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PHOTOGRAMMETRIC TAKE-OFF AND LANDING MEASUREMENTS

By Bruno Spieweck

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Until near the end of 1925, only the distance from the starting to the take-off point was measured in the acceptance tests of an airplane. Since, however, it is of the utmost importance for an airplane to be able to rise over any obstacles after taking off, the stipulations were changed to the effect that an airplane must reach a height of at least 20 m (66 ft.) within 650 m (2133 ft.) from its starting point.

The task then devolved on us to determine the first part of the flight path in the simplest possible manner. That is, the measuring apparatus had to be portable and render unnecessary all distance measurements on the aviation field. Theodolites could not be used, or at the most only phototheodolites, when thereby the basis could also be determined photographically.

In order to economize in personnel, a new method was used, which required only one photographic camera. We subsequently learned that this method had already been tried in Holland and was described by A. G. Von Baumhauer under the title "Fotograf-

*"Photogrammetrische Start- und Landungsmessungen" from the Yearbook of the Wissenschaftliche Gesellschaft für Luftfahrt, Dec., 1926, pp. 79-84.
See also articles on the same subject by P. Raethjen, in Zeitschrift für Flugtechnik und Motorluftschiffahrt, Dec. 14 and 28, 1926 (N.A.C.A. Technical Memorandum No. 409: "Kinetographic Determination of Airplane Flight Characteristics," 1927.

ische tijdstudies van vliegtuigbanen" in Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart, Part III, 1925, pp. 101-108 (For translation, see N.A.C.A. Technical Memorandum No. 345: "Photographic Time Studies of Airplane Paths," by A. G. Von Baumhauer). Nevertheless, we strove for greater accuracy from the beginning. I do not consider it superfluous to describe the method here once more, especially as it can also be used in other fields of research.

Since the airplane starts against the wind, its direction of motion is not changed at first and its flight path lies in a single (vertical) plane. If the airplane, in starting, is photographed directly from behind, its distance from the observation point at the instant the photograph is taken can be calculated from a known transverse dimension (e.g., span, or distance between the struts or wheels). Furthermore, the altitude of the airplane above the ground can be determined from its distance above the horizon in the picture.

Figure 1 illustrates the principle of the method:

r, distance of observation point from starting point;

e, " " " " " airplane;

b, span (or distance between struts or wheels);

a, width of picture on plate;

h, measured height on plate;

f, focal length of lens;

w, projection of e;

x, ground distance of airplane from starting point;

y, altitude of airplane above the ground.

O denotes the position of the lens and hence the standpoint of the observer; S is the starting point of the airplane; F is the position of the airplane; and M is the point where the optical axis of the lens meets the plane of the picture.

From the similar triangles in Figure 1 and for the horizontal distance w and the coordinates x and y of the airplane, we obtain the three formulas:

$$w = \frac{bf}{a}, \qquad y = \frac{wh}{f}, \qquad x = w - r \qquad (1)$$

These hold good for the case when the optical axis of the camera is horizontal and in the plane of the flight path. Should this not be the case, i.e., if the optical axis is inclined or if the airplane lies outside the vertical plane passing through the optical axis, allowance therefor must be made in the calculation, if the deviations from the normal case are considerable. If the plan form of the airplane is known, a further correction can be made, when the picture is not taken directly from behind. However, this error can usually be disregarded, since it increases only as the cosine of the angle considered.

The pictures were taken with a camera of 25 cm (9.84 in.) focal length with plates in exchangeable holders. Six pictures could be taken at intervals of 2-3 seconds. There was then a pause of 7-8 seconds to change plate holders, after which six more pictures could be taken. Since it was desirable to know the exact time of the exposure, a stop watch, placed at the focus of a lens, was simultaneously photographed. Figure 2 is is such a picture. A special camera (Fig. 3) was made, in order to simplify the process.

With this camera, 30 m (98.4 ft.) of film 12 cm (4.72 in.) wide, is passed from the upper box over a frame 9 x 18 cm (3.54 x 7.1 in.). A lens of 25 cm (9.84 in.) focal length is so mounted that its optical axis meets the film at a distance cf 4 cm (1.57 in.) from its upper edge. It is therefore placed eccentrically. Another lens projects the image of the stop watch on the film. Small notes can also be placed near the watch. A half turn of the crank shifts the film and simultaneously cocks the shutter. Further turning releases the shutter. The exposure may be made at desired intervals of not less than 0.9 second. The camera is mounted on a tripod and is leveled by three screws with the aid of two bevels on top of the camera. A folding sight renders it possible to tell whether the airplane is still in the field of the camera. The camera is perfectly fast, but can be turned horizontally by means of a releasing device. This is especially important when the airplane flies in a different direction than was anticipated. Moreover, by turning the camera 180°, it is possible to continue the experiment, when the airplane flies over the observer. The range of the experiment can thus be extended to about 3 km (1.86 mi.) for an ordinary airplane.

Figure 5 is a picture taken with such a camera. The horizon is indicated by two marks on opposite sides of the picture, for which reason the camera must be correctly leveled. The horizontal marks divide the picture into two parts of 4 and 10 cm (1.57 and 3.94 in.) height. Due to the eccentric position of the lens, the field of the picture extends high above the horizon. The stop watch, which shows twentieths of a second, is pictured at the top. The nature of the experiment is noted on a nearby card, in this case "G" for "Geschwindigkeitsmessung" (speed measurement). Figure 6 comes from the South German flight. Here the notations beside the watch mean experiment No. 57, airplane D 854, first start of this airplane with 90% disposable load.

The measuring of the picture is done with a "comparator" which permits an accuracy of 0.01 mm (0.0004 inch). The measurements are repeated several times for increasing and verifying the accuracy. These "comparator" readings are given in Table I. If the span cannot be measured, any other transverse dimension can be used. Thus in Table I two readings (3 and 5) of the distance between the wheels were made. With Junkers airplanes the black stripes on the wings are clearly distinguishable at long distances.

TABLE I.

Photogrammetric Flight Measurement 1.

Starting Measurement 23.

No.	t	a	h	w	y	x
1	1' 20.9" 0	127.31 54.12 29 14 30 10 127.30 54.12 73.18		66	0	0
2	1' 27.2" 6.3"	110.78 65.06 75 10 76 08 110.76 65.08 45.68		103	0	37
3	1' 33.2" 12.3"	89.20 85.54 20 53 20 54 89.20 85.54 3.66 Track gage		191	0	125
4	1' 35.5 14.6	94.11 73.20 12 23 14 24 94.12 73.22 20.90	113.32 113.00 28 00 28 00 113.29 113.00 0.29	231	< 1	165
5	1' 38.7" 17.8"	80.54 78.18 53 19 54 20 80.54 78.19 2.35 Track gage	112.93 112.50 92 51 93 52 112.93 112.51 0.42	297	< 1	231
6	1' 41.5" 20.6"	82.28 68.70 24 73 24 72 82.25 68.72 13.53	113.13 112.17 14 17 13 112.18 113.13 112.17 0.96	358	1.4	292

TABLE I (Cont.)

Photogrammetric Flight Measurement 1.

Starting Measurement 23.

No.	t	a	h	w	y	x
7	1' 50.7" 29.8	69.64 61.13 64 14 62 16 69.63 61.14 8.49	112.56 105.16 54 16 58 18 112.56 105.17 7.39	572	17.0	506
8	1' 53.8" 32.9	68.34 61.00 33 60.97 30 98 68.32 60.98 7.34	114.35 105.68 37 70 36 72 114.36 105.70 8.66	660	22.8	594
9	1' 56.5" 35.6"	68.35 61.75 38 73 36 74 68.36 61.74 6.62	114.40 105.53 38 52 42 54 114.40 105.53 8.87	733	26.1	667
10	1' 59.5" 38.6	69.30 63.42 30 41 33 41 69.31 63.41 5.90	114.87 105.12 85 15 86 16 114.86 105.14 9.72	822	32.1	756
11	2' 2.7" 41.8"	71.19 65.80 21 79 20 80 71.20 65.80 5.40	114.14 103.24 10 24 10 23 114.11 103.24 10.87	896	39.0	830
12	2' 6.0" 45.1	73.10 68.20 09 18 12 18 73.10 68.19 4.91	114.80 103.36 76 36 76 34 114.77 103.35 11.43	986	45.1	920

No distance measurements need to be made on the aviation field. The distance r of the observer from the starting point is given by the first exposure, which is made at the instant of starting. The distance of the lens from the ground must be known, since this must be added to the calculated altitude, in order to determine the flight altitude y.

TABLE II

Photogrammetric Flight Measurement 2

Starting Measurement 23

No.	Time s	Distance m	Height m	v km/h
1	0	0	0	21.2
2	6.3	37	0	52.9
3	12.3	125	0	62.6
4	14.6	165	< 1	74.1
5	17.8	231	< 1	78.6
6	20.6	292	1.4	84.0
7	29.8	506	17.0	102.5
8	32.9	594	22.8	97.5
9	35.6	667	26.1	106.5
10	38.6	756	32.1	83.9
11	41.8	830	39.0	98.5
12	45.1	920	45.1	

The results are recorded in Table II and by the curves in Figure 7. Accordingly the take-off point is 160 m (525 ft.) from the starting point. The length of the run can be very accurately determined, if it is accurately timed. For the accurate determination of the run, the distance must be added which is traversed by the wind during the starting time. The starting or take-off time was 14 seconds and the wind velocity was 5.5

m/s (18 ft./sec.). Accordingly, the true take-off distance was 160 + 14 x 5.5 = 210 m (689 ft.).

According to the upper curve in Figure 7, the starting speed increases very rapidly and attains the value of 65 km/h (40.4 mi./hr.) at the take-off. To this should be added a wind speed of about 20 km/h (12.4 mi./hr.), so that the actual take-off speed is 85 km/h (52.8 mi./hr.). The speed then increases gradually and falls again after a distance of 700 m (2297 ft.) and then increases again. At this point the flight path first becomes steeper and then again flatter.

In Figure 8 the take-off speed is 74 + 11 = 85 km/h (52.8 mi./hr.). The airplane rose at the same speed until it was nearly 1000 m (3280 ft.) from the starting point, when the speed increased somewhat and the flight path became correspondingly flatter.

Figure 9 was obtained with the new camera. Here the exposures were made at shorter intervals and included the take-off run. The take-off speed was 78 + 8 = 86 km/h (53.4 mi./hr.), while the previous measurement gave 85 km/h (52.8 mi./hr.). The agreement was therefore very good. The same value was found by a comparative measurement with an air-speed indicator. The disadvantage of the latter consists in the fact that this degree of accuracy can be obtained only with rapidly revolving drums and hence for only a very short space of time.

All three starting measurements show the same fact, that the airplane, after taking off, hovers above the ground for a short distance, before beginning to climb. The speed increases very rapidly at first and the airplane climbs somewhat farther at the take-off speed and then assumes a uniform climbing speed. In the first experiment (Fig. 7) the speed curve climbs somewhat slower than in the others. This was made with a heavy commercial airplane, which had to overcome a greater inertia than the others.

Figure 10 represents a landing glide to the first contact with the ground, the airplane flying toward the observer. It sank gradually at first, then somewhat faster and finally hovered close to the ground for about 200 m (656 ft.). Correspondingly, the speed first decreased, then increased somewhat and then remained at 88 km/h (54.7 mi./hr.) shortly before landing. With a wind velocity of 10 km/h (6.2 mi./hr.) the landing speed was accordingly about 98 km/h (61 mi./hr.). The experiment had to be interrupted because the airplane taxied directly past the observation point. Hence the next landing test (Fig. 11) was so made that the airplane flew over the camera before the landing. It was therefore only a short distance above the ground, hovered for quite a long distance and then landed at a distance of 315 m (1033 ft.) with a speed of 70 km/h (43.5 mi./hr.). At a wind velocity of 8 km/h (5 mi./hr.) the landing speed was accordingly 78 km/h (48.5 mi./hr.).

TABLE III.

Photogrammetric Flight Measurement 2.

Speed Measurement.

No.	Time s	Distance m	Height m	Speed km/h	Remarks
1	0	233	51	141	With the wind
2	2.6	335	53	151	
3	5.7	465	55	146	
4	8.1	562	57	144	
5	10.55	660	60		
1	0	565	36	105	Against the wind
2	4.8	425	33	109	
3	8.8	304	27	109	
4	11.3	223	27	101	
5	13.4	170	28		

Results: With the wind, 427 m in 10.55 s, 146 km/h (90.7 mi./hr.)

Against " " 395 " " 13.40 s, 106 " (65.9 ")

Ground speed of airplane, 126 " (78.3 ")

Wind velocity, 20 " (12.4 ")

Table III gives the results of a speed experiment. The airplane flew twice over the camera, with the wind and against the wind. The total distance and the total time in one direction were determined. The time values served only for control, as to whether the altitude remained nearly constant or not. The speeds were naturally not so accurate, because the exposures were made at very short intervals. We here had a wind velocity of 20 m/s (65.6 ft./sec.), while 5 m/s (16.4 ft./sec.) or 18 km/h (11.2 mi./hr.) was measured. The air speed was accordingly 126 km/h (78.3 mi./hr.). The accuracy of a speed measurement depends on the accuracy with which the time can be read. The range of error of a measurement can therefore be readily determined. If a watch is used which indicates twentieths of a second, the error cannot exceed 1/40 of a second. In order, therefore to determine the speed to within 1%, 2.5 seconds must elapse between two successive exposures. In testing the accuracy of the flight-path measurement, it is obviously not sufficient to say that readings can be made with the "comparator" to 0.01 mm (0.0004 in.) but it is chiefly a question of how accurately it can be adjusted. For this purpose several readings must be made. In the formula

$$w = \frac{bf}{a} \tag{2}$$

b and f are constant and the size of the image a is diminished by Δa for an increase of Δw in the distance w. Hence

$$w + \Delta w = \frac{bf}{a - \Delta a}$$

from which follows

$$\Delta w = \frac{\Delta a}{a - \Delta a} w \tag{3}$$

Correspondingly we obtain from the second formula (1)

$$\frac{\Delta y}{y} = \frac{\Delta h}{h} . \tag{4}$$

The error in the determination of the altitude is proportional to the error in the reading. Let reading 8 in Table I serve as an example for formula (3).

Readings		a	λ	$\lambda\lambda$
68.34	61.00	7.34	0	4
33	60.97	36	2	0
30	98	32	-2	4
		7.34	0	8

The mean error in reading is

$\sqrt{\frac{8}{2}} = \pm 2,$ whence $a = \pm 0.02$ mm (0.0008 in.) and

$$\Delta w = 660 \frac{0.02}{7.32} = +\ 1.80 \text{ m}$$

$$\Delta w = 660 \frac{-0.02}{7.36} = -\ 1.79 \text{ m}$$

The mean value of the distance is therefore 1.8 m (5.9 ft.) at w = 660 m (2165 ft.), which is 0.27%.

This error can generally be reduced by taking a larger number of readings. For Figure 5 the following ten readings were taken.

Readings		a	λ	$\lambda\lambda$
109.72	116.53	6.81	+1	1
72	52	80	+2	4
71	54	83	-1	1
71	52	81	+1	1
71	53	82	0	0
70	52	82	0	0
72	53	81	+1	1
71	53	82	0	0
69	52	83	-1	1
70	55	85	-3	9
		6.82	0	18

Here the mean error is

$$\sqrt{\frac{18}{9}} = \sqrt{2} = \pm 1.4,$$

whence, for the errors in the distance, we obtain

$$\Delta w = 354 \frac{0.014}{6.806} = 0.73 \text{ m}$$

$$\Delta w = 354 \frac{0.014}{6.834} = 0.726 \text{ m}$$

or about 2%.

The last readings were taken from a motion-picture film.

The accuracy, even in unfavorable cases, is within 0.5% and is therefore so great that the method can be used even for fine measurements. It was used in the D. V. L. (German Research Institute for Aeronautics) in acceptance tests and lastly in the South German Round-Flight Contest. Moreover, it is to be used in seaplane contests, since it is especially suitable for measurements with seaplanes.

The camera can also be advantageously used for other measurements, e.g., in flow research, as described in Zeitschrift für Flugtechnik und Motorluftschiffahrt No. 9, 1926;* furthermore, for photographing processes which take place slowly and for which an ordinary motion-picture camera is too small, as, for example, in cloud measurements.

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

*P. Raethjen, "Das zweidimensionale, atmosphärische Stromfeld um ein Hinderniss" (The two-dimensional field of flow around an obstacle), Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 14, 1926, pp. 185-192.

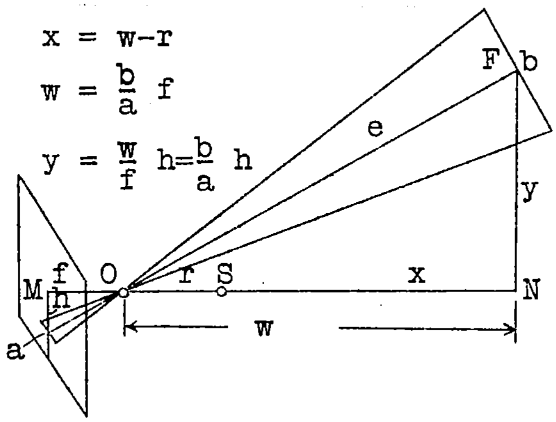

Fig.1

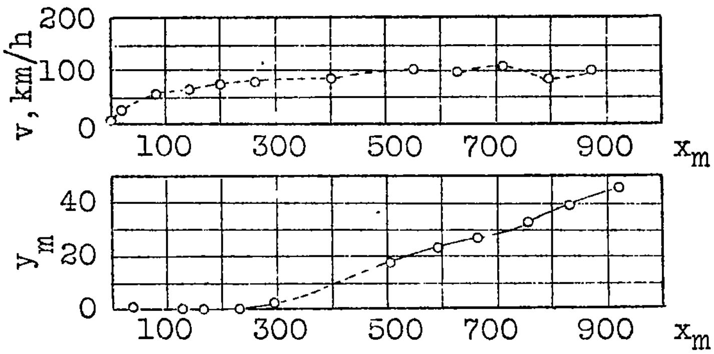

Fig.7

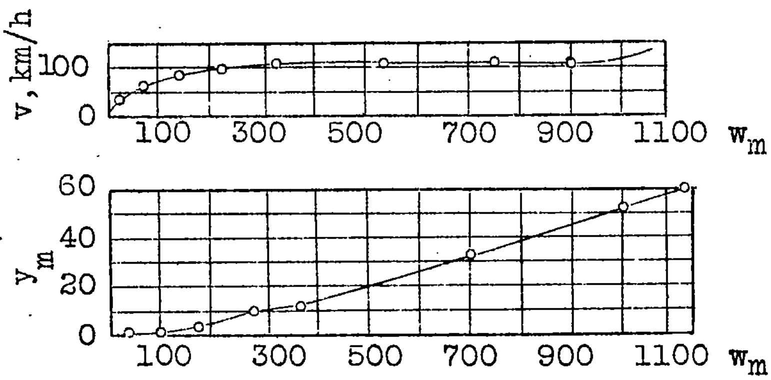

Fig.8

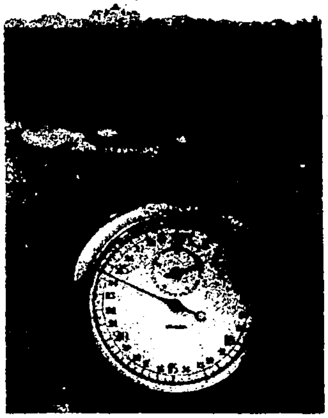

Fig.2

Fig.5

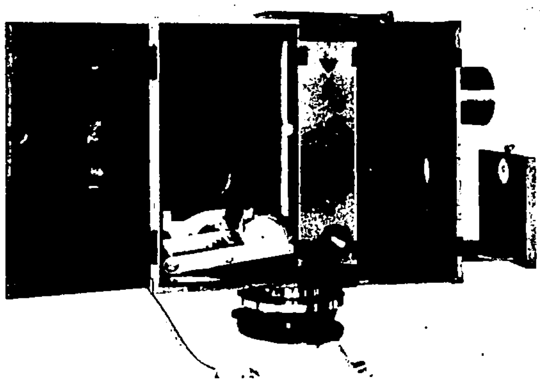

Fig.3

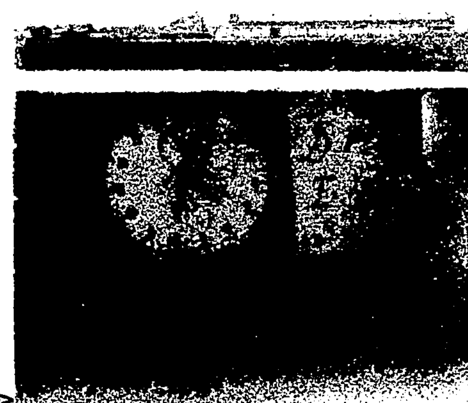

Fig.6

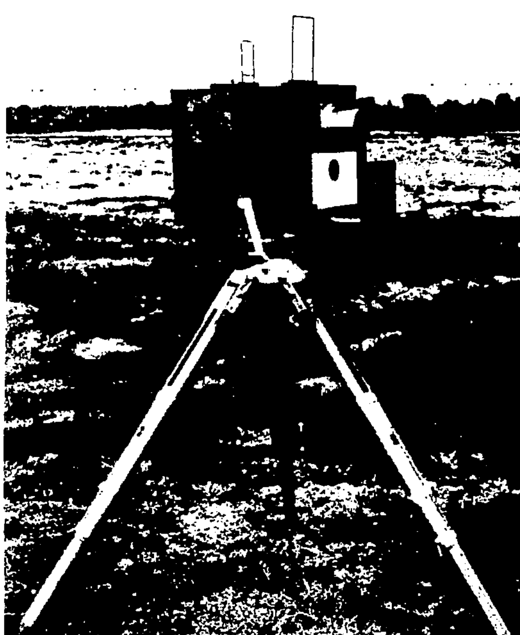

Fig.4

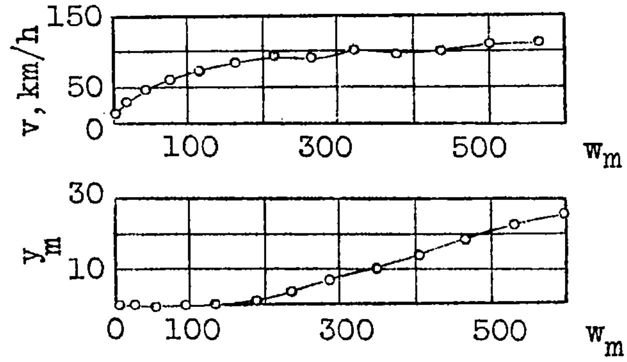

Fig.9

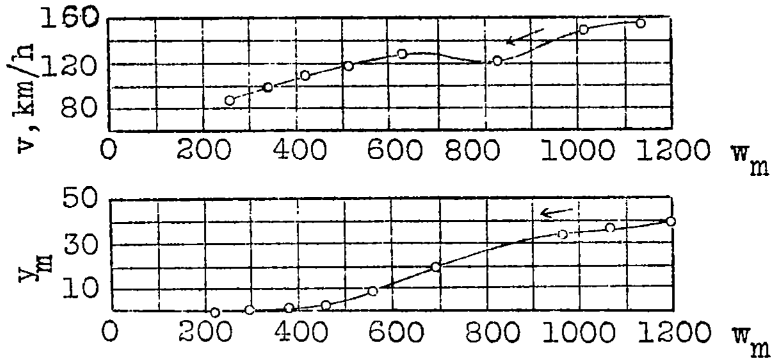

Fig.10

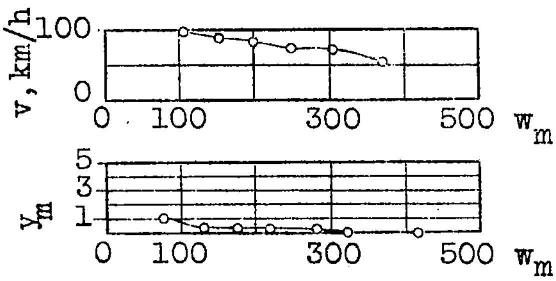

Fig.11