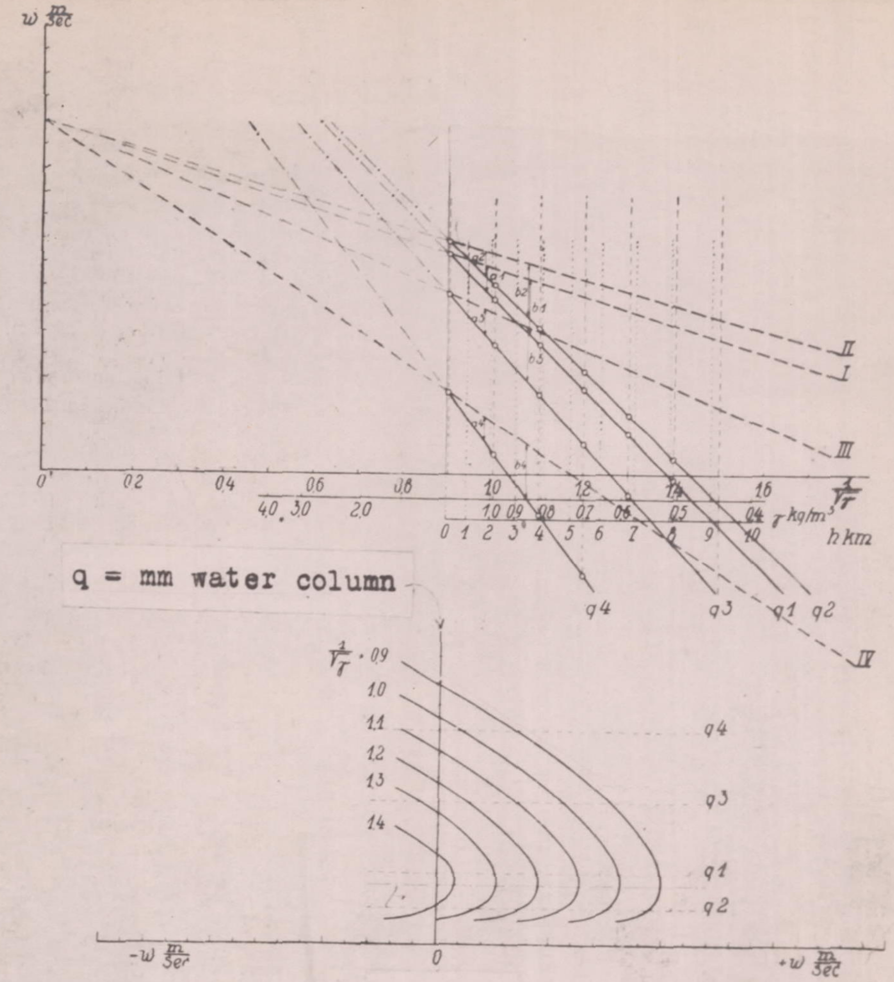

q = mm water column
q4
q3
q1
q2
I
II
III
IV
h km
-w m/sec
+w m/sec
0

Fig.10

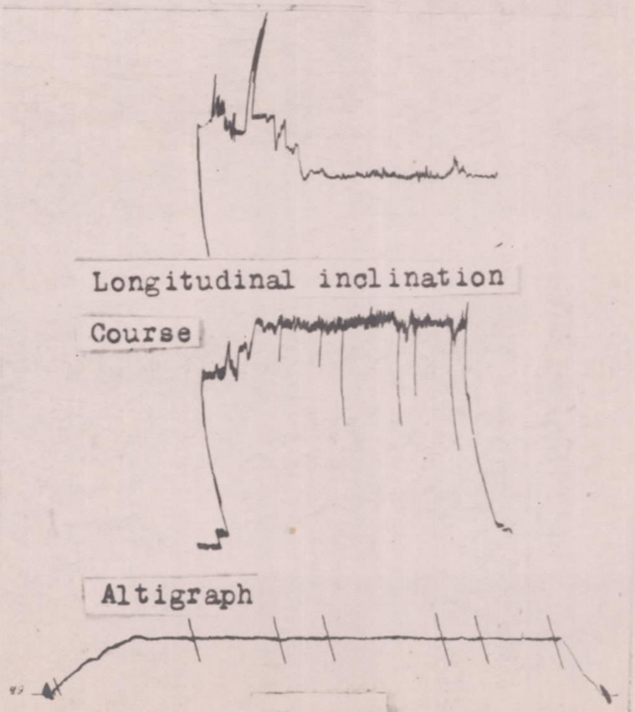

Longitudinal inclination
Course
Altigraph

Fig.12

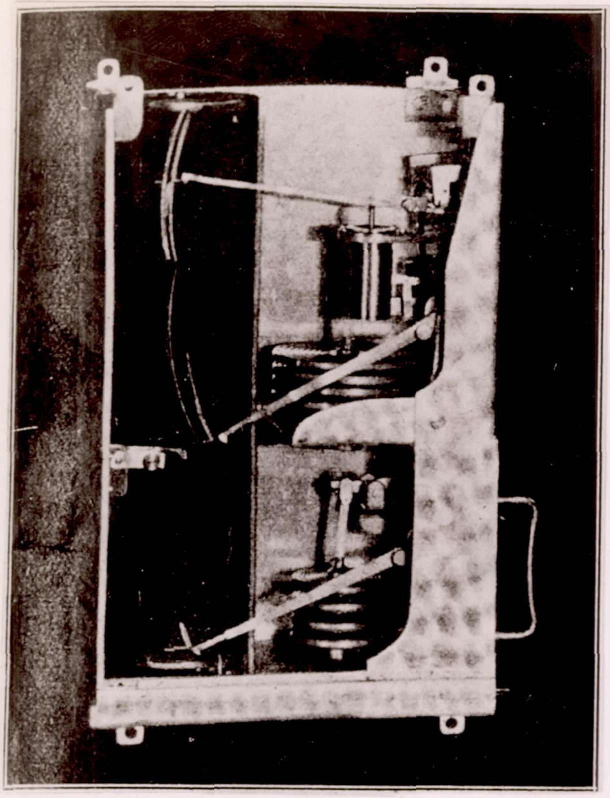
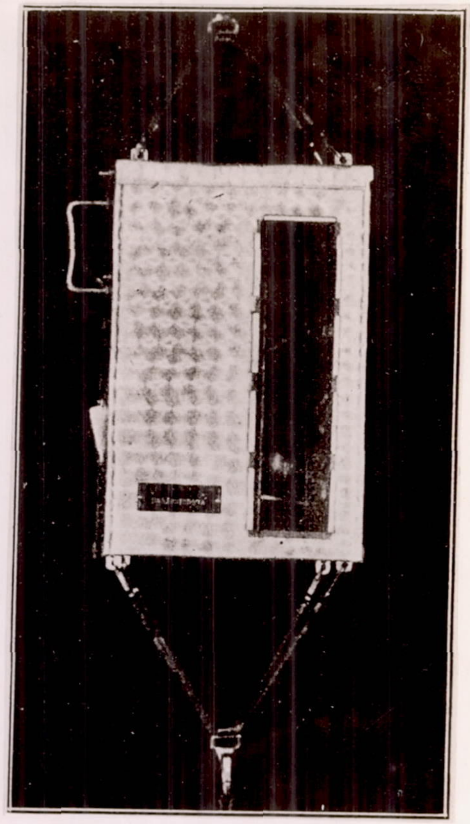


Fig.13



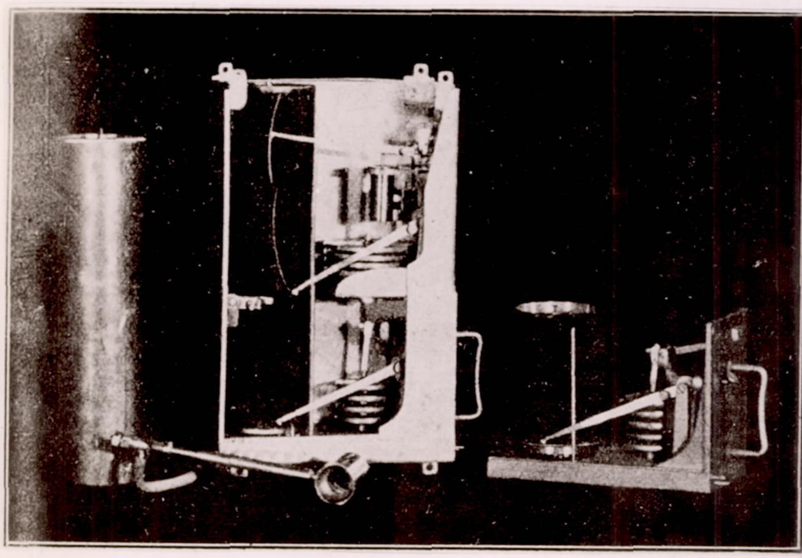


Fig.14

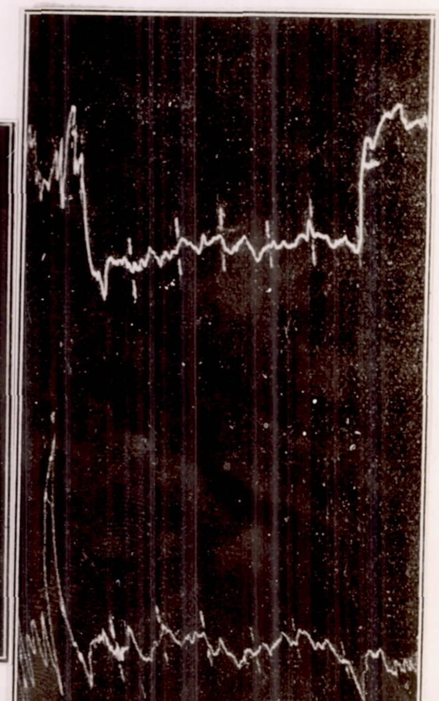


Fig.16

2704 A.S.

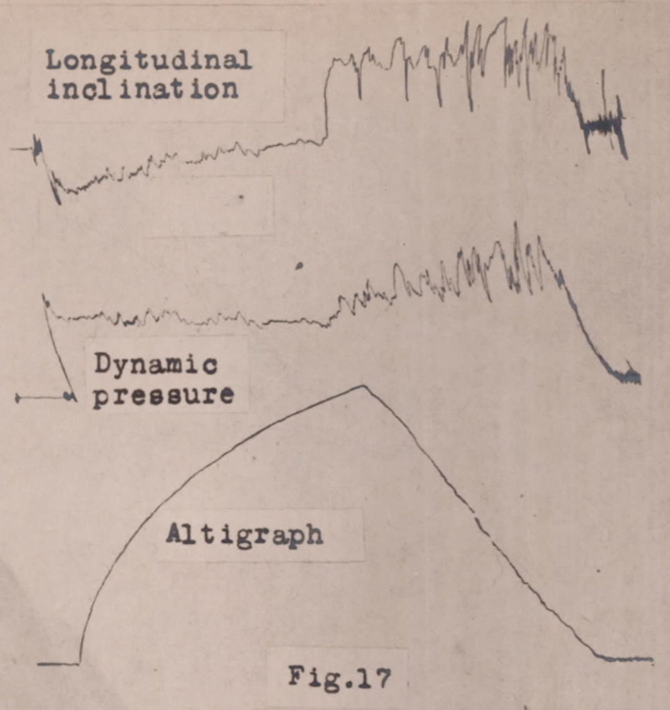

Longitudinal inclination
Dynamic pressure
Altigraph

Fig.17

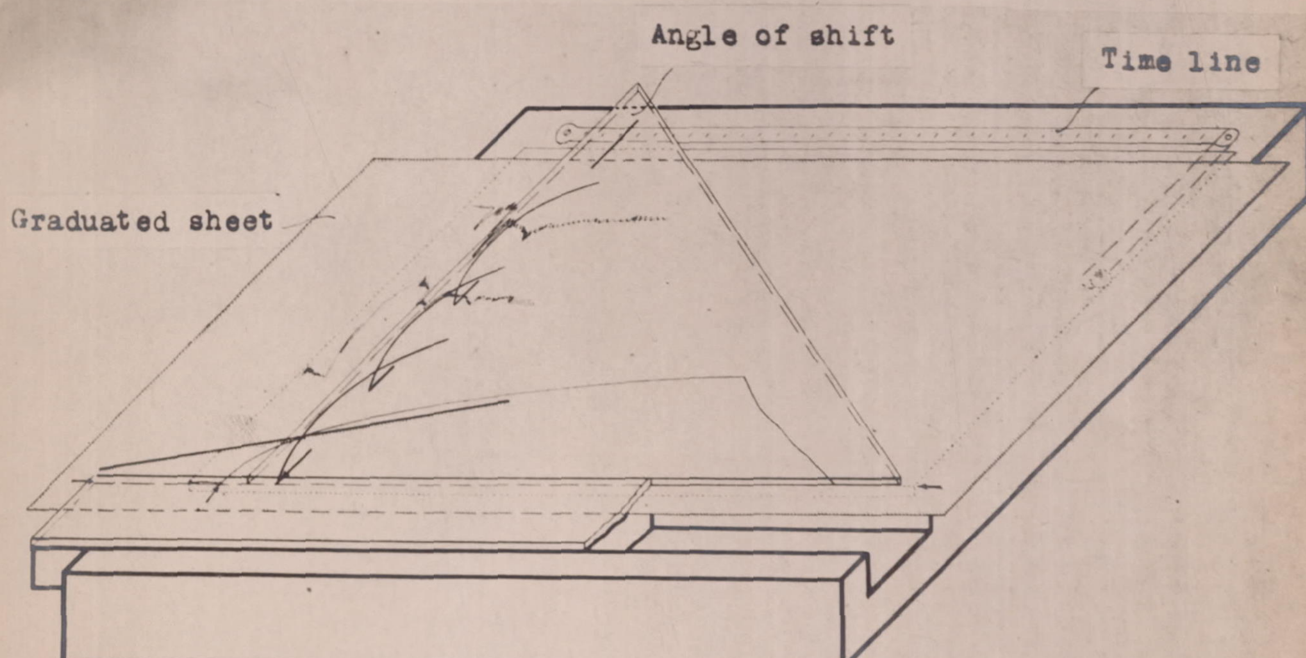

Angle of shift
Time line
Graduated sheet

Fig.18