NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 283

A PRELIMINARY INVESTIGATION OF SUPERCHARGING AN AIR-COOLED ENGINE IN FLIGHT

By MARSDEN WARE and OSCAR W. SCHEY

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/sec.$^2 = 32.1740$ ft./sec.^{2}

m, Mass, $= \frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $= 0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3 = 0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $= \frac{1}{2} \rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho \frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $= (i_t - i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Langley Memorial Aeronautical Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

This report presents the results of tests made by the National Advisory Committee for Aeronautics in a preliminary investigation of the effects of supercharging an air-cooled engine under airplane flight conditions.

This investigation comprises the first of its kind that has been conducted and for which results have been published.

Service training airplanes were used in the investigation equipped with production types of Wright J engines. An N. A. C. A. Roots type supercharger was driven from the rear of the engine.

In addition to measuring those quantities that would enable the determination of the climb performance, measurements were made of the cylinder-head temperatures and the carburetor pressures and temperatures. The supercharging equipment was not removed from the airplane when making flights without supercharging, but a by-pass valve, which controlled the amount of supercharging by returning to the atmosphere the surplus air delivered by the supercharger, was left full open.

With the supercharger so geared that ground-level pressure could be maintained to 18,500 feet, it was found that the absolute ceiling was increased from 19,400 to 32,600 feet, that the time to climb to 16,000 feet was decreased from 32 to 16 minutes, and that this amount of supercharging apparently did not injure the engine.

INTRODUCTION

The air-cooled engine has reached such a stage of development in recent years that investigation of its application to all kinds of service conditions becomes of great interest. In this respect, the investigation of the effects of supercharging air-cooled engines is of considerable importance.

While supercharging consists merely of the delivery to the engine of an air-fuel charge of greater density than it could induce normally, its influence upon the engine depends on the nature of the application. For instance, the application may require that an engine be supercharged at ground level in order to increase the power per unit volume of displacement. On the other hand, the amount of supercharging may be zero at ground level and may be increased in amount as the altitude of operation is increased for the purpose of compensating for the decrease in power due to the reduction in density of the atmosphere. In the former case, supercharging causes an increase in both heat and mechanical stresses, while in the latter, the mechanical problems are comparatively inconsequential. Aircraft engine supercharging is concerned primarily with the latter case, especially when any considerable amount of supercharging is involved. It is this phase of supercharging that will be considered in this report.

In the case of water-cooled engines the alteration of cooling conditions can be readily provided for by changing the amount of radiation. Regulation of the cooling as operating conditions require may be made in a given installation by means of shutters.

Obviously this same condition does not apply to the present day air-cooled engine, where the amount of the cooling surface is fixed by the design of the engine and control of the amount of air passing over the surface in the usual installation is not as simple as in the water-cooled engine. If the air-cooled engine were to be designed with sufficient cooling surface to meet the extremes of cooling requirements encountered and with provision for controlling the amount of air passing over the surface, the problems of the two types of engines would be practically the same. At present, however, the problem of supercharging an air-cooled engine is not as simple as that of supercharging a water-cooled, and depends primarily on the cylinder design.

The purpose of the work reported herein was to make a preliminary investigation of the general problem of supercharging an air-cooled engine, using an engine that had proven successful in service under conditions of normal operation. The work was done at Langley Field, Va., by the staff of the National Advisory Committee for Aeronautics.

DESCRIPTION OF APPARATUS

Standard service airplanes and engines were used in this work. Two airplanes of the training type were used: The first was a single-seater (Navy symbol—TS); the second was a two-seater of more refined design (Navy symbol—UO–1), which is shown in Figure 1. The engines were production types of the Wright J series. Details of construction for this series of engines are given in a paper entitled "The Development of the Wright Whirlwind Type J–5 Aircraft Engine," by E. T. Jones. (Reference 1.)

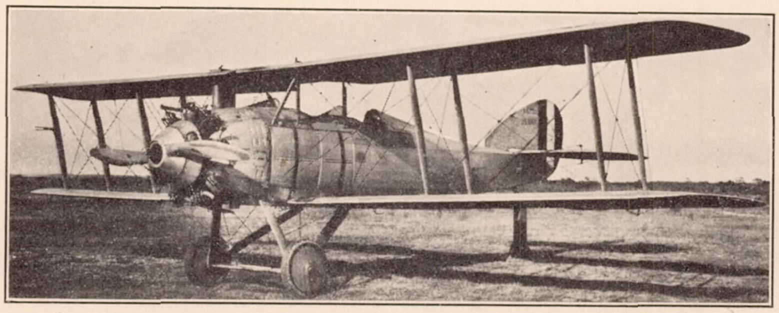

FIG. 1.—UO–1 airplane with Wright J–4 engine and experimental installation of N. A. C. A. Roots type supercharger

An N. A. C. A. Roots type supercharger was installed at the rear of the engine and was connected directly to the end of the engine crank shaft. The supercharger was essentially the same as described in Technical Report No. 230. (Reference 2.) Since this supercharger was designed for use with the Liberty engine, which has a displacement of 1,649 cubic inches, while the displacement of the Wright J engine is only 787 cubic inches, this supercharger is considerably oversize for the latter engine. For most of the tests the capacity of the supercharger was reduced so that ground-level pressure could be maintained to about 18,000 feet by driving the supercharger impellers at crank-shaft speed.

A large size duct of streamline form was provided on the intake side of the supercharger. This duct extended well above the fuselage to minimize the induction of hot air from the engine cylinder. The discharge side of the supercharger was connected directly to the engine carburetor by a pipe 5 inches in diameter, in a branch of which was located a valve for the control of the amount of supercharging. The control was effected by returning excess air to the atmosphere. The branch pipe carrying the control or by-pass valve may be seen in Figure 1 extending a short distance below the bottom of the fuselage.

When the work was started with the TS airplane, a receiver having a volume of 1.8 cubic feet was inserted in the air duct between the supercharger and the carburetor to dampen the pulsating pressure created by the supercharger and thus to prevent impairment of engine performance. Since later tests with a direct connection gave equal engine performance, no receiver was used for work herein reported.

In the usual engine installation, the fuel pressure is maintained somewhat in excess of the atmospheric pressure. Fuel would not flow into the carburetor if the system were tried in the supercharged engine installation with the carburetor located between the supercharger and the engine, due to the fact that the carburetor air pressure is considerably greater than the atmospheric pressure. Modifications were made to the fuel system to maintain the fuel pressure a definite amount above the carburetor pressure and automatically dependent on the amount of supercharging pressure, in the same manner as made in previous work at this laboratory with water-cooled engines as described in Technical Report No. 263. (Reference 3.)

Cylinder-head temperatures were measured by iron-constantan thermocouples and an indicating pyrometer. The couples were inserted in each cylinder at a point immediately in the rear of the spark plug located on the top and near the front of each cylinder, as may be seen in Figure 2. The pyrometer and instruments for measuring the carburetor air temperature, the free air temperature, the carburetor air pressure, and the engine speed were installed in a light-tight box and pictures of the instrument dials were taken automatically at regular intervals with a small motor-driven camera using moving-picture film. Since space permitted the use of only one pyrometer for the cylinder temperatures, and the temperatures of all nine cylinders were desired, the various thermocouples were connected consecutively to the pyrometer by means of a motor-driven switch.

The diameter of the propeller was 8 feet 9 inches and the pitch was 6 feet 2.3 inches. The weight of the airplane ready to fly was 1,980 pounds.

TEST RESULTS

Due to the preliminary nature of this investigation the work was confined primarily to the determination of the performance with and without supercharging. Cylinder-head temperatures were measured in all flights as an indication of the thermal stress created by supercharging. In addition, measurements were made of flight performance as given in Tables I to VI.

Figures 3, 4, and 5 show the results obtained with the UO-1 airplane in those tests where the supercharger impeller speed was equal to the engine crank-shaft speed. These results are plotted from average data obtained in three supercharged and three unsupercharged flights. The fuel was a 30-70 blend of benzol and aviation gasoline.

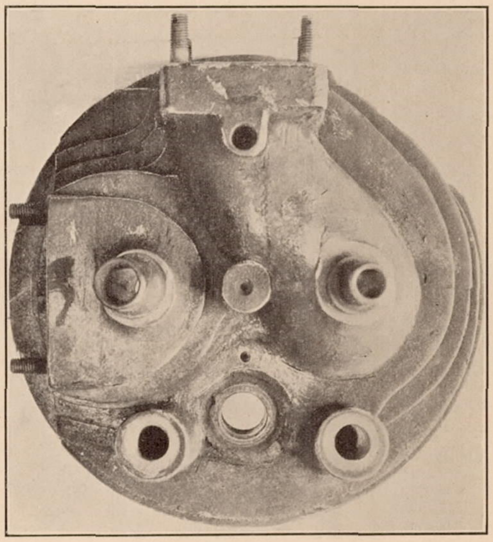

FIG. 2.—Top view of cylinder head, showing location of hole for thermocouple plug between spark plug and center of cylinder

Some work was done with the supercharger impellers operating at 1.5 times crank-shaft speed. This change permitted ground-level pressure to be maintained to much higher altitudes, at which considerable trouble was experienced from detonation. This work was therefore discontinued.

The equipment was not changed in making the flights without supercharging, but the supercharger by-pass valve was kept full open. The power required to drive the supercharger under the condition of free inlet and discharge resulting from this method of operation is less than 5 HP., so that the power of the engine was essentially the same as that of the normal engine. Since the same propeller was used for all tests, higher engine speeds were obtained when supercharging.

A series of climbs to an altitude of 15,000 feet was made with the TS airplane and with some variation in the amounts of supercharging. While some differences in performance and temperature were noted, they were not definite enough to show the influence of the different amounts of supercharging. The work demonstrated, however, that little trouble would be encountered in maintaining full supercharging to moderate altitudes. In continuing with the work on the UO-1 airplane, practically all flights were made with the carburetor pressure maintained at approximately 29 inches of mercury.

A comparison was made of the effect of oil cooling with the TS airplane by making comparative flights with and without an oil radiator. At 20,000 feet the cylinder temperature was 505° F. with the oil radiator and 550° F. without the radiator. While these data are hardly sufficient to justify making a definite conclusion, they indicate that the lubricating oil has an appreciable effect on cooling and it may be an important consideration in the application of supercharging an air-cooled engine when the cylinder temperature approaches a dangerous limit.

DISCUSSION OF RESULTS

Figures 3, 4, and 5 show that a material improvement in performance is obtained as the result of supercharging; the absolute ceiling is increased from 19,400 to 32,600 feet, and the time required to climb to 16,000 feet is reduced from 32 to 16 minutes. The supercharged engine performances were obtained without any impairment of the engine structure, and it seemed evident from the experiences of the entire work that the engine could endure satisfactorily this amount of supercharging.

While it would be necessary to have temperature measurements of other parts of the cylinder to form any very satisfactory conclusions of the effect of supercharging on the heat flow through the cylinder, these tests indicate the temperature increase that may be expected to result from supercharging. According to the maximum permissible temperature of 550° F. for satisfactory operation given by Heron (Reference 4), the temperatures recorded under the supercharged condition can not be said to be excessive. Although no maximum permissible operating temperature has been published for this engine, its excellent performance may be taken as an indication that this temperature approaches that set by Heron. It is of interest to note that the maximum cylinder temperature is reached at an altitude slightly above that at which the carburetor pressure begins to drop or the altitude where the increase in engine power resulting from supercharging is a maximum.

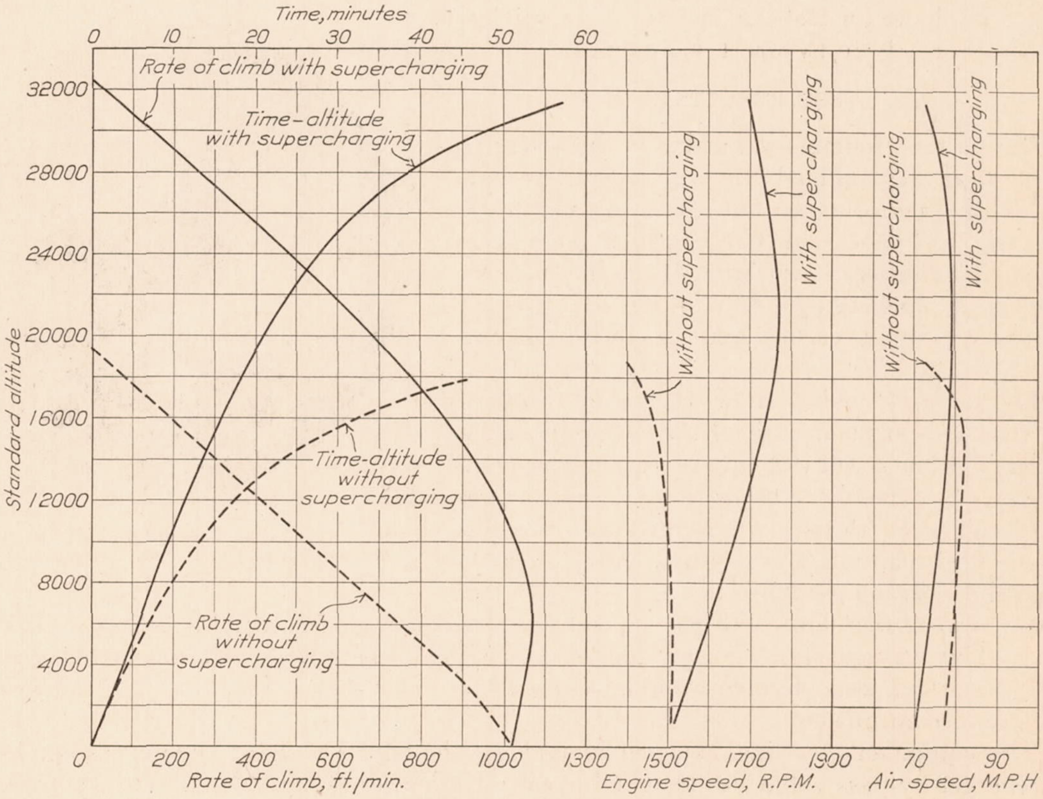

FIG. 3.—UO-1 performance with and without supercharging

There are a number of important specific problems entering into the question of supercharging that were left for further investigation. Among these, the influence of air-fuel ratio is one of the most important. Heron (Reference 4) has shown the relation between cylinder

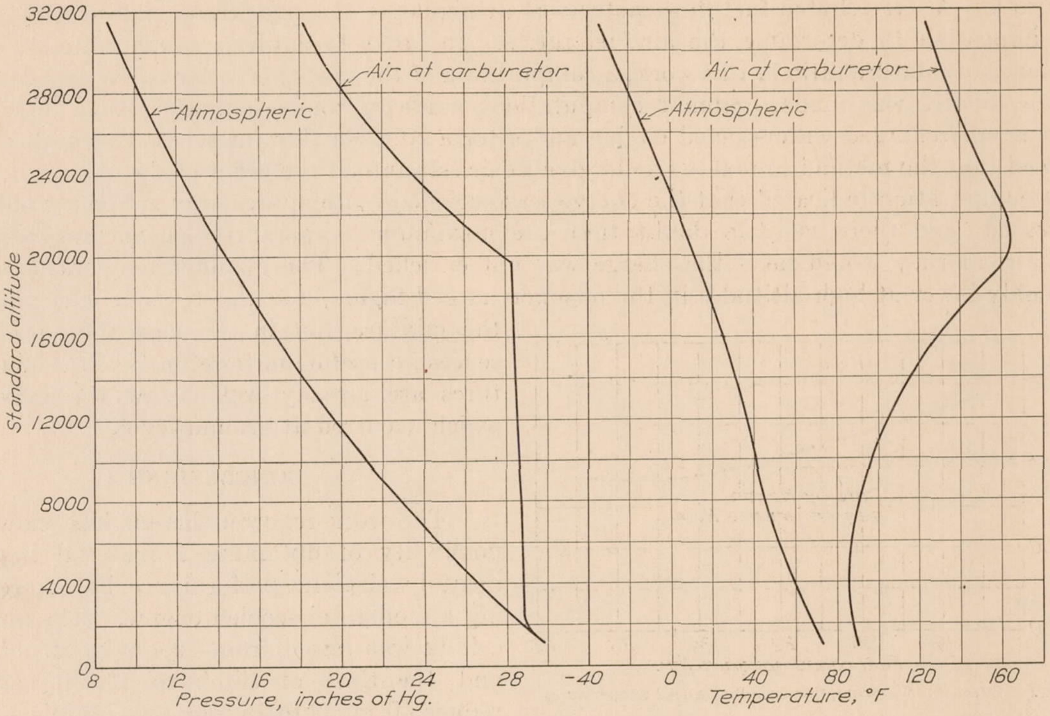

FIG. 4.—Effect of supercharging on carburetor air temperature and pressure

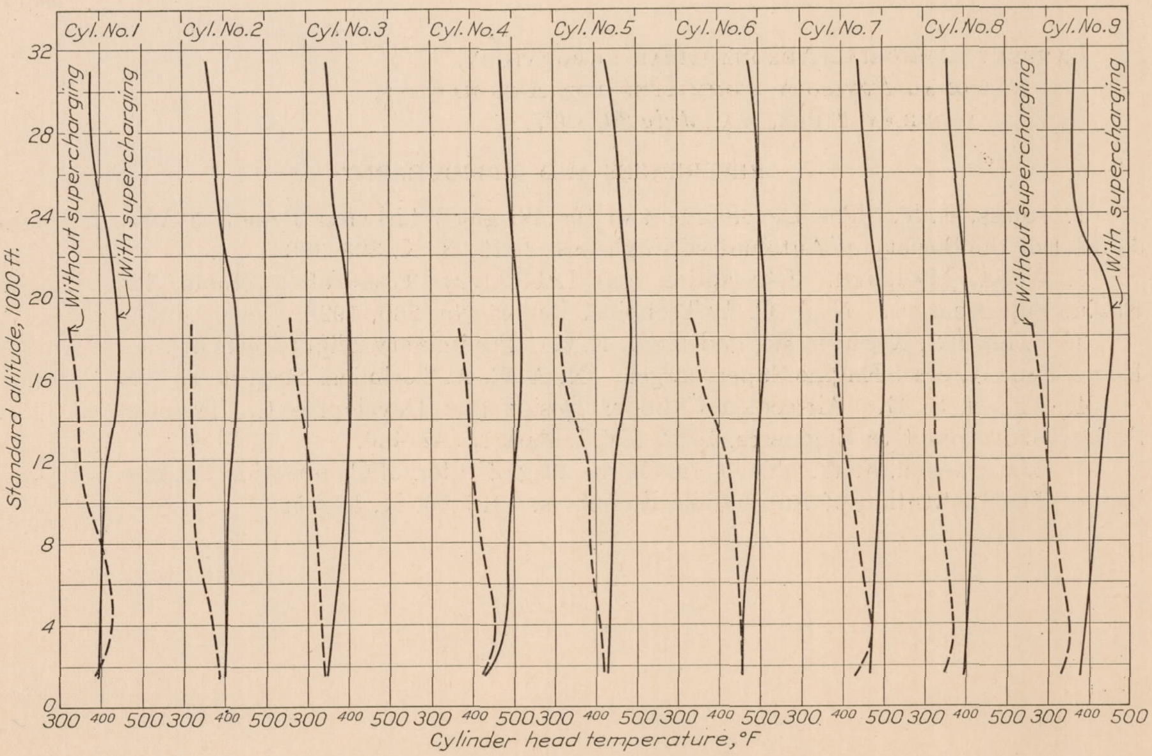

FIG. 5.—Effect of supercharging on cylinder-head temperatures

temperature and air-fuel ratio. A portion of the data given in the reference is reproduced in Figure 6. As no reliable fuel flow meter was available at the time these tests were made, it was impossible to determine the air-fuel ratios. In order to obtain a rough estimate of the influence of mixture ratio in this work, a computation of the probable ratios based on carburetor characteristics was made. Similar computations made in connection with some later work with a supercharged water-cooled engine and after a suitable flow meter had been developed showed that the method probably would give a fair estimate of the order of the change in ratio. This computation indicated that the charge was enriched quite appreciably as the altitude was increased, and there is little doubt that the maximum temperatures shown are somewhat lower than they would be if the charge was not enriched. The cylinder temperatures were probably lower at high altitudes in the unsupercharged flights, due also to some enrichment of the mixture, but in this case the enrichment serves no useful purpose, in that the temperatures are already well below the maximum which occurred at ground level.

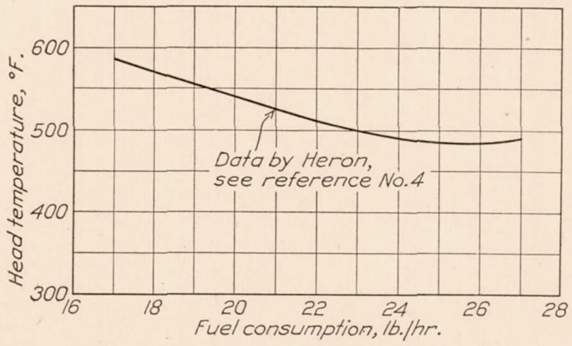

Fig. 6.—Effect of fuel consumption on cylinder-head temperatures

CONCLUSIONS

The work reported herein has shown the possibility of obtaining a material improvement in airplane performance by supercharging a modern air-cooled engine. The absolute ceiling was raised from 19,400 to 32,600 feet, and the time of climb to 16,000 feet was reduced from 32 to 16 minutes. While no limit of supercharging was established, it is evident that ground-level pressure may be maintained up to an altitude of 18,500 feet without imposing excessive stresses upon the engine.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *July 30, 1927*.

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TABLE I.—*Flight data for UO–1 airplane (supercharged)*

Standard altitude (feet)	Time (minutes)	Engine speed (R. P. M.)	Air speed (M. P. H.)	Atmospheric pressure (in. Hg.)	Carburetor pressure (in. Hg.)	Atmospheric temperature (°F.)	Carburetor temperature (°F.)
700	0. 64	1, 600	73	30. 35	30. 40	77	97
2, 650	2. 42	1, 555	71	28. 25	28. 95	69	90
4, 300	4. 18	1, 572	73	26. 65	28. 45	65	86
6, 000	5. 90	1, 605	74	24. 95	28. 30	59	93
7, 700	7. 65	1, 635	75	23. 35	28. 95	51	95
9, 250	9. 41	1, 625	76	21. 98	28. 00	45	98
10, 900	11. 18	1, 690	79	20. 60	28. 60	39	102
12, 900	13. 29	1, 710	80	19. 27	28. 40	37	115
14, 800	15. 21	1, 720	81	17. 97	28. 35	33	126
16, 650	17. 16	1, 730	81	16. 80	28. 25	30	137
18, 100	18. 76	1, 760	81	15. 74	27. 95	21	148
19, 800	20. 64	1, 775	83	14. 75	27. 95	17	163
21, 350	22. 59	1, 760	82	13. 90	26. 60	14	165
22, 600	24. 44	1, 760	82	13. 22	25. 20	9	163
23, 550	26. 03	1, 730	81	12. 64	24. 10	5	157
24, 250	27. 52	1, 725	79	12. 20	23. 20	0	151
24, 950	28. 94	1, 725	82	11. 75	22. 45	−5	145
25, 650	30. 73	1, 722	81	11. 40	21. 70	−8	140
26, 200	32. 32	1, 705	80	11. 10	21. 10	−11	134
26, 600	33. 70	1, 700	78	10. 85	20. 65	−15	130
27, 000	35. 39	1, 677	72	10. 65	20. 30	−16	126
27, 350	36. 85	1, 670	72	10. 45	19. 90	−19	124
27, 650	38. 49	1, 665	72	10. 30	19. 60	−20	122
28, 100	40. 93	1, 685	74	10. 15	19. 50	−20	122
28, 550	43. 33	----------	73	10. 00	----------	−20	95

TABLE II.—*Flight data for UO–1 airplane (supercharged)*

Standard altitude (feet)	Time (minutes)	Engine speed (R. P. M.)	Air speed (M. P. H.)	Atmospheric pressure (in. Hg.)	Carburetor pressure (in. Hg.)	Atmospheric temperature (°F.)	Carburetor temperature (°F.)
400	0. 53	----------	--------	30. 65	----------	78	90
550	. 72	1, 480	70	30. 35	30. 65	74	90
2, 150	2. 30	1, 510	70	28. 38	28. 60	64	86
3, 900	4. 20	1, 570	73	26. 70	28. 73	60	86
5, 650	5. 95	1, 600	73	24. 95	28. 73	53	88
7, 600	7. 89	1, 600	74	23. 30	28. 60	48	90
9, 200	9. 57	1, 640	75	21. 80	28. 73	40	91
11, 100	11. 54	1, 680	77	20. 25	28. 32	36	99
13, 000	13. 55	1, 700	75	18. 90	28. 93	33	108
14, 600	15. 23	1, 700	77	17. 80	28. 20	26	115
16, 550	17. 25	1, 720	73	16. 60	27. 93	22	126
17, 750	18. 92	1, 740	77	15. 75	28. 52	16	138
19, 300	20. 75	1, 780	83	14. 80	28. 73	11	151
20, 650	22. 68	1, 760	81	14. 05	27. 25	6	164
21, 600	24. 27	1, 760	76	13. 43	25. 86	1	160
22, 600	25. 95	1, 750	82	12. 84	24. 65	−4	151
23, 800	27. 75	1, 740	81	12. 20	23. 61	−8	147
24, 550	29. 49	1, 740	79	11. 80	22. 70	−10	142
25, 400	31. 19	1, 730	77	11. 35	22. 10	−14	138
26, 250	33. 21	1, 730	72	10. 98	21. 48	−15	138
26, 950	35. 37	1, 730	77	10. 70	21. 10	−16	138
27, 650	37. 13	1, 740	77	10. 37	20. 80	−18	138
28, 000	38. 81	1, 740	77	10. 20	20. 40	−20	136
28, 600	40. 52	1, 740	76	9. 92	20. 10	−23	135
29, 000	42. 68	1, 735	74	9. 73	19. 92	−25	135
29, 300	44. 47	1, 730	74	9. 60	19. 70	−26	133
29, 700	46. 01	1, 730	77	9. 40	19. 55	−29	133
30, 000	48. 28	1, 730	76	9. 30	19. 35	−29	131
30, 400	50. 27	1, 725	73	9. 15	19. 15	−30	131
30, 750	51. 98	1, 725	74	9. 00	18. 94	−31	127
30, 800	52. 72	1, 720	74	8. 95	18. 75	−32	126
31, 200	54. 94	1, 720	73	8. 82	18. 56	−33	126
31, 350	56. 48	1, 715	73	8. 75	18. 50	−34	126
31, 450	57. 92	1, 715	--------	8. 70	----------	−35	----------

TABLE III.—*Flight data for UO-1 airplane (supercharged)*

Standard altitude (feet)	Time (minutes)	Engine speed (R. P. M.)	Air speed (M. P. H.)	Atmospheric pressure (in. Hg.)	Carburetor pressure (in. Hg.)	Atmospheric temperature (°F.)	Carburetor temperature (°F.)
500	0.60	----------	--------	30.36	----------	74	----------
700	.84	----------	71	30.20	----------	74	----------
2,450	2.61	1,545	71	28.30	29.00	67	88
3,800	4.17	1,530	69	26.70	28.95	58	84
5,400	5.75	1,600	71	24.93	28.80	49	84
7,200	7.59	1,630	73	23.30	28.95	42	88
9,600	9.62	1,630	76	21.45	29.20	38	93
11,900	11.58	1,680	77	19.78	28.10	34	102
13,900	13.56	1,670	80	18.41	28.10	31	115
15,300	15.34	1,730	81	17.40	28.30	24	124
16,900	17.11	1,750	82	16.30	27.95	19	137
18,650	18.94	1,800	84	15.20	28.70	14	158
20,050	20.87	1,800	88	14.40	27.15	9	165
21,400	22.68	1,800	86	13.62	25.75	5	162
22,700	24.50	1,770	85	12.90	24.40	0	158
23,550	26.05	1,770	84	12.37	23.60	−4	157
24,350	28.08	1,790	87	12.00	23.20	−6	157
25,300	29.80	1,770	86	11.50	22.40	−9	157
25,950	31.71	1,740	85	11.20	21.80	−12	149
26,500	33.15	1,740	85	10.87	21.20	−16	146
27,150	35.35	1,750	85	10.62	20.80	−16	146
27,700	36.77	1,720	81	10.30	20.40	−20	145
28,200	38.80	1,740	81	10.10	20.10	−21	141
28,700	40.79	1,740	80	9.90	19.80	−22	138
28,850	41.97	1,720	76	9.80	19.60	−24	136
29,300	43.73	1,700	77	9.60	19.50	−26	134
29,500	45.28	----------	78	9.50	----------	−26	130

TABLE IV.—*Flight data for UO-1 airplane (without supercharging)*

Standard altitude (feet)	Time (minutes)	Engine speed (R. P. M.)	Air speed (M. P. H.) (1)	Atmospheric pressure (in. Hg.)	Carburetor pressure (in. Hg.)	Atmospheric temperature (°F.)	Carburetor temperature (°F.)
700	0.75	1,520	--------	30.10	30.20	70	88
1,600	1.72	1,500	--------	28.65	28.80	61	84
3,100	3.67	1,500	--------	27.20	27.25	56	79
4,500	5.50	1,510	--------	25.82	26.00	52	72
5,950	7.65	1,530	--------	24.66	24.90	51	70
7,100	9.42	1,520	--------	23.58	23.80	46	68
8,050	11.09	1,500	--------	22.67	22.75	41	64
9,200	13.15	1,500	--------	21.80	21.95	39	62
10,150	15.05	1,510	--------	21.05	21.15	37	58
10,800	16.72	1,490	--------	20.48	20.65	35	55
11,450	18.66	1,500	--------	20.00	20.00	33	54
12,200	20.51	1,480	--------	19.43	19.55	30	52
12,850	22.58	1,490	--------	19.00	19.15	28	50
13,200	23.94	1,480	--------	18.65	18.75	25	48
13,700	25.60	1,470	--------	18.25	18.40	23	46
14,000	26.92	1,470	--------	17.95	18.05	20	45
14,450	28.59	1,460	--------	17.60	17.60	17	42
14,700	29.87	1,470	--------	17.35	17.50	14	42
15,000	32.12	1,460	--------	17.18	17.25	14	42
15,500	34.36	1,460	--------	16.90	16.95	14	42
15,900	36.61	1,450	--------	16.68	16.80	14	41
16,100	37.97	1,450	--------	16.50	16.65	13	40
16,450	41.51	1,450	--------	16.38	16.55	13	39
16,600	42.52	1,430	--------	16.20	16.30	12	38
16,600	42.52	1,430	--------	16.20	16.25	12	37
17,000	46.51	1,410	--------	16.08	16.20	13	37
17,100	47.98	1,390	--------	16.00	16.20	13	40

[1] No air speed because of failure of recording instrument.

TABLE V.—*Flight data for UO-1 airplane (without supercharging)*

Standard altitude (feet)	Time (minutes)	Engine speed (R. P. M.)	Air speed (M. P. H.)	Atmospheric pressure (in. Hg.)	Carburetor pressure (in. Hg.)	Atmospheric temperature (°F.)	Carburetor temperature (°F.)
500	0.57	1,500	84	30.20	----------	71	----------
2,100	2.40	1,500	83	28.50	28.70	65	88
3,750	4.31	1,500	84	26.90	27.25	61	84
5,200	6.11	1,520	83	25.48	25.95	56	80
6,500	7.90	1,520	84	24.25	24.75	51	73
7,750	9.67	1,500	85	23.10	23.60	45	68
8,800	11.47	1,480	87	22.18	22.70	41	62
9,950	13.25	1,500	89	21.20	21.90	38	60
10,800	14.91	1,470	87	20.45	21.10	34	55
11,700	16.83	1,480	87	19.78	20.50	32	52
12,400	18.66	1,460	87	19.25	19.90	29	50
13,200	20.72	1,470	87	18.72	19.35	28	50
13,750	22.69	1,460	87	18.35	18.90	27	50
14,350	24.69	1,480	88	17.95	18.55	25	50
14,950	26.84	1,490	90	17.60	18.30	24	48
15,300	28.22	1,470	89	17.28	18.00	22	46
15,650	30.65	1,470	88	17.10	17.70	22	43
16,000	32.18	1,460	88	16.82	17.50	20	42

TABLE VI.—*Flight data for UO-1 airplane (without supercharging)*

Standard altitude (feet)	Time (minutes)	Engine speed (R. P. M.)	Air speed (M. P. H.)	Atmospheric pressure (in. Hg.)	Carburetor pressure (in. Hg.)	Atmospheric temperature (°F.)	Carburetor temperature (°F.)
500	0.42	----------	--------	30.40	----------	75	90
2,300	1.92	1,560	78	28.30	28.50	65	88
4,050	3.71	1,540	78	26.50	26.90	58	81
5,700	5.62	1,530	79	25.00	25.50	55	73
7,250	7.59	1,530	79	23.70	24.20	51	70
8,400	9.17	1,530	79	22.50	23.10	43	63
9,700	11.31	1,520	80	21.57	22.40	44	63
10,950	13.43	1,520	81	20.70	21.33	42	59
11,850	15.50	1,510	81	20.08	20.65	40	59
12,600	17.28	1,500	81	19.50	20.05	39	57
13,350	19.12	1,500	82	18.95	19.60	35	55
14,000	20.87	1,500	82	18.46	19.13	33	54
14,550	22.61	1,500	82	18.05	18.68	31	52
15,250	24.59	1,490	83	17.60	18.38	30	52
15,950	26.76	1,480	82	17.20	17.92	29	52
16,300	28.19	1,470	80	16.90	17.57	26	48
16,600	29.64	1,470	80	16.65	17.30	25	46
16,800	31.24	1,470	79	16.50	17.18	23	46
17,100	33.02	1,460	77	16.30	16.96	22	45
17,350	34.48	1,440	76	16.10	16.72	20	43
17,700	36.56	1,440	75	15.90	16.53	20	43
17,950	38.48	1,450	78	15.75	16.40	20	43
18,050	39.63	1,440	77	15.65	16.30	18	39
18,350	41.91	1,430	76	15.50	16.18	18	39
18,500	44.03	1,420	74	15.42	16.10	18	39
18,650	45.43	1,410	72	15.30	16.00	16	39

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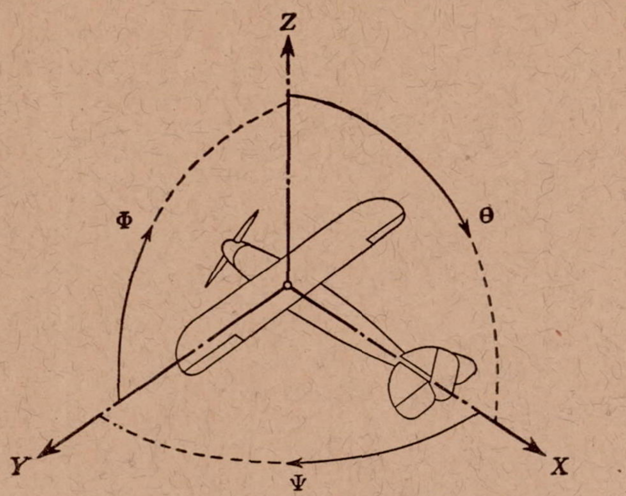

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS} \quad C_M=\frac{M}{qcS} \quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.