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MEDICAL RESEARCH COMMITTEE.

REPORTS

UPON

THE PHYSIOLOGICAL AND MEDICAL ASPECTS OF FLYING.

No. 1.

THE OXYGEN NEEDS OF FLYING OFFICERS.

18*th February*, 1918.

REPORTS UPON THE PHYSIOLOGICAL AND MEDICAL ASPECTS OF FLYING.

No. 1.—THE OXYGEN NEEDS OF FLYING OFFICERS.

CONTENTS.

I.—REPORT ON THE EXAMINATION OF A SERIES OF SUCCESSFUL AND UNSUCCESSFUL PILOTS FROM THE POINT OF VIEW OF "OXYGEN WANT."

These pilots were examined chiefly from the point of view of applied physiology.

In the first place attention was directed to the following points :—

(1) By the correlation of simpler with more elaborate methods, tests were devised which indicated the possibility of exclusion from the flying services of candidates who were likely to suffer from discomfort in the air, headache, giddiness, fainting, dizziness, nausea, vomiting, pressure in the head, blood rushing to the temples, palpitation of the heart, etc., symptoms which might be due to lack of proper oxygenation of the blood and were likely to render them unfit as flying officers.

(2) To find some fairly simple method by which the

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statements of pilots as to their disabilities in the air might be tested, and an opinion formed as to whether the symptoms complained of were due to lack of oxygen or to some other cause.

1. Methods of Research.

From a number of pilots a sample of blood was taken, the hæmoglobin content, the corpuscular count, and the total oxygen capacity after submission to rarefied atmosphere, determined.

The first two points were barren of results ; of the third it is not fair to speak, since the conditions under which the work was done were not suitable for so delicate a technique, and for this reason this method of research was discarded after about ten examinations. The research then proceeded by the taking of

(*a*) the tidal air ;

(*b*) the vital capacity ;

(*c*) the composition of the alveolar air after full expiration and full inspiration ;

(*d*) the composition of the alveolar air after full expiration and inspiration and holding the breath as long as possible, the length of time being noted ;

(*e*) by getting the subject to breathe in and out of a bag (described later), the carbon dioxide being absorbed by a cartridge containing coke coated with caustic soda.

It is not proposed to give here the results of all the analyses of the alveolar airs. These are still being examined and will be more fully recorded later. It is sufficient to say that the analyses revealed fairly constantly an oxygen content in the alveolar air, after full expiration and inspiration, of about 16 per cent., giving the oxygen content of the lung upon the full vital capacity.

The oxygen content of the alveolar air after holding the breath gave an idea of the amount of diminution of oxygen which can take place in the alveoli before discomfort is induced. This was found to vary from 13·5 to 10 per cent. according to the individual. The idea underlying the test of holding the breath is that, during the holding of the breath, the oxygen content of the air in the lung becomes less and less, so that the subject is, so to speak, at the time ascending to a rarer atmosphere and therefore the degree of rarefaction which can be tolerated without discomfort gives an indication of the height to which an individual can ascend without discomfort. It was argued that a man who can hold his breath long, until the alveolar oxygen content is low, should make a good altitude flyer ; a man who can hold his breath but a short time should make but a poor high flyer, or a flyer with poor resolution. This test therefore has been carefully correlated with the bag experiment described later, to which the objections as to the accumulation of carbon dioxide and the embarrassment of the circulation do not apply.

From the point of view of simple tests, therefore, attention has been directed to the vital capacity, and this power to hold the breath after full expiration and inspiration.

2. Results.

In Table I. are given figures obtained from normal successful pilots. They were obtained from pilots of the Flying Services who were admitted without any *special* medical examination. In general, they were pilots of great experience, and represent therefore the survival of the fittest. The setting of the normal standard by the examination of normal successful aviators has been adopted in regard to all tests here described. Aerodromes are visited for this purpose, and the pilots in question are selected for examination by the officer in command.

Table I.

No. in C.	Name.	Vital capacity in c.c.	Time breath held after full expiration and inspiration. Secs.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
1	Capt. S. C. ...	3,750	53	525	15,000	8,000	From overseas. A little stale.
2	Capt. L. M. ...	3,500	50	270	11,500	5,000	A little jumpy.
3	2/Lt. V. ...	3,500	60	280	9,000	5,000	Just back from overseas for rest.
4	Capt. T. G. ...	4,900	80	2,000–3,000	18,500	5,000 (latterly)	——
5	Capt. M. ...	4,000	50	250	17,000	5,000	Too much tobacco.
6	Capt. J. A. C.	3,800	72	480	20,500	15–17,000	——
7	Lt. L. G. ...	3,900	43 av. 46 max.	260	12,000	4–5,000	Stale. Just from overseas.
8	Capt. L. C. ...	4,300	68	220	19,000	13,000	——
9	Capt. C. M. L.	3,550	78	500	14,000	5–8,000	——
10	Flt. Lt. C. V. A.	3,400	65	360	15,000	8–10,000	——
11	Capt. E. W. P.	3,800	77	400	16,000	10,000	——
12	Capt. A. P. M.	3,400 3,500	78	250	16,000	10–12,000	——
13	Major M. ...	3,900	75	500	13,800	10–11,000	——
14	Lt. D. A. S.	4,100	61	400	13,000	10,000	——
15	Capt. N. ...	3,750	59	130	9,000	2,000	——
16	Lt. J. S. ...	4,000	70	320	11,500	—	——
17	Capt. M. ...	3,900	50	1,060	14,000	6–11,000	——
18	Capt. F. ...	3,700	81	300	11,000	6–7,000	——
19	Flt. Lt. S. ...	4,300	69	150	17,000	8,000	——
20	Flt. Lt. S. M.	4,300	75	230	8,000	2,000	——
21	Lt. J. B. ...	3,800	55	200	18,000	10,000	Flying lately 16,000–18,000.
22	Capt. E. M. B.	3,700	57	600	17,500	7,000	——
23	Capt. H. L. S.	3,700	94	623	19,250	8,000	——
24	Capt. M. ...	3,800	68	300	10,000	3,000	——
25	Capt. W. ...	4,500	60	400	13,000	5–7,000	——
26	Capt. H. ...	4,000	62	5–600	12,000	5–7,000	——

TABLE I.—*continued.*

No. in C.	Name.	Vital capacity in c.c.	Time breath held after full expiration and inspiration. Secs.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
27	Lt. W. ...	4,700	75	200	17,000	12,000	——
28	Lt. H. H. ...	3,800	60	200	16,500	12,000	——
29	Capt. C. ...	3,600	73	6–800	12,000	3,000	——
30	Major R. C.	4,400	64	1,000	16,000	13,000	——
31	Capt. G. H. H.	3,700	60	500	17,000	5–7,000	——
32	Lt. H. K. McK.	4,000	68	230	16,000	5–7,000	——
33	Lt. R. H. S....	3,800	63	200	16,000	12,000	——
34	Capt. E. C. E.	4,900	74	200	10,000	6 000	——
35	Major H. O. M.	4,500	99	500	14,000	7–9,000	——
36	Capt. A. D. ...	4,000	61	500	13,000	6,000	——
37	Lt. N. ...	3,700	68	150	15,500	10,000	——
38	Flt. Sub.-Lt. G.	3,750	65	250	16,000	10,000	——
39	Sq. Com. F. E. T. H.	4,200	65	1,000	15,000	5,000	——
40	Capt. H. G. R.	3,800	60	400	14,000	6,000	——

It will be seen that the minimum vital capacity of any successful pilot is 3,400 c.c., and the minimum time for holding the breath 46 seconds; this in a "stale" pilot direct from hard work overseas. The average vital capacity of these forty successful pilots is approximately 3,950 c.c.; the average time the breath is held a fraction over 66 seconds. In every case a point of great importance, what may be termed a normal answer, such as "I wanted more breath," "I felt like bursting," was stated as the reason for giving up holding the breath. Since the above table was compiled over 100 successful pilots have been examined, and this standard has been fully maintained.

As the result of the preliminary experiments it was recommended that 3,400 c.c. be taken as the minimum vital capacity, and 45 seconds as the time the breath should be held. These it will be seen are approximately the minima found in any successful pilot, and considerably below the average found.

The results obtained from a number of officers exhibiting definite symptoms possibly attributable to lack of oxygen are set out in Table II., a column stating the answer given (where recorded), after holding the breath, being inserted. Since this table was compiled the number has been considerably increased in the course of routine work.

TABLE II.

No.	Name.	Vital capacity in c.c.	Time breath held on full inspiration and expiration. Secs.	Remarks after holding breath.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
1	2/Lt. T. N. ...	2,200 (average of 6)	35	——	28	8,000	200	Giddy above 4,000; cardio-vascular debility and psychasthenia. Bag method "oxygen want" at 4,000.
2	2/Lt. E. ...	2,100 (Max. 2,400)	25	"Made him fuzzy"	10½	6,000	1,000	Giddiness and blurring of vision when flying at 6,000. Bag method "oxygen want" (6,000).
3	Lt. N. ...	3,400 (Max. 3,500)	35	"Things looked far away; head throbbing and aching."	140	10,000 (very ill)	4,000	Fainted twice in air above 8,000. Fainted momentarily with bag experiment (8,800).
4	2/Lt. J. E. H.	2,850	26	——	300	8,000 (once)	Low	Uneasiness, and difficulty of breathing above 3,000 feet. Bag experiment "oxygen want," 4,000.
5	Capt. G. G. ...	2,200 (Max. 2,400)	34	"Suffocating" ...	—	11,000	5–6,000	Suffocating feeling above 5,000 feet. Suffers from mountain sickness. Bag experiment, 8,000.

TABLE II.—*continued*.

No.	Name.	Vital capacity in c.c.	Time breath held on full inspiration and expiration. Secs.	Remarks after holding breath.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
6	2/Lt. J. A. W.	3,350	36	"Giddy" ...	54	10,000 (once for 5 minutes)	3–4,000	Giddy and sick at 4,000. Debility on ground also. Bag experiment, 7,000.
7	2/Lt. S. ...	4,100	42 (Max.)	"All out, dashed uncomfortable"	33	9,500	2,000	Nausea above 7,000 feet (only three times ever above this, very bad at 9,500). Bag experiment, 9,000.
8	2/Lt. S. S. ...	2,850	32	"Head hurt at scar."	150	6,000	1,500	Pains in head about 3–4,000 feet, especially in scars from motor accident. Bag experiment, 4,400.
9	2/Lt. F. M. ...	4,000	33	"Fullness of head, fuzzy, conscious of heart beat."	60	16,000	2,000	Faint in air; suffers above 6,000. Bag experiment just below 6,000.
10	2/Lt. E. R. ...	4,100	40	"Blood rushing to head."	200	10,000	7,000	Since crash, constant headaches above 3,000 with bag experiment; signs of "oxygen want," but persisted till nearly 17,000.

11	Lt. G. B. ...	2,800	36 (av., once 43)	" Dizzy "	300	15,000	5,000	Since crash, fainted twice in air at 8,000 and 10,000 with bag ; very definite " oxygen want " at 6,000.
12	2/Lt. A. L. ...	4,200	31	——	4 (as Observer)	6,000	2,500	Great difficulty in breathing, and dizziness at 5,000 after four hours flying.
13	Lt. R. T. ...	5,100	31	" Tended to go dizzy."	50	7,400	5,000	Headache and compression, and tending to dizziness above 3,000. Emphysema. Very quick oxygen use found by bag method.
14	Lt. E. C. ...	4,100	37* (Max. 41)	——	25	8,000	300	Vomited twice in air after crash.
15	2/Lt. J. H. ...	3,900	35	" Giddy " ...	26	8,000	5,000	Dizziness in air, especially latterly.
16	2/Lt. Bo. ...	3,800	19	" Head inclined to swim."	6	6,000 (once)	—	Has fainted three times below 5,000 feet. With bag method nearly fainted at 3,000 feet.
17	2/Lt. H. W. A.	3,750	34	" Headache and throb."	16 (solo)	5,000 (as Observer) 3,000 (as Pilot)	1–2,000	Headaches—worse after one hour ; has had concussion. By bag method, " oxygen want " at 4,000.

* Breath not held after full expiration.

TABLE II.—*continued.*

No.	Name.	Vital capacity in c.c.	Time breath held on full inspiration and expiration. Secs.	Remarks after holding breath.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
18	Capt. P. S. M.	3,700	36	"Little dizzy; warm in head."	30	8,000	2,000	Goes dizzy and sick in air, with bag method "oxygen want" at 4,000.
19	2/Lt. D. W. S.	3,500	21	"Sort of funny"	2 (solo)	—	—	Dizzy every time he went up.
20	2/Lt. H. G. G.	3,700	40	"Head bursting, especially at temples."	P.U.I.	—	—	Bad pressure in head, and discomfort, especially about 2,000.
21	2/Lt. E. A. P.	3,400	45	"Rather dizzy"	P.U.I.	—	—	Sick and dizzy in air, 2–3,000 feet (probably partly nervous).
22	2/Lt. S. C. ...	2,400	47	"Things began to go round."	60–70	20,000	8,000	Giddiness and sickness in air especially while descending and on landing.
23	2/Lt. S. B. M.	2,800	30	"Felt little giddy"	"Just got Wings."	5,000	—	Feels giddy and faint above 5,000. By bag method, "oxygen want" at 4,500 feet.

24	2/Lt. J. B. ...	3,300	21	" Little giddy " ...	8	2,000	—	Giddy above 1,000.
25	2/Lt. D. K. L.	3,000	55 (with resolution)	" Felt heart " ...	P.U.I.	8,000	—	Dizzy and headache, 5–6,000 feet. By bag method, " oxygen want " at 5,500.
26	2/Lt. E. W. C.	3,200	26	" Uneasy " ...	25	12,000 (once, as Observer)	—	Solo, feels faint over 2,000. " Oxygen want " and " nerves." By bag method, " oxygen want " at 8,500.
27	2/Lt. J. P. W.	3,100	45	" Head seems to swell."	60	10,000 (once, as Observer)	—	At 6,000 gets less alert, then not all there. With bag method went very dazed and reached 12,000.
28	2/Lt. V. P. J.	2,700	15	" Blood rushing to temples " (visible).	P.U.I.	2,000	—	Gets headache and blood rushing to temples at 2,000. Was stood off flying, now P.U.I.
29	2/Lt. G. W. ...	3,200	20	" Pressure in head and temples."	" Just got Wings "	8,000	—	Above 5–6,000 feet pressure in head and temples ; blurring of vision. With bag method, " oxygen want " at 5,000.
30	2/Lt. G. N. ...	3,200	35	" Queer in head "	P.U.I.	—	—	Giddy during first flight ; with bag, " oxygen want " 4,500.

TABLE II.—*continued.*

No.	Name.	Vital capacity in c.c.	Time breath held on full inspiration and expiration. Secs.	Remarks after holding breath.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
31	Lt. J. E. C. ...	2,600	23	"Blood coming up"	400	12,000	2,500	At first all right, then on three occasions felt faint at 7,000 feet. Nervous—could not manage bag method.
32	2/Lt. G. H. ...	3,700	32	"Tendency head to swim."	(14 mths.)	—	—	Flying every day for fourteen months. At first all right to 12,000 feet; now giddy at 5,000. Bag shows "oxygen want" at 4,500 (? partly nervous).
33	Lt. P. S. J. T.	5,300	30	"Unpleasant" ...	(15 mths.)	—	—	Fifteen months' service. Discomfort in air at heights. Breath holding and pulse improved by oxygen.
34	Capt. C. C. B.	3,500	35	"Queer in head"	—	—	—	Constant headache now while flying. Much flying in France, 8–10,000 feet. By bag method, "oxygen want" at 10,000.
35	2/Lt. J. E. C.	4,100	34	"Partially giddy"	—	—	—	At first all right at 6,000, but progressively uneasy at heights. (Cardio-vascular debility well marked.)

It will be seen at a glance that *all the above fail to pass the standard required for the tests.* The borderline case, No. 21, gave an abnormal answer.

In the list are probably three classes of cases :—

(1) Those who have too small a vital capacity to fly at high altitudes (*e.g.*, cases 22–30).

(2) Those who have a sufficient vital capacity but experience a definite " oxygen want " which manifests itself early in their flying career (*e.g.*, cases 7, 13, 15–21).

(3) Those in whom " oxygen want " has developed after an accident or after stress of service (*e.g.*, cases 11, 14, 31–35).

It is not suggested that the tests would eliminate the last class of pilot, although it is possible that, in some cases at any rate, deficient oxygenation of the blood may have led to the accident, and has certainly brought about the gradual onset of symptoms which may be termed those of " accumulated oxygen want " that is gradually increasing nervous and cardiac symptoms due to flying. It is probable, therefore, that some of these officers would have been eliminated by the application of the tests which they now fail to pass. On the other hand the first two classes would have been excluded had the tests here suggested been applied at their entrance medical examination.

The importance of the answer made after holding the breath is seen from a study of the column in Table II.

The application in cases of doubt of the test of holding the breath after regulated exercise (touching the toes four times in 15 seconds) has been of value in giving information of " oxygen want " or of lack of tone. The subject suffering from " oxygen want " is likely to give an abnormal answer ; the subject from lack of condition to give a normal one. The application of this test to normal pilots shows that the breath is usually held about 10–20 seconds less than before, but always more than 30 seconds. On the other hand, subjects who have experienced the worst symptoms of " oxygen want " in the air usually hold the breath less than 20 seconds.

From the last column of Table II it will be seen that the bag method, described in Part II, has continued to yield useful confirmatory evidence of the symptoms complained of, and has been of great assistance in estimating the height at which the symptoms of " oxygen want " are likely to develop. This method has also been found useful in establishing a diagnosis between effects of true " oxygen want " and " nerves " when the subject states his inability to fly above a certain height.

For the sake of comparison, in Table III are given the results of investigations upon subjects who had exhibited no symptoms of " oxygen want." It will be seen that these mostly fall into the category of nerves, except possibly No. 13, where the headaches developing after two months may be due to lack of oxygen. It is interesting to note that this subject is a borderline case according to the standard of vital capacity and breath holding. Case No. 12 is a hopeless neurasthenic who did not try to hold his breath, and gave up the bag experiment as "horrid" in 38 seconds with an abundance of oxygen.

TABLE III.

No. in B.	Name.	Vital capacity in c.c.	Time breath held after full expiration and inspiration. Secs.	No. of hours flying.	Max. height in feet.	Average height in feet.	Remarks.
1	Capt. H. ...	4,200	62	5–600	11,000	—	Neurasthenia.
2	Lt. W. ...	4,750	72	200	17,000	12–15,000	Temporary loss of nerve.
3	Capt. L. ...	3,800	54	5–600	10,000	5,000	Cardio - vascular debility.
4	2/Lt. H. ...	3,800	50	200	16,500	12,000	Nerve gone.
5	Lt. S. ...	4,200	46	—	15,000	—	Cardio - vascular debility.
6	Capt. F. ...	3,500 (max.) 3,200 (av.)	78	200	11,000	2,000	Nervous debility.
7	Lt. C. ...	3,500	64	33	15,000	3,000	Nervy after two crashes in two days, and resuming flying two days after crashes.
8	Lt. C. ...	3,100 3,400 (max.)	51	300	15,000	5,000	Nervy after crashes and unconsciousness.
9	Capt. Co. ...	3,600	73	6–800	12,000	3,000	Nerves.
10	2/Lt. M. ...	4,200	78	30	10,000	4,000	Gassed as infantryman. Developed acute bronchitis while flying in bad weather. Has definite quickened usage of oxygen.
11	Flt. Lt. F. ...	3,200 3,400 (max.)	62	85	13,300	7–8,000	Neurasthenia.
12	2/Lt. T. ...	4,000	27	800	17,000	5,000	Neurasthenia.
13	Lt. J. A. ...	3,400	42 43	2–300	13,000	5,000	Headaches after two months flying overseas. No relation to flying. Cardio - vascular debility.

Finally it may be of interest to quote the following cases examined, from the point of view of high flying, while visiting aerodromes to fix standards by tests on normal pilots. The commanding officers were asked to send for examination any other officers they chose, in order to confirm the reliability of the tests. In the following table (Table IV) are given the results of these tests (made without asking any questions), my opinion, and the opinion of the Commanding Officer or Flight Commander.

TABLE IV.

No.	Name.	Vital capacity.	Time breath held. Secs.	Time breath held after exercise. Secs.	Opinion of M.F.	Opinion of C.O. or Flight Commander.
1	Lt. Ko.	2,900	30, 32	26	Unfit for R.F.C.	Rejected P.U.P. by Medical Board the week before, after 200 hours flying.
2	2/Lt. Br.	3,200 3,500	45	38	"Borderline case." Will probably feel effect of rarefaction of air.	Feels queer in air, but good man; anxious to continue.
3	2/Lt. F.	4,400	89	52	Good man	Very good pupil.
4	Lt. W. ...	3,600	56	37	No disability.	Suspected of disinclination to fly for no reason. Tested in air by C.O. (Subject says once vomited in air when feeling bilious after "stunts" with Flight Commander.)
5	Lt. F. ...	3,700	62	46	Good man	Good man.
6	Lt. K. ...	2,900	45	30	Doubtful stayer; probably suffers from "oxygen want."	"Nervy." Has been queer at 15,000; dreads going above 7,000. Of doubtful future use overseas.
7	2/Lt. Bo.	3,400	18, 20	16	Will suffer from "oxygen want."	Has fainted three times in six hours flying below 5,000 ft.

3. CONCLUSIONS.

As the result of the examination of succesful pilots and of individuals, who suffer in the air from symptoms of "oxygen want," it was suggested that adoption of the following standards will prevent admission of candidates likely to suffer from work in the rarefied atmosphere :—

(1) Rejection of all candidates with vital capacity below 3,000 c.c.

(2) Rejection for high flying of all candidates who have a vital capacity below 3,400 c.c. and who hold their breath below 45 seconds (in three times), and *give an answer indicative of "oxygen want."*

(3) Rejection or deferring of candidates who have a larger vital capacity (over 3,400) but only hold breath 45 seconds or under.

(4) Rejection (when test applied) of candidates who cannot hold breath 20 seconds after graduated exercise, and deferring or rejection according to circumstances of those who cannot hold breath for 30 seconds.

The standards laid down in (1) and (2) have been adopted, by the Commissions Board, and as the result of the application of this test, together with the consideration of other points found in the special medical examination, the height to which a candidate should be permitted to fly is assessed. Some candidates are passed as "artillery pilots" others as "ferry pilots." Such candidates will not be placed on scout or other high-flying work.

In the carrying out of these tests the candidate should be in as normal a condition as possible.

(1) To show the vital capacity the subject should take as deep a breath as possible, and then, while holding his nose, expire as deeply as possible at a fair rate through the meter. Preferably three determinations should be taken.

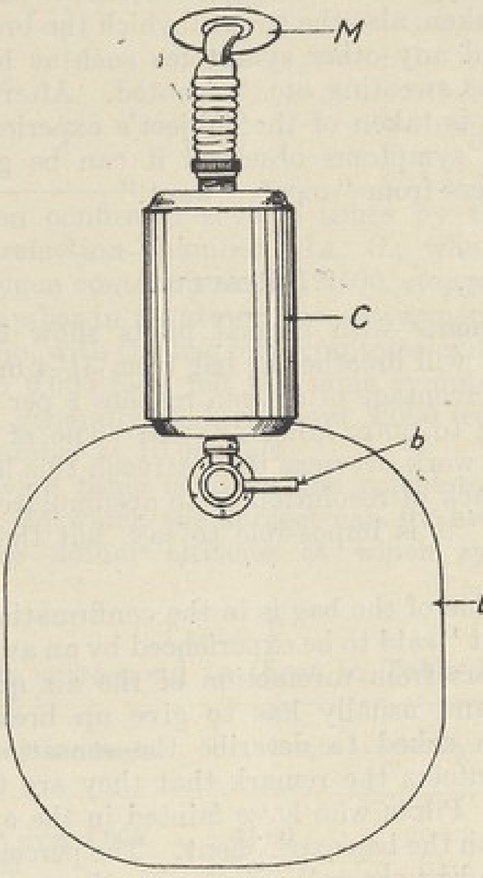
(2) In holding the breath the subject should expire *once* as deeply as possible, and then inspire fully and hold the breath in a sitting position with the nose clipped or held. In cases of doubt three observations should be made. A sufficient time should be allowed between tests. If too full a breath be taken the subject may allow some air to escape, but care must be exercised that none is taken in. It is essential that the nose be clipped or held, preferably clipped. The reason for giving up holding the breath should be carefully noted.

(3) After the regulated exercise the subject should immediately resume his seat and repeat the test as above.

In the breath holding tests care should be taken not to make the subject take several deep breaths before beginning the test.

II.—THE BAG METHOD FOR THE INVESTIGATION OF AIR DISABILITIES OF AVIATORS.

The apparatus consists of a rubber mouth-piece (M) fitting over a flat metal tube, which is joined by a flexible rubber tubing to an absorbent cartridge for carbon dioxide (C), which in turn is attached to a bag (B) of about 5 litres capacity. Just below the cartridge is a by-pass tube (b) through which the contents of the bag may be sampled.*



1. Method.

The subject is given the bag empty, is asked to adjust the mouth-piece comfortably in the mouth, and then to inspire deeply through the nose and blow several times into the bag to fill it.

* For more accurate work a modification is used in which, by means of valves, the air is expired through the cartridge and drawn directly in from the bag. The valves are placed close to the mouth, and the dead space much diminished. The apparatus, however, is not so simple and easy to use; moreover, in the simpler form, the large dead space tends to prevent the subject fainting right off, and in calculations of height gives a margin in favour of the subject. The apparatus is manufactured by Messrs. Siebe, Gorman & Co., 187, Westminster Bridge Road, S.W.

When the bag is just filled to distension a clip is placed on the subject's nose and he is asked to breathe quickly in and out of the bag until he feels he can go on no longer. At this point he expires as deeply as possible into the bag; the flexible tubing is clamped and a sample of the contents taken by means of a vacuum tube from the by-pass, as much air as possible being taken from the cartridge by folding the bag about the main mass of air or closing the entrance hole to the bag with the hand.

This sample, which represents approximately the alveolar air after inspiration and expiration, is now analysed, and the percentage of oxygen in the bag determined. The time of the experiment is taken, also the time at which the breathing deepens appreciably, and any other symptoms such as blueness of lips, circumoral pallor, sweating, etc., are noted. After the experiment a brief account is taken of the subject's experience. From his statements and symptoms observed it can be gauged whether the subject suffers from "oxygen want."

2. Results.

The experiments with normal pilots show that in general the normal pilot will breathe the bag from 3½–4 minutes or more, and until the percentage of oxygen reaches 8 per cent. or under. It is interesting to note, however, that some of the pilots just back from hard work overseas do not reach this level. Whether this be due to lack of resolution or to accumulated symptoms of "oxygen want" it is impossible to say, but the latter view is suggestive.

The chief value of the bag is in the confirmation of symptoms of "oxygen want" said to be experienced by an aviator. Anyone who really suffers from rarefaction of the air quickly develops a hyperpnœa, and usually has to give up breathing inside 2 minutes. When asked to describe the sensations experienced he usually volunteers the remark that they are the same as he gets in the air. Pilots who have fainted in the air have fainted momentarily with the bag experiment. The percentage of oxygen in the air of the bag generally gives an estimate of the height to which the aviator can go without unpleasant sensations. This, however, is not always the case, as a resolute man will push on beyond the stage at which the unpleasant symptoms begin to develop. The calculation is made as follows:—

> Taking 16 per cent. of oxygen as the content of the alveolar air on the full vital capacity at 760 mm. Hg (average of many estimations), then by simple proportion the number of millimetres of Hg corresponding to the percentage of oxygen can be calculated. Thus, supposing the bag content is 11·5 per cent., then

$$\frac{760 \times 11{\cdot}5}{16} = 546 \text{ m.m. Hg.} = 9{,}000 \text{ ft. (approx.).}$$

Table giving Relationship between Oxygen content of Bag, Barometric Pressure and Altitude.

Percentage of Oxygen in Bag.	Barometric Pressure (15° C.) in m.m. Hg.	Approximate Altitude in feet.
15	713	2,000
14	665	3,800
13	617	5,700
12	570	7,900
11	522	10,500
10	475	13,000
9	427	15,800
8	380	19,000
7	332	22,600
6	285	27,000
5	237	over 31,000

This has been confirmed several times by the use of the experimental rarefaction chamber. Lt. C., who breathed the bag until the oxygen content was = 17,500, staggered about and felt ill in the chamber in an atmosphere corresponding to 18,000 feet. 2/Lt. S. who, with the bag felt symptoms, with a percentage corresponding to 9,000 feet, felt the same symptoms in the air badly at 9,500; generally slightly about 7,000 feet; and in the experimental chamber at 10,000 feet.

In the following table is given the calculated altitude, by the bag method, to which the subject can fly before symptoms develop and the actual altitude at which symptoms have developed.*

Table V.

(The numbers correspond to those in Table II, Part I.)

No. of subject.	Calculation height.	Height at which symptoms develop.
1	Just over 4,000 ...	4,000.
2	6,000	4,000.
3	8,800	Max. 10,000; fainted twice above 8,000.
4	4,000	3–4,000.
5	Just above 8,000	Max. 11,000; uncomfortable about 5,000.
6	7,000	4,000 (after long flight).
7	9,000	Max. 9,500; queer above 7,000. Confirmed in chamber at 10,000.
8	4,400	Pains in head, 3–4,000.
9	Just below 6,000	About 6,000.
10	Nearly 17,000 ...	Headache after long time, 7–10,000.
11	6,000	Begins to feel suffocated at 7,000. Fainted since crash at 8,000 and 10,000.

* Many further cases have been examined since this table was compiled.

TABLE V.—*continued*.

No. of subject.	Calculation height.	Height at which symptoms develop.
12	16,000	Difficulty at 5,000, only four hours flying.
14	17,500	Vomiting twice after crash. Confirmed in chamber as 18,000.
16	3,000	Fainted three times below 5,000.
17	4,000	Above 3,000.
18	4,000	Dizzy and sick above 4,000.
23	4,500	Giddy and faint about 5,000.
25	5,500	Dizzy and headache, 5–6,000.
29	5,000	Pressure in head; blurring of vision, 5–6,000.
32	4,500	Giddy, 5,000.
34	10,000	Constant headache about 8,000.

It will be seen that in many cases the agreement is striking, but, as already mentioned in some cases, allowance has to be made for the fact that the subject pushes beyond the beginning of the unpleasant stage, *e.g.*, Nos. 10 and 12.

The results are, however, sufficiently near, since the chief object of the bag experiment is to confirm the pilot's statement, and future flying will be confined to several thousand feet below that at which symptoms develop.

The bag is also of service in the diagnosis of the neurasthenic or the man suffering from lack of resolution. Such a person gives up the bag without exhibiting any marked symptoms, and does not generally describe any sensations to be attributed to want of oxygen. The neurasthenic usually ventures some such remark as "beastly" or "horrid." One such could only breathe the bag for 38 seconds. On the other hand some subjects unsuspectingly attain a diminution of oxygen far in excess of the utmost height to which they say they can ascend, as, for example, a man who always suffered anxiety at 5,000 feet reached a percentage of oxygen corresponding to 18,000 feet without much discomfort.

3. CONCLUSIONS.

(1) The bag method described is of service in confirming statements made by aviators as to disabilities presumably due to lack of oxygen.

(2) After analysis of the oxygen content of the bag, by simple calculation an estimate in most cases can be arrived at of the approximate height at which such symptoms should develop.

(3) The bag is of service in deciding between symptoms due to lack of oxygen and those due to want of nerve.

III.—REPORT ON THE VALUE OF OXYGEN TO AVIATORS AT RELATIVELY LOW ALTITUDES.

1. Introduction.

Various considerations led us, independently, to think that if flying officers were, under certain conditions, supplied with oxygen during flights beneficial results might ensue. These can be briefly summarised as follows :—

(*a*) Mitigation of the fatigue always present after long flights.
(*b*) Abolition of staleness from long periods of flying at the Front.
(*c*) Increase of mental alertness.
(*d*) Increase of muscular vigour.
(*e*) Amelioration of symptoms such as giddiness, fainting, etc.

The advantages likely to accrue, if evidence in support could be secured, are obvious, but for the sake of clearness may be noted :—

(1) Fewer breakdowns at the Front.
(2) The skilled pilot is able to use his knowledge to the full.
(3) Air fights should be more successful on account of increased mental and muscular tone.
(4) The return to flying, or its continuance, by many officers whose symptoms prevent efficient air work.

Before passing to a brief survey of the physiological and other considerations that led to this investigation it should be emphasised that we have not attempted to deal with great altitude flying for two reasons ; first, because the general principle that oxygen is absolutely necessary at such heights is now fully accepted, and secondly, because if the case be proved for low altitudes and short flights it is also proved for great altitudes and long flights.

2. Physiological Considerations.

Over a period of many thousands of years man has made his progress tied to the earth ; a progress, chiefly mental in nature, which has been and is being secured through an increasingly indoor existence, and too often at the expense of physical fitness.

If, therefore, a man is called upon in the course of a few weeks to break these century old bonds and to rise from ground level to great altitudes, from comparative warmth often to intense cold, from relative quiet to a continuous rush and roar, from a state of equilibrium to one of instability, from muscular and mental rest to highly skilled and nerve-trying evolutions, from safety to possible death—all this in the space of a few minutes, with a return at least as sudden—it is no exaggeration to say that such a man has taken a greater bound forward than did his ancestors in several hundreds of years. In a sentence he is subjected to intensive, intermittent, and cumulative stimuli of a degree to which man has never been exposed before.

Such a step must, of necessity, throw an enormous strain on the human organisation, and the work of the aviator is essentially that of the fittest of the fit.

To consider the effects of a flight in more detail, there is :—

(*a*) The effect on the cardio-respiratory system ;

(*b*) The effect on the nervous system ;

(*c*) The effect on the muscular system.

(A) *The effect on the Cardio-Respiratory System.*

With increasing altitude, apart from consideration of temperature and other conditions, there is in the first place a deepening of the respiration in order to secure the oxygen necessary to maintain the bodily functions. At the same time the heart quickens, and thus is established the beginning of a "vicious circle." For, an increase in the rate of heart beat means an increase in the amount of work done by the heart. This increased work entails an increased oxygen consumption, the supply of which is diminishing ; thus each factor reacts unfavourably upon the other.

In support of these statements we quote the following figures from Waller's Physiology :—

Pulse frequency, per minute.	Ratio of systole to cardiac cycle.	Hours of work, per day.
50	·31	7·5
70	·37	8·9
100	·45	10·8

It has also been shown experimentally that the usage of oxygen by the heart corresponds to the rate and maximal pressure of the pulse.*

All the devices to render the circulation efficient will, therefore, be called into play to meet the varying conditions, so that with prolonged strain a breakdown of the cardiomotor and vasomotor control mechanisms is to be anticipated. It is to be borne in mind that the strain ultimately falls on the circulatory rather than the respiratory system. This is because with increasing

* Barcroft and Dixon, Rohde, and other investigators (*see* Barcroft's "Respiratory Function of the Blood," p. 91. *Cambridge University Press*).

depth of respiration the accessory and adjuvant muscles of respiration are progressively called into play, but there are no accessory hearts on to which the extra strain can be thrown. The position of the pilot in the machine is such that but little help can be rendered by the pumping action of muscle movement, and even allowing for the relief given through the respiratory mechanism this is liable to become fatigued, and the circulatory mechanism must in the end suffer.

The possibility, too, of ill effects due to the washing out of carbon dioxide by the increasing depth of breathing must be borne in mind. It is a well established fact that deep breathing in itself gives rise to symptoms of marked discomfort, which frequently approach a sensation of giddiness.

(B) *The effect on the Nervous System.*

In addition to the psychical strain incurred by the judgment displayed in simple straight-forward flight there is the added need of quick response to changing atmospheric conditions (bumps); and in war time flying there is superadded the strain of judgment involved in work to be done.

But this strain is not only cerebral in nature; there is the constant instreaming of impulses

(*a*) to the cerebellum concerned in the process of equilibration;

(*b*) to the medulla oblongata in making the necessary adjustments of the respiratory and circulatory mechanisms;

(*c*) to the spinal cord for the co-ordination of the reflex movement in the static muscular work involved;

all this in a rarefied, and frequently in a progressively rarefying, atmosphere.

(C) *The effect on the Muscular System.*

The point of prime consideration in connection with the muscular system is that with increasing height the muscles are called upon to work with a less and less available supply of oxygen. This results in the progressive formation of lactic acid within the muscles, so that, after a flight, as Zuntz has also pointed out, the muscles of the aviator are in the condition of an athlete after a strenuous piece of work. The work of the aviator varies according as he be pilot or observer. The muscles of the pilot engaged in the direction of the machine are always in a state of semi-tension, owing to the antagonistic action of the muscles engaged in the "static" work performed. This state is in itself inimical to a good supply of blood, and when the disadvantage of the rarefied atmosphere is added it can be understood that a state of fatigue is easily induced without the need of a large amount of actual work being formed. The observer is usually called upon to do more actual muscular movement, and thus brings about a similar state of fatigue in the muscle.

(D) *The Summation of Effects.*

It is not suggested that one flight, whatever be its nature, is in itself deleterious, or, except in the case of great altitudes, calls in any way for the administration of oxygen, except to those totally unfitted to fly. But, from what has been written, it will be seen that the strain of flying will tell, soon or late, upon the aviator through the cardio-respiratory, nervous or muscular mechanisms, the degree depending largely upon the individual—thus causing many of the failures in the Field.

3. Experience of Medical Boards.

That the above surmise is true is proved by experience. Medical Boards on flying officers and examination of pilots in the Field have led to the recognition of symptoms and signs, which may now be considered as directly due to prolonged air work at various altitudes. The symptoms are not so definite or simple that anything in the nature of a definite air disease syndrome can yet be claimed for them ; but the appearance and reappearance of them in overlapping groups is distinctly suggestive.

Thus, in the "stale" pilot we find definite evidence either of a breakdown in the cardio-respiratory mechanism, or in the nervous or muscular systems.

The cardio-respiratory type is recognised by an increased frequency of the pulse, which is also poor in volume and low in tension ; distress on slight exertion accompanied by a rapid rise in the pulse rate, which returns only after a long interval to its former rate. The breathing also is frequently shallow and rapid, and the extremities poor in colour and cold.

The nervous type demonstrates itself by poor muscular control over balance movements, fine tremors of hands and eyelids, greatly increased reflexes, loss of sleep, nightmares, starts, apprehensions, increasingly bad landings or giddiness in the air.

The muscular type manifests itself chiefly by tender muscles (often erroneously called rheumatism), the tone and power of which are also markedly diminished.

This last type, in its pure state, is only found among the successful pilots, and yields rapidly to rest. It is usually associated in a greater or lesser degree with the cardio-respiratory or nervous type.

This brief and incomplete résumé of the signs and symptoms so frequently found in the flying officer is sufficient, however, to show clearly that they correspond closely with the symptoms and signs that, it has been shown, would be expected on physiological grounds.

It is possible that objections to the use of oxygen in excess of that existing in normal atmosphere may be raised, on the grounds that it is "drugging" and liable to lead to temporary exaltation with subsequent depression, or to an oxygen habit.

Such objections, however, are not in any circumstances valid, and certainly not under those in which it is proposed to use the oxygen. It must be recognised that oxygen is always available under normal conditions in excess of the requirements of the body; and it is only when we make the conditions abnormal, and repeat them day after day for long periods, and, in addition, diminish the available oxygen to a greater or less degree, that an artificial supply of this vital gas may be required.

4. Reasons for the Administration of Oxygen.

It has been shown by one of us, in conjunction with Leonard Hill, that oxygen greatly improves the condition of athletes (runners, hockey players and boxers). If administered *before* a short period of exertion, *e.g.*, 100 yards, it may improve the time of the performance, and certainly alleviates the distress of it; if at intervals *during* a performance, *e.g.*, boxing, it greatly diminishes the distress caused by the previous performance, improves the form for the next round, and increases the staying power of the combatant. If administered *after* a period of long work, *e.g.*, a three mile race, it decreases the subsequent symptoms of fatigue—the runner will suffer little or no "stiffness" or other after effects. By the administration of oxygen (M.F.) was able to restore a delirious cross-channel swimmer to consciousness, brace him to renewed effort, enable him to surpass any previous performance and almost to achieve his end.

Briefly stated it has been shown (Hill and Flack) that the administration of oxygen

(1) tends to keep an efficient slow pulse;

(2) tends to keep up a good arterial pressure and delay the onset of arterial hypotension (blood pressure below normal);

(3) keeps off the onset of hyperpnœa or dyspnœa (distressful breathing);

(4) mitigates any ill effect due to excessive deep breathing.

In sport the use of oxygen is regarded as a "dope." In warfare it is not a question of "doping" but of "efficiency." No athlete could stand a repeated performance of hard muscular work day in day out, often several times daily, without developing "staleness." The aviator is in the same position, but has the extra disadvantage of the psychical strain and the performance of his task in a rarefied atmosphere. We suggest that it is not necessary for this atmosphere to be so rare as to produce immediate symptoms when there can be no denial as to the use of oxygen, but that oxygen, which has been shown to be of the value already mentioned, will from the above considerations be likely to prove of value in preventing many of the symptoms attributable to flying.

We have made, in support of this contention, some preliminary observations which are given below.

5. Methods of Research.

It was not found possible to carry out observations on pilots flying machines to considerable altitudes for some hours; observations therefore were made chiefly on the B.E. 2E type of machine, making short flights of approximately half an hour at comparatively low altitudes, and flown both by pilots of experience and ones suffering from some disability. If, therefore, the results only show moderate advantage from the use of oxygen it must be remembered that short, low flights in stable machines by pilots of experience are the absolute minimum of flying effort.

The apparatus used for supplying the oxygen is known as the Siebe Gorman Oxygen Apparatus, and is similar to that recently despatched to the Expeditionary Force.

The observations taken may be divided up into cardio-respiratory and nervous. It had been intended to make the observations more comprehensive, *e.g.*, by dynamometer tests, vital capacity measurements and alveolar air analysis, but considerations of the daily work and routine of the squadron were held to be more important, and these and other tests are reserved for the future.

The *cardio-respiratory* observations made before and after each flight were :—

(1) Pulse rate (taken twice or three times over half a minute).

(2) The ability to hold the breath ; this is done by expiring deeply followed by a full inspiration, the nose is held, and the time taken from then until the individual is compelled to let go—the length of time being considered a gauge of the rate of use of oxygen at the particular moment that the experiment is made.

(3) Arterial Pressure was taken in the majority of cases by means of the small Leonard Hill sphygmomanometer ; the accuracy of the reading being secured by one observer taking the pulse, and the other reading the instrument where any doubt existed.

The *nervous system* tests had to be limited to Macdougall's dotting machine, as it had been found impossible to arrange for wireless signalling or battery work tests on account of the unreliability of results. This is because sending rates by wireless in the air vary remarkably from flight to flight even with the most experienced pilot ; it is, however, hoped eventually to devise some form of actual mental work in the air that will be capable of measurement.

The Macdougall machine, the use of which we owe to the suggestion of Sir Walter Fletcher, F.R.S., consists of a clockwork apparatus which passes a slip of paper through a small opening, and on the slip small circles with a dot in the centre are printed at irregular intervals and positions. The subject endeavours to spot the bull's eye of every circle as the slip of paper passes through the opening. The rate of movement of the paper is gradually increased until a breakdown is secured. The slip is then marked according to the following rules. Ten complete misses out of twenty circles constitute a complete breakdown at the particular rate at which this occurs. The rate immediately preceding this breakdown is then assessed as follows* :—

> Plus 5 marks for a bull's eye, and minus 1 for a miss (20 circles being counted). The fastest nominal rate is 1, and for this 100 marks are given ; for rate 3, 80 marks ; rate 5, 60 marks, and so on. Thus, Lt. J. has 11 misses at rate 5 and is considered to have broken down, but he has only 8 misses and has secured four absolutely accurate spots = bull's eyes. His marks, therefore, would be 40 − 8 (misses) = 32 + 20 (4 bull's eyes) = 52.

Psychical.—Note was also taken of expressions of opinion volunteered by pilots, and these appear where they are considered of value in the " remarks " column of the data.

In regard to the *muscular system* it was felt that the flights were not of such duration or height as to warrant correct deductions being drawn. It is hoped to make dynamometer experiments before and after long flights, with and without oxygen, at some future date.

6. Results of Observations.

Table I.

Table showing the effects of a flight upon the Cardio-Respiratory and Nervous Systems without and with the administration of Oxygen.

Name.		Pulse.	B.P.	Breath held. Secs.	McDougall marks.	Remarks.
1. Lt. K. ...	(1) Before flight.	96/88	120	47/59	29	Flights were 20 minutes, up to 5,550 and down again.
	(2) After flight without oxygen.	108/96	95	34	24	
	(3) After flight with oxygen.	100/86	125	47/55	63	
2. Lt. K. ...	(1)	84	125	51	45	Flight (2) without oxygen was straight flight for *half* hour. (3) With oxygen approximately same sort of flight for *one* hour.
	(2)	84	95	35, 45	54	
	(3)	84	120	52, 51	47	

* The following simple method of marking is now used : 2 marks for a bull's eye or completely within the circle, 1 mark if touching outer circle, 0 for a miss. Twenty circles are counted at each speed.

TABLE I—*continued.*

Name.		Pulse.	B.P.	Breath held. Secs.	McDougall marks.	Remarks.
3. Lt. S. ...	(1)	74	105	61, 80	− 8	In flight about half hour without oxygen. (2) Half looped, side slipped, etc. Flight (3), with oxygen, "more strenuous."
	(2)	96, 84	110	67, 80	32	
	(3)	75, 72	120	90	69	
4. Lt. C. ...	(1)	79, 84	110	73, 79	98	Both flights approximately the same. Straight up to 3,000 (without), 3,500 (with oxygen), and back.
	(2)	98, 84	120	58	124	
	(3)	96, 84	120/130	86	136	
5. Lt. P. ...	(1)	84	115	55	24	Both flights to 5,000 with "stunts," more "stunts" with oxygen.
	(2)	60	150	52, 57	− 4	
	(3)	72	130	61, 68	15	
6. Sgt. C. ...	(1)	96	120	68	21	Straight climbing to 6,000 and back. Feeling of weirdness without oxygen; no such feeling with oxygen.
	(2)	84, 92	100	50, 77	7	
	(3)	72	125	66, 81	39	
7. Capt. R. ...	(1)	88	110	47, 58	2	Straight flights to 3,000 and back. Subject just off sick leave.
	(2)	112/88	Retn. 90, 130	69, 75	40	
	(3)	96, 92	140	85	61	
8. 2/Lt. H. ...	(1)	80	100	90	106	Contradictory result with oxygen test; arrived down with cylinder empty, and suffering partly from effects thereof.
	(2)	96	120	76	40	
	(3)	84	105	61	(not taken)	
9. 2/Lt. C. ...	(1)	78	105	95	25	Artillery shoot of just over an hour, *without* oxygen.
	(2)	64	95	95	5	
10. 2/Lt. H. ...	(1)	96, 80	130, 120	74, 72	116	Artillery shoot of over an hour, *with* oxygen.
	(3)	74, 72	115, 120	87	148	
11. Capt. F. ...	(1)	72	130	81	92	Flight of 20 minutes by experienced pilot, without oxygen. Some "stunts."
	(2)	75	150	63	83	
12. Capt. J. ...	(1)	64, 60	—	81, 86	—	Flight of 20 minutes by experienced pilot, with some "stunts."
	(2)	72, 68	—	62, 70	—	
13. Lt. F. ...	(1)	88	—	56	—	Flight, 30 minutes, by experienced pilot, *without* "stunts."
	(2)	72	—	58	—	
14. Lt. F. ...	(1)	68	—	59	—	Flight by same pilot on another day, *with* "stunts."
	(2)	104	—	47	—	

TABLE I—*continued.*

Name.		Pulse.	B.P.	Breath held. Secs.	McDougall marks.	Remarks.
15. 2/Lt. W. S. (Pilot)	(1)	92	—	45	—	After strenuous artillery shoot at 1,500 feet for 30 minutes.
	(2)	140	—	25	—	
		116	—	35	—	
		100	—	41	—	
6. Obs. S. ...	(1)	92	—	35	—	After artillery shoots without (2) and with (3) oxygen. The oxygen result is complicated by the fact that the subject opened the by-pass, emptied his cylinder, and arrived with oxygen exhausted.
	(2)	148	—	32	—	
		104 after 5 mins.	—	44	—	
	(3)	120	—	30	—	
		84	—	50	—	
			—	60	—	
17. Obs. Lt. F.	(1)	108, 88	—	47, 57	—	An excitable subject on graduated flying. Twenty minutes flight, with "stunts"; stated next day "never felt so well after similar flight before."
	(3)	96, 80	—	61, 61	—	
18. Obs. Lt. B.	(1)	108	—	57, 50	—	Flights to 1,500 and back in 30 minutes.
	(2)	108, 96	—	32, 50	—	
	(3)	88, 84	—	55, 62	—	
19. Obs. Lt. R.	(1)	108	—	57, 60	—	Flights to 3,000 and back in 40 minutes; after oxygen *hurried back some distance for observations.*
	(2)	108	—	50, 37	—	
	(3)	108	—	55, 80	—	

TABLE II.

The effect of Administration of Oxygen after landing from Flight.

Subject.	On landing.			After one minute's oxygen.		
	Pulse.	B.P.	Breath held. Secs.	Pulse.	B.P.	Breath held. Secs.
E. L. (Observer)	108	—	55	72	—	74
R. McD. ,,	80	—	74	72	—	121
B. ,,	120	85	18, 20 (after exercise 16)	87	110	24 (after exercise)

Discussion of results.—It is not pretended that these observations on flights at comparatively low altitudes and generally of short duration are altogether conclusive. Certain facts, however, appear to emerge. In regard to the cardio-respiratory system the results appear to be analogous to those already observed as the result of exercise. In general, the pulse is accelerated, the arterial pressure raised, and if the effort be prolonged or cause strain a hypotension supervenes. It is, perhaps, well not to pay too much attention to the pulse rate before a flight owing to the initial excitement, especially in subjects of a nervous temperament. A short flight without oxygen appears to have little effect upon an experienced normal pilot. If he has stunted at all he may have acceleration of the pulse, an increase in arterial pressure, a diminished power to hold the breath and some nervous exhaustion as shown by the McDougall machine.

To pilots to whom the strain of flying is greater (*e.g.*, Table 1, Nos. 1, 2, 6, 7) there results an arterial hypotension analogous to that of prolonged exercise. The administration of oxygen has a beneficial effect, the subject, even when of an excitable nature, landing with a slow, full pulse, a normal or raised arterial pressure, an increased power to hold the breath.

The abolition of the onset of the hypotension of arterial pressure is of great significance (Table I, Nos. 1, 2, 6, 7).

The results of the observations 9 and 10, Table I, are suggestive ; 2/Lt. C. and 2/Lt. H. make approximately the same performance (an artillery shoot of one hour's duration). Lt. C. arrives back with some signs of circulatory and nervous fatigue. Lt. H., although slightly longer in the air, arriving back in good condition with no signs of fatigue, his only complaint being of the smell of the mask used.

The results with the dotting machine indicate an all round improvement with the administration of oxygen. Of nine cases, six deteriorate after the flight without oxygen and three improve ; after the flight with oxygen all make improved performances, and in the cases where there was previously a deterioration surpass the previous performances.

The contradictory results, obtained when the oxygen supply fails, point to the necessity of the employment of a thoroughly well tested and reliable apparatus.

The beneficial results of oxygen administered after a flight are well seen in two of the three instances given in Table 2. Observer B. is a particularly interesting case. After a flight of twenty miles at 1,000 feet he arrived with a rapid pulse, an arterial pressure of 85, and a very limited power to hold the breath (only 16 seconds after the exercise of touching the toes four times). After the administration of oxygen for one minute, the pulse was slower, the blood pressure and power to hold the breath increased. This officer has already fainted in the air three times in six hours' flying experience. Similar results, especially in the improvement of the rate of pulse, have been obtained by the administration of oxygen to pilots home from overseas with cardio-vascular debility after long periods of service.

No observations have been made as to the effect of administration of oxygen after flight upon the performance with the dotting machine. Two instances may be quoted in which the administration of oxygen for one minute to mentally fatigued persons improved the performance 30–40 per cent.—in one case raising the percentage of hits from 65 to 97·5, with the machine going at a medium rate.

7. Discussion as to the best methods of Administration of Oxygen.

As pointed out in Section 4, experiments have been made giving oxygen

(*a*) before work;

(*b*) intermittently during work;

(*c*) after work.

Experiments have also been made giving oxygen all the time that the work is being done. This has the disadvantage of necessitating the wearing of the mask all the time during the performance of the work. It is the method which, up till now, has been considered best for aviators owing to the fact that the atmosphere is rarefied. It is the method which we have employed in our experiments. The method has, in addition to the disadvantage already mentioned, that of requiring a relatively large supply of available oxygen. We would suggest, however, that there is much to be said *for an intermittent supply of oxygen* when in the air. Several pilots have stated that they could not fight with a mask on the face and with a tube in their way. As a pilot of experience said: "Would it not be better to have a good dose when the Hun was coming, then put it aside and go for him and take another dose when he was finished with." We believe there is much to be said for this method, a conclusion supported by the boxing results already referred to. We understand that this method of intermittent administration has proved efficient enough to enable Capt. Hucks to attain his maximum heights. A few breaths of oxygen he says "soon gives the sensation of being at ground level again."

We would suggest also that it would be a good practice to administer oxygen for a few minutes to all airmen after heavy flights at any altitudes, e.g., *bombing raids, etc.* We support this contention from the effects obtained by administration to three mile runners.

In our opinion such administration would, as with the long distance runner, abolish much of the effects of fatigue and appreciably increase the length of service in the Field.

8. Conclusions.

It is provisionally concluded that :—

(1) In flights at low altitudes there is a certain degree of cardio-respiratory and nervous fatigue, varying with the nature of the flight and with the individual.

(2) The administration of oxygen abolishes this fatigue in short flights, and delays its onset in longer flights.

(3) The administration of oxygen after a flight improves the cardio-respiratory condition of the subject.

(4) From this and from previous experience upon athletes it is suggested that beneficial effects would accrue from the administration of oxygen to aviators on landing, especially after long strenuous flights. The necessary length of time of such administration would have to be determined. It is also suggested that beneficial results would be obtained by the intermittent supply of oxygen to aviators on flights where a constant supply is not considered essential. It has not been possible to put this point to the test.