NAL ADVISORY COMMITTEE
FOR AERONAUTICS

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Mr. Truscott

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 147.

SPEED MEASUREMENTS MADE BY DIVISION "A" OF THE AIRPLANE DIRECTORATE (FLUGZEUGMEISTEREI), SUBDIVISION FOR FLIGHT EXPERIMENTS.

By V. Heidelberg and A. Hölzel.

From Technische Berichte, Volume III, No. 5, (1918).

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Summary.

1. The various speeds of an airplane can only be measured in horizontal flight, since there are no means for measuring the angle of ascent or descent.
2. The measurements must be corrected for the density of the air. This is obtained by simultaneous pressure and temperature measurements during flight.
3. Calculation from the mean yearly values in accordance with Everling's suggestion (Technische Berichte, Vol. I, No.2) can only be considered an approximation, since the distribution of pressure and temperature in the individual strata at different attitudes undergoes such large variations that the yearly mean gives inaccurate values.
4. Thermographs of the present form are useless for temperature measurements on an airplame.
5. In altitude data, the following are to be distinguished: the height above the earth, the barometric altitude and the altitude corresponding to the yearly mean air density.

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*rom Technische Berichte, Volume III, No. 5, pp. 174-179 (1918).

3. Variometers are not suited for the mechanical control of high altitude flight.

Arrangement and Procedure followed in the Experiments.

Speed measurements were made on seven different airplanes at altitudes of 2500 to 4000 meters (8200 to 13100 feet), using Jacoby's method (Technische Berichte, Volume II, No.1, p.99). with theodolites from two fixed points. The base was 1.4 kilometers (.87 mile) long. The effect of the wind was eliminated by a triangular flight, each side of the triangle requiring about two minutes flying time. The readings were taken about every 30 seconds or six times on each leg. The airplanes carried the required useful load for the flight.

The airplane speeds obtained were corrected for the density of the air. For the sake of clearness, the altitude figures corresponding to the yearly mean on the assumption of normal distribution of pressure and temperature, are given in the tables and diagrams. The air densities were determined in each flight from barograph curves regarded as pure pressure curves and from temperature readings on alcohol thermometers. The readings of three thermometers agreed closely.

In the calculation of these air densities, it is apparent that computation from the yearly mean, according to Everling's method, is not reliable and can only be employed as an approximation, since the distribution of pressure and temperature in the individual strata is subject to considerable variations. This result was expected when Everling's method was adopted.

In temperature measurements it was found that alcohol thermometers lagged so much that readings during ordinary gliding flight were inaccurate, although, on the other hand, they registered quickly enough during climbing flight. In order to avoid errors due to lag of the thermometer, readings were not taken until after the triangular flight. Comparison of the readings of thermometers and thermographs showed great inaccuracy in the latter, due to the great difficulty in preventing the oscillation and vibration of the airplane from being transmitted to the thermographs, the recorded curves being so thick that the mean value could not be obtained with certainty.

The measurements are recorded in Table I, three values being given for the altitudes:

1. The actual height above the ground as measured by the theodolites, i.e., the vertical projection.
2. The barometric altitude indicated by the barographs, which corresponds to a calculated air pressure for the yearly mean at all altitudes. A ground temperature of 10°C is assumed and a temperature decrease of 0.5°C per 100 meters. The barograph curves were compared with their calibration curves which were obtained by regularly changing the air pressure in a vacuum chamber.
3. From the curve of air density ρ calculated from the temperature and pressure observations, an altitude curve is finally

obtained, which took into consideration the fall in pressure and temperature. In Figs. 1, 2 and 3, the barograph curve, the ordinates of which are originally arcs of circles, is shown by a dotted line. Beside these dotted curves, the mean yearly altitudes, corresponding to the air densities are given.

In Figs. 4 to 8, the temperatures observed in the test flights are plotted against the observed air pressures. The course of the temperature curve for Pfalz D III a and Junkers C I airplanes, is noteworthy. Although both flights lie within the same pressure range, their difference is shown up to 8°C. With Halb CL IV, the temperature falls from +1 to -4°C between 2.5 and 3 kilometers (8200 and 9800 feet) altitude. These examples show that all calculations which depend on the assumption of a temperature fall of 1°C per 200 meters (656 feet) can claim only approximate accuracy in any particular case.

Since the flight characteristics depend only on the air density, all comparative values are to be corrected accordingly. It follows that, in speed flights, neither the actual nor the barometric altitudes are alone involved and we must consequently employ for velocity measurements an air density indicator, which is used in speed flights in place of a barograph and renders superfluous all approximate calculations, of the inaccuracy of which, we have been convinced for some time.

In Figs. 9 to 11, the climbing speed for the standard air density is given, the curve being obtained by differentiating the barograph curves. From these curves it is apparent as to how efficiently an airplane is flown.

In Fig. 12, the horizontal speeds are shown for the standard air density. An example of the calculation of the mean of the three observed speeds of the triangular flight, diagrams of three flights made with Fokker D VII and Junkers C I airplanes are given in Figs. 13 to 18. For airplanes without strut wires and with thick wing sections, the speeds are greater. Moreover, the curves slope rather rapidly downward and within the given range, the speed decreases only slightly with the altitude. On the other hand, the curves for the airplanes with smaller horizontal speeds are flat, i.e., the speeds decrease rapidly with increasing altitude.

Experiments, carried out with variometers during the speed measurements, show that they are useless in practical work. Sensitive variometers clearly indicate changes in the vertical speed, so that in changes due to elevator, the pointer shows vibrations about a mean position. Furthermore, the pilot would only attain mechanically controlled altitude flying, if he were compelled to keep the pointer of the variometer on that point of a predetermined curve suitable for the airplane and corresponding to the determined altitude. This curve would have to be that of the climbing speed which, for the actual atmospheric conditions could be maintained when the airplane is flown most efficiently, and would, therefore, have to be accurately determined previously and accompany the variometer for the airplane in question. A self-recording variometer would then, within the curve of climbing velocities given by Fig.

19, give a record similar to that shown. In using the variometer, a further difficulty arises with C and D types* of airplanes, in consequence of the very great range of their vertical speeds. For horizontal flight, a variometer, which has high sensitivity in the neighborhood of the zero position and a large oscillation range would have to be used and the nozzle adjustment would therefore be great. Since the downward speeds possess high values in C and D types of airplanes, up to 25 m/sec (82 ft/sec) an unadjustable instrument suitable for horizontal flight fails in gliding flight. Nozzle adjustments for horizontal, climbing and gliding flight might eliminate a part of this difficulty, but it is not suitable for practical use on C and D airplanes, although it can be used in the present case for scientific experiments. In G and R types, having a small rate of change in climbing speed, it would be applicable to a limited extent. Moreover, a variometer is not absolutely essential for horizontal flight, while the large series of experiments has shown that, with the help of a good altimeter, horizontal flight can be carried out with sufficient accuracy, since the barographs are so sensitive that, in the barogram (Fig. 20), even small changes of altitude, in the necessarily short turning flight (arcs of about 300°), are clearly seen.

Error of the Theodolite Measuring Method.

In a large series of flights with the same airplanes and under similar conditions, it was found that the base of 1.4 kilometers, used in the present case, is not reliable for altitudes of over

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* Observation and pursuit airplanes.

4000 meters, since the sighting lines intersect at too sharp an angle. Hence the values for 4500 and 5000 meters are omitted. At an altitude of 4000 meters the greatest error was found to be ±3%, from comparisons of a series of measurements. The measurements can also be made for altitudes of 4000 to 7000 meters (13100 to 23000 feet) if a larger base is chosen for the theodolites. The errors are also smaller, if three theodolites are employed, the readings follow more quickly after each other, and the accuracy of the automatic recording theodolites is increased. The above measurements are only the beginning of a larger work on speed measurements, which has been planned for Lake Muritz. A base of 3000 or 5000 meters (9800 or 16400 feet) is there taken and the sequence of readings may be shortened to 1/2 second. It must be left to these detailed experiments to determine the limits of error of the theodolites up to an altitude of 6000 meters (19700 feet). Yet it may be expected that this method can be improved so as to serve for calibrating speed indicators for use on airplanes, (Pitot tubes, Venturi tubes, etc.).

The sole aim of the present paper is to remedy the complete lack of data from actual flights and to give the order of magnitude of airplane speeds rather than their accurate values. The investigations described above show, however, that the previously assumed horizontal speeds of airplanes are very far from having been attained and have led to quite erroneous views, not only with us but also in other countries. This astonishing fact is due to not having

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* Bombing airplanes.

carried out reliable speed measurements above 2000 meters (6560 feet). According to English and French reports their customary measuring methods (with camera obscura, etc.) can only be used up to altitudes of 1500 meters (4900 feet).

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Table 1. Results of recent Speed Measurements.

No.	Date of Test	Airplane	Air Pressure		Temperature		Air Density	
			mm. Hg.	in. Hg.	°C	°F	kg/m³ ρ	lb/ft³ ρ
1	March 5, 1918.	Rol DII a	530	20.87	- 7	19.40	0.925	.0577
			503	19.80	-11	12.20	0.890	.0556
			480	18.90	-14	6.80	0.860	.0537
2	March 15, 1918.	Pfal D III a	525	20.67	- 7	19.40	0.920	.0574
			488	19.21	-12	10.40	0.870	.0543
			460	18.11	-15	5.00	0.830	.0518
			400	15.75	-22	-4.00	0.740	.0462
3	March 18, 1918.	Junk C I	523	20.59	0	32.00	0.890	.0556
			485	19.09	- 4	24.80	0.840	.0524
			435	17.13	-11	12.20	0.770	.0481
4	March 23, 1918.	Halb CI IV	525	20.67	- 4	24.80	0.910	.0568
			492	19.37	- 7	19.40	0.860	.0537
			461	18.15	- 9	15.80	0.770	.0481
5	April 3, 1918.	Fok DVII	535	21.06	- 9	15.80	0.940	.0587
			496	19.53	-13	8.60	0.890	.0556
			464	18.27	-17	1.40	0.840	.0524
6	April 27, 1918	S E	545	21.46	- 8	17.60	0.960	.0599
7	April 9, 1918.	Fok Dr I	538	21.18	- 5	23.00	0.930	.0581
			505	19.88	- 7	19.40	0.880	.0549
			443	17.44	-12	10.40	0.790	.0493

Table I. Results of recent Speed Measurements (Cont.)

No.	Climbing		Climbing		Barometric height		Height based on yearly mean.	
	Speed m/sec.	Height m.	Speed ft/sec	Height ft.	m.	ft.	m.	ft.
1	-- -- --	2842 3350 3750	-- -- --	9324 10991 12303	2900 3300 3700	9514 10827 12139	2900 3250 3550	9514 10663 11647
2	1.95 1.85 1.65 0.70	2955 3450 3980 5000	6.40 6.07 5.41 2.30	9695 11319 13058 16404	3000 3575 4000 5100	9842 11729 13123 16732	2960 3450 3900 4900	9711 11319 12795 16076
3	2.10 1.60 0.80	2900 3350 4300	6.89 5.25 2.62	9514 10991 14108	3000 3600 4450	9842 11811 14600	3250 3750 4500	10663 12303 14764
4	-- -- --	2950 3450 3970	-- -- --	9678 11319 13025	3000 3500 4000	9842 11483 13123	3050 3550 4070	10007 11647 13353
5	3.00 2.55 2.20	2775 3250 3780	9.84 8.37 7.22	9104 10663 12402	2850 3450 3950	9350 11319 12959	2750 3250 3750	9022 10663 12303
6	2.00	2620	6.56	8596	2700	8858	2580	8465
7	4.00 3.80 2.20	2780 3200 4180	13.12 12.47 7.22	9121 10499 13714	2800 3300 4300	9186 10827 14108	2800 3300 4300	9186 10827 14108

Table I. Results of recent Speed Measurements (Cont.)

No.	Horizontal Speed.				Corrected Horizontal Speed.			
	m/sec.	ft/sec.	km/hr.	M.P.H	m/sec.	ft/sec.	km/hr.	M.P.H.
1	41.4	135.83	149.0	92.58	41.4	135.83	149.0	92.58
	39.7	130.25	142.9	88.79	39.7	130.25	142.9	88.79
	37.7	123.69	135.7	84.32	37.7	123.69	135.7	84.32
2	40.5	132.87	145.8	90.60	41.4	135.83	149.0	92.58
	40.6	133.20	146.0	90.72	39.8	130.58	143.2	88.98
	37.7	123.69	135.7	84.32	38.5	126.31	138.5	86.06
	37.0	121.39	133.0	82.64	33.9	111.22	129.2	80.28
3	44.7	146.65	161.0	100.04	44.7	146.65	161.0	100.04
	43.6	143.04	156.0	96.93	44.0	144.36	158.5	98.49
	43.0	141.08	156.0	96.93	43.0	141.08	154.6	96.06
4	41.1	134.84	148.0	91.96	41.1	134.84	148.0	91.96
	37.3	122.37	134.0	83.26	37.3	122.37	134.0	83.26
	34.1	111.88	123.0	76.43	34.1	111.88	123.0	76.43
5	45.0	147.64	162.0	100.66	45.0	147.64	162.0	100.66
	44.5	146.00	160.0	99.42	44.5	146.00	160.0	99.42
	43.2	141.73	156.0	96.93	43.2	141.73	156.0	96.93
6	42.0	137.79	151.2	93.95	42.0	137.79	151.2	93.95
7	43.6	143.04	157.0	97.55	43.3	142.06	155.8	96.81
	40.9	134.19	147.0	91.34	41.3	135.50	148.9	92.52
	38.8	127.30	139.0	86.37	38.4	125.98	138.0	85.75

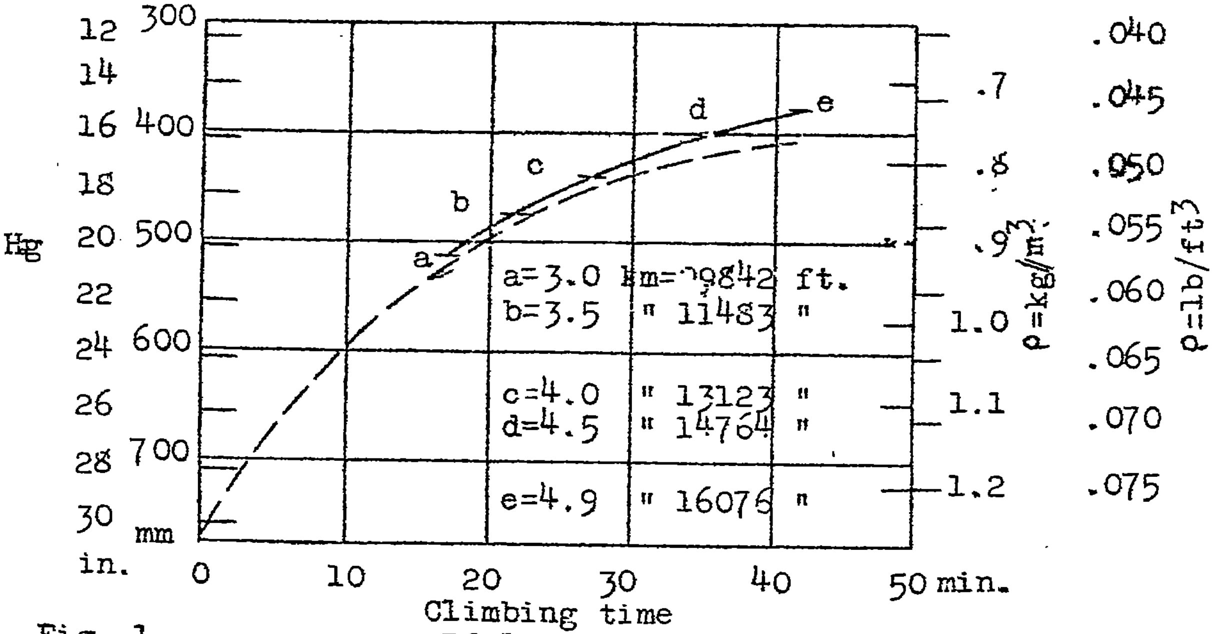


Fig. 1

Pfal.DIIIa

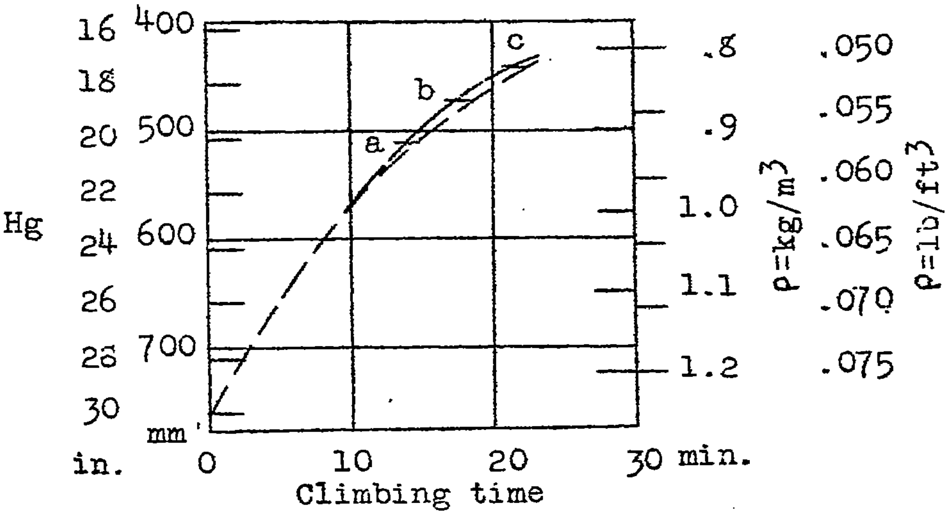


Fig. 2

Fok. DVII

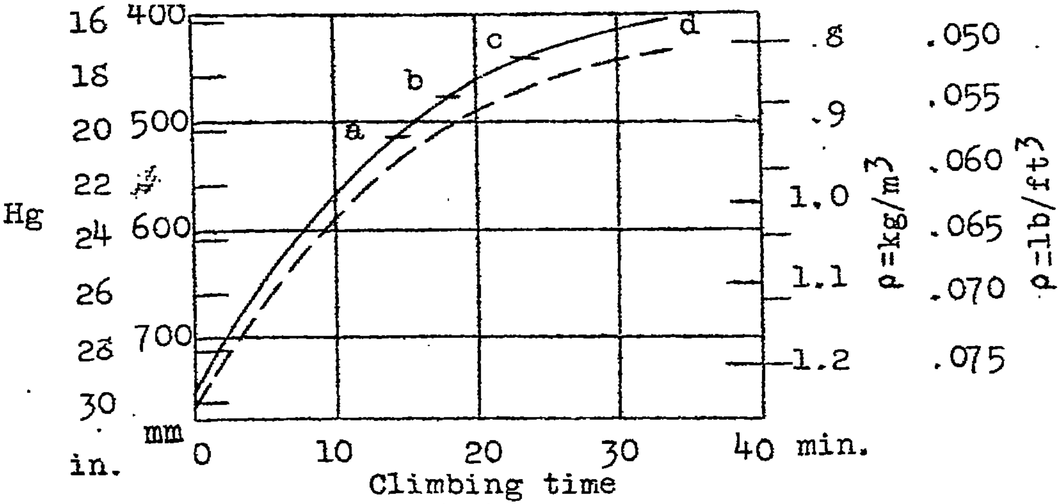


Fig. 3

Junk. CI

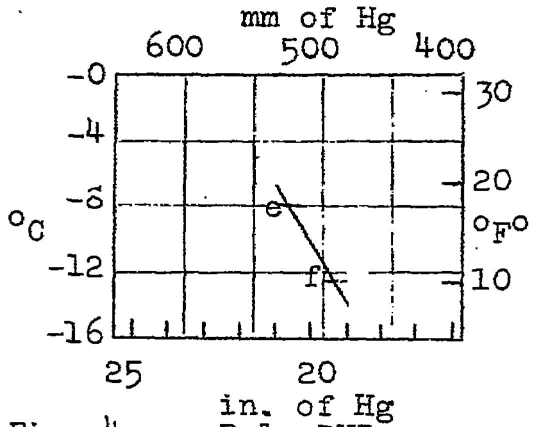


Fig. 4 Rol. DVI

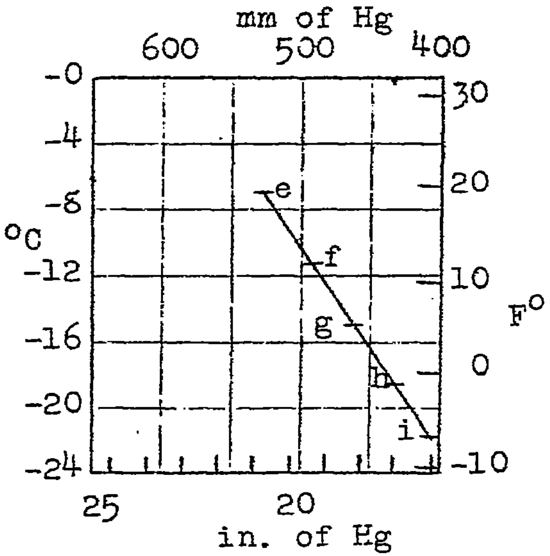


Fig. 5 Pfal. DIIIa

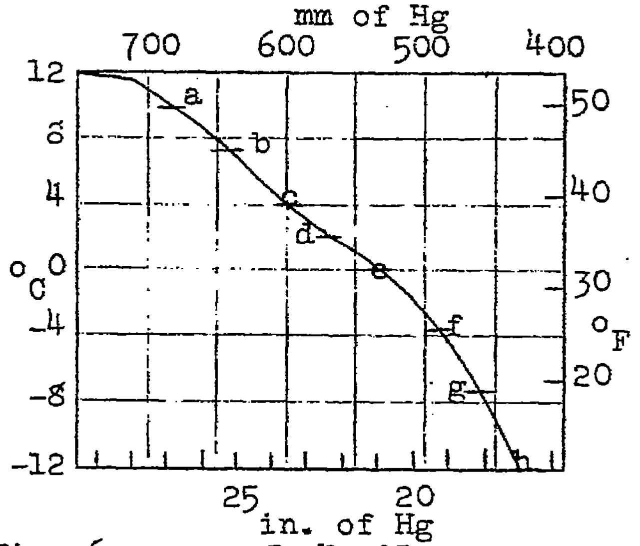


Fig. 6 Junk. CI

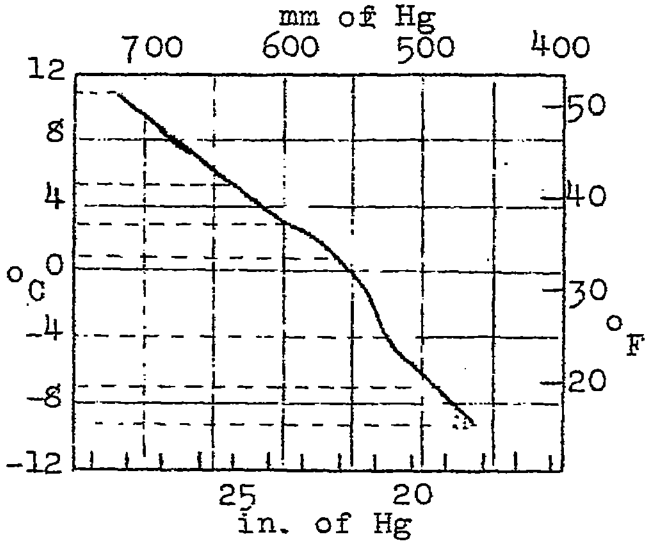


Fig. 7 Halb. CLIV

a = 1.0 km = 3281 ft.
b = 1.5 km = 4921 ft.
c = 2.0 km = 6562 ft.
d = 2.5 km = 8202 ft.

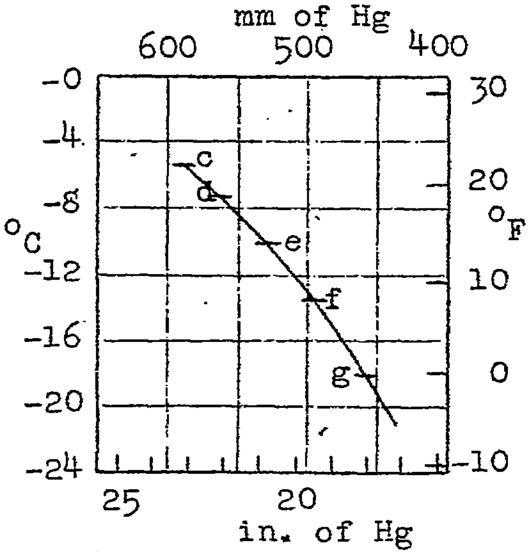


Fig. 8 Fok. DVII

e = 3.0 km = 9842 ft.
f = 3.5 km = 11483 ft.
g = 4.0 km = 13123 ft.
h = 4.5 km = 14764 ft.
i = 5.0 km = 16404 ft.

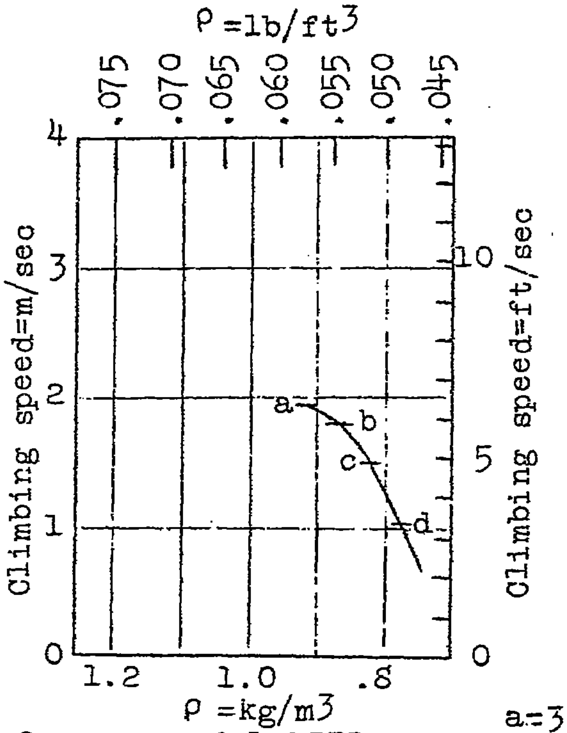


Fig. 9 Pfal.DIIIa

a=3.0 km=9842 ft.
b=3.5 " 11483 "
c=4.0 " 13123 "
d=4.5 " 14764 "

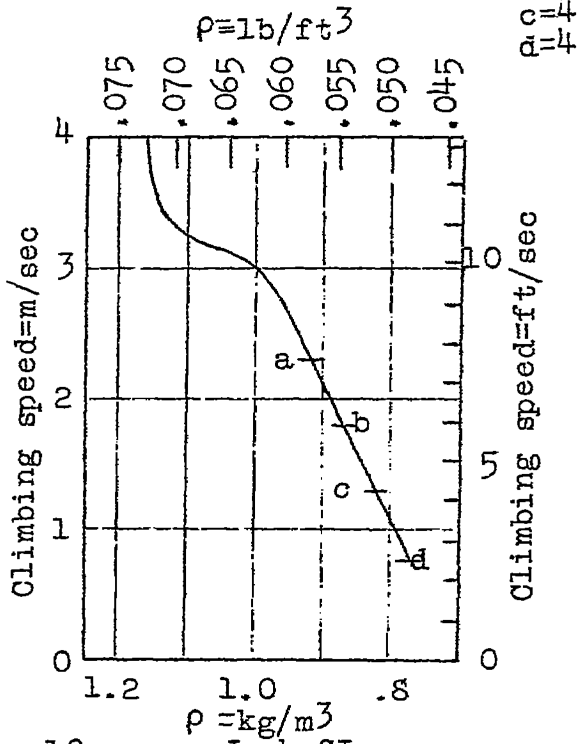


Fig. 10 Junk.CI

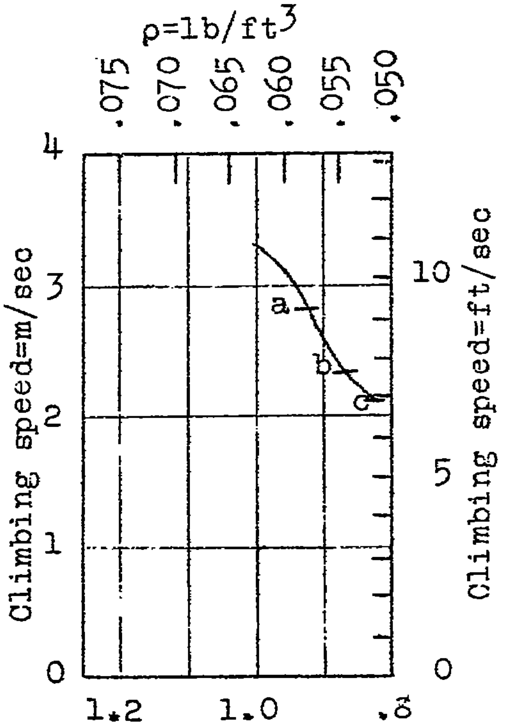


Fig. 11 Fok. DVII

a=3.0 km=
9842 ft.
b=3.5 km=
11483 ft.
c=4.0 km=
13123 ft.

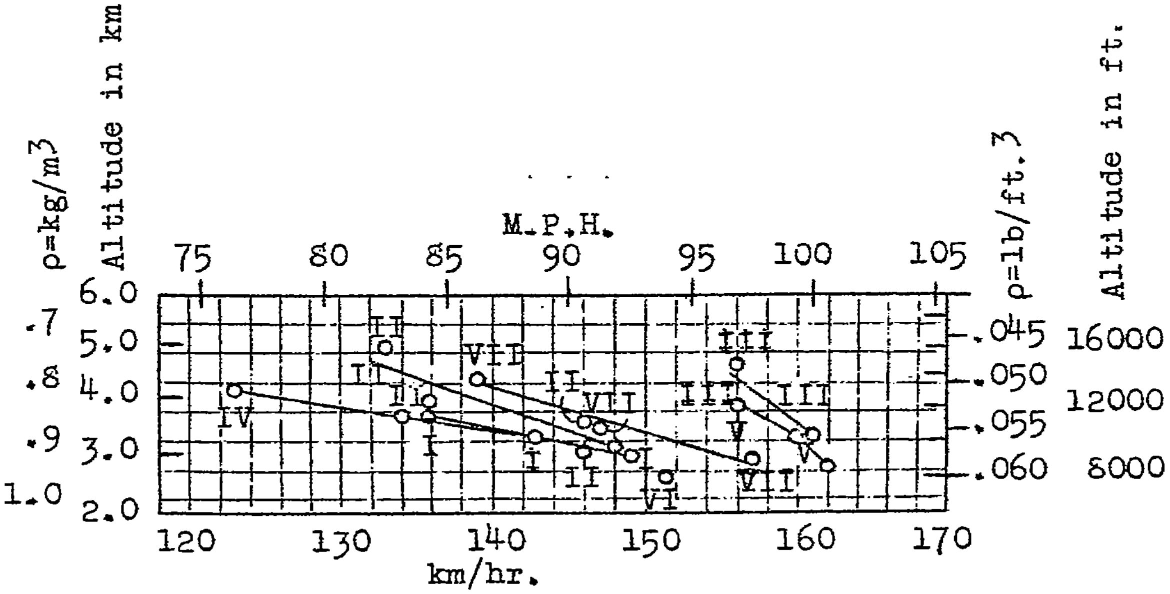


Fig. 12 Horizontal flight

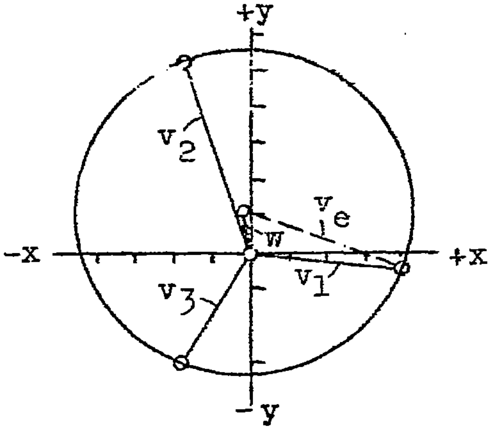


Fig. 13
1st. Triangle
2775 m
9100 ft.

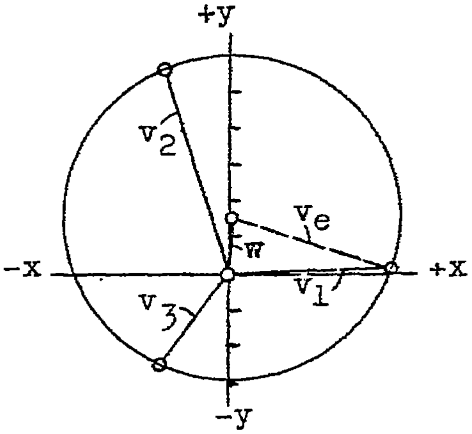


Fig. 14
2nd. Triangle
3250 m
10663 ft.

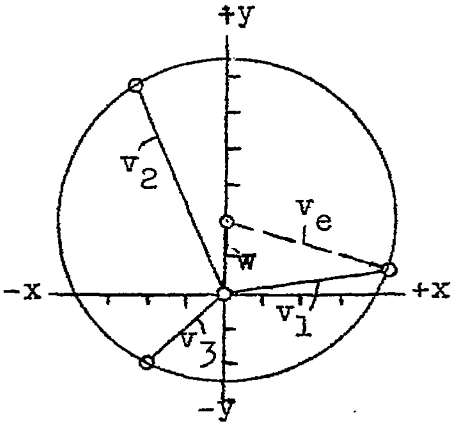


Fig. 15
3rd. Triangle
3780 m
12401 ft.

Fig. 13

1st. Triangle, mean altitude 2775 m (9100 ft.)

v_1 = 40.8 m/sec (133.86 ft/sec)
v_2 = 55.3 " " (181.43 " ")
v_3 = 35.6 " " (116.80 " ")
v_e = 45.0 " " (100.66 M.P.H.) 162 km/hr.
w = 10.7 " " (35.10 ft/sec)

Fig. 14

2nd. Triangle, mean altitude 3250 m (10663 ft.)

v_1 = 42.2 m/sec (138.45 ft/sec)
v_2 = 60.0 " " (196.85 " ")
v_3 = 30.0 " " (98.42 " ")
v_e = 44.5 " " (99.54 M.P.H.) 160 km/hr.
w = 16.5 " " (54.13 ft/sec)

Fig. 15

3rd. Triangle, mean altitude 3780 m (12401 ft.)

v_1 = 41.9 m/sec (137.47 ft/sec)
v_2 = 26.2 " " (85.96 " ")
v_3 = 61.3 " " (201.11 " ")
v_e = 43.2 " " (96.64 M.P.H.) 156 km/hr.
w = 20.7 " " (67.91 ft/sec)

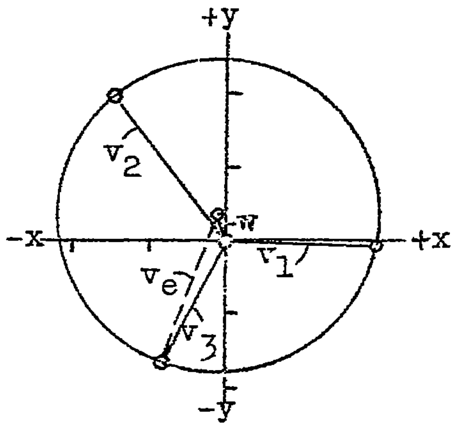


Fig. 16
1st. Triangle
2900 m
9514 ft.

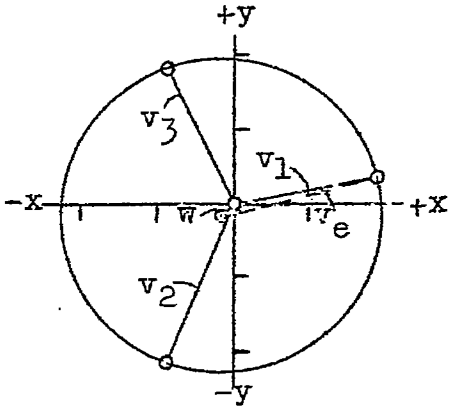


Fig. 17
2nd. Triangle
3350 m
10991 ft.

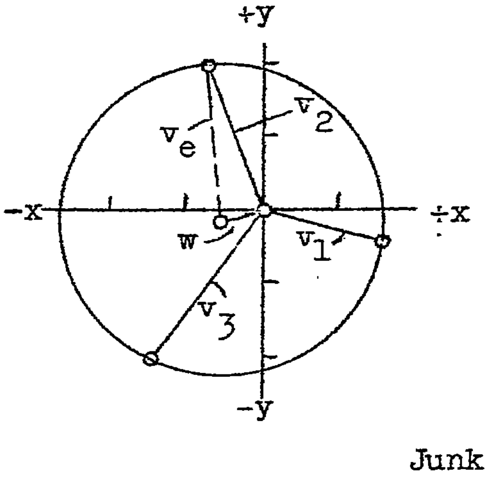


Fig. 18
3rd. Triangle
4300 m
14108 ft.

Fig. 16

1st. Triangle, mean altitude 2900 m (9514 ft.)

v_1 = 42.1 m/sec (138.12 ft/sec)

v_2 = 51.1 " " (167.65 " ")

v_3 = 39.6 " " (129.92 " ")

v_e = 44.7 " " (96.86 M.P.H.) 161 km/hr.

w = 6.8 " " (22.31 ft/sec)

Fig. 17

2nd. Triangle, mean altitude 3350 m (10991 ft.)

v_1 = 39.5 m/sec (129.59 ft/sec)

v_2 = 47.3 " " (155.18 " ")

v_3 = 41.5 " " (136.15 " ")

v_e = 43.4 " " (97.08 M.P.H.) 156 km/hr.

w = 4.2 " " (13.78 ft/sec)

Fig. 18

3rd. Triangle, mean altitude 4300 m (14108 ft.)

v_1 = 32.8 m/sec (107.61 ft/sec)

v_2 = 43.1 " " (141.40 " ")

v_3 = 50.5 " " (165.68 " ")

v_e = 43.3 " " (96.85 M.P.H.) 156 km/hr.

w = 11.1 " " (36.42 ft/sec)

Junk.CI

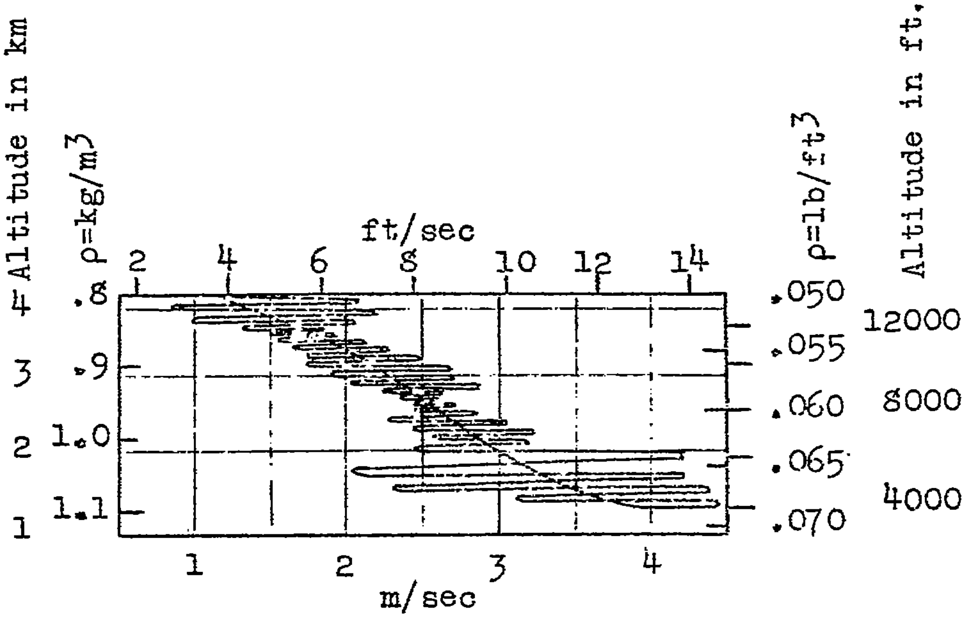
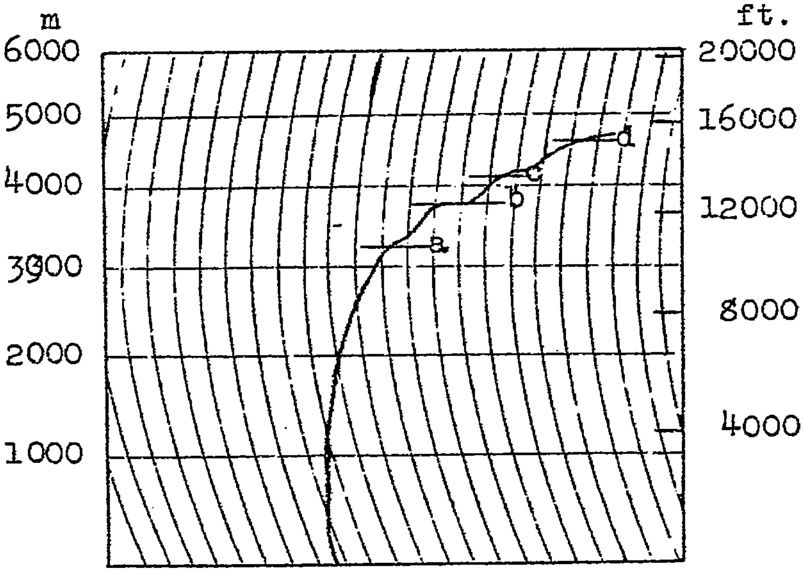


Fig. 19



a = .89 kg/m³ = .056 lb/ft³ = ρ
b = .84 " " = .052 " " = "
c = .80 " " = .050 " " = "
d = .77 " " = .048 " " = "

Fig. 20 Junk. CI