NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 225

THE AIR FORCES ON A MODEL OF THE SPERRY MESSENGER AIRPLANE WITHOUT PROPELLER

By MAX M. MUNK, and WALTER S. DIEHL

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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		m/sec		mi./hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W=mg$.

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

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

Density (mass per unit volume), ρ

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}

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

Area, S; wing area, S_w, etc.

Gap, G.

Span, b; chord length, c.

Aspect ratio $=b/c$.

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

Coefficient of viscosity, μ.

3. AERODYNAMICAL SYMBOLS

True airspeed, V.

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

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

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

Cross-wind force, C; absolute coefficient

$$C_C=\frac{C}{qS}$$

Resultant force, R.

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

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

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

Dihedral angle, γ.

Reynolds Number $=\rho\frac{Vl}{\mu}$ 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.

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

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

Angle of attack, α.

Angle of downwash, ϵ.

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SUMMARY

This is a report on a scale-effect research which was made in the variable density wind tunnel of the National Advisory Committee for Aeronautics at the request of the Army Air Service. A 1/10 scale model of the Sperry Messenger airplane with USA–5 wings was tested without a propeller at various Reynolds numbers up to the full scale value. Two series of tests were made: The first on the original model which was of the usual simplified construction, and the second on a modified model embodying a great amount of detail.

While the present report is of a preliminary nature, the work has progressed far enough to show that the scale effect is almost entirely confined to the drag. In the tests so far conducted, the drag at any given angle of attack within the normal flying range is found to vary as $\left(\frac{Vl}{\nu}\right)^n$. The exponent n is constant for any one angle of attack, and ranges from -0.045 at large angles of attack to -0.17 at small angles.

It was also found that the model should be geometrically similar to the full-scale airplane if the test data are to be directly applicable to full scale. If the condition of geometric similarity be fulfilled, the data obtained at a full-scale value of Reynolds number agree very closely with free-flight data. The variable density wind tunnel therefore appears to be a very promising instrument for procuring test data free from scale effect. It is also admirably suited for studying the scale effect and obtaining information which is necessary in an interpretation of the results obtained in atmospheric wind tunnels at low values of the Reynolds number.

INTRODUCTION

Until recently the only method of increasing the Reynolds number $\left(\frac{Vl}{\nu}\right)$ in a wind-tunnel test was to increase either V or l or both together, but the maximum practicable value of $\left(\frac{Vl}{\nu}\right)$ thus obtainable is far below that corresponding to the average airplane in free flight. The variable density wind tunnel of the National Advisory Committee for Aeronautics, using models of normal size and employing moderate speeds, while varying the kinematic viscosity ν $\left(=\frac{\mu}{\rho}\right)$ by changing the density, supplies a means for bridging the entire gap between a conventional wind-tunnel test and full scale.

Owing to the interest attached to the results of the variable-density tests on account of their novel nature and their probable value to the designer, it has been considered advisable to make available immediately a preliminary report on the first complete series of tests. The tests with which this preliminary report is concerned are the part of an extensive free-flight and wind-tunnel research conducted by the National Advisory Committee for Aeronautics for the Army Air Service on the Sperry Messenger airplane.

In a new field of research such as that opened by this report, it is to be expected that the test data will show some inconsistencies, partially due to the personal elements, or to the newness of the work, or possibly to some unknown and unsuspected physical law. There are certain inconsistencies to be observed in the data in this report, but time has not been sufficient to investigate them more fully and ascertain the cause or causes. It is expected that the present report will prove instructive both as to the nature of scale effect and as to the probable value of the variable density wind tunnel in further testing.

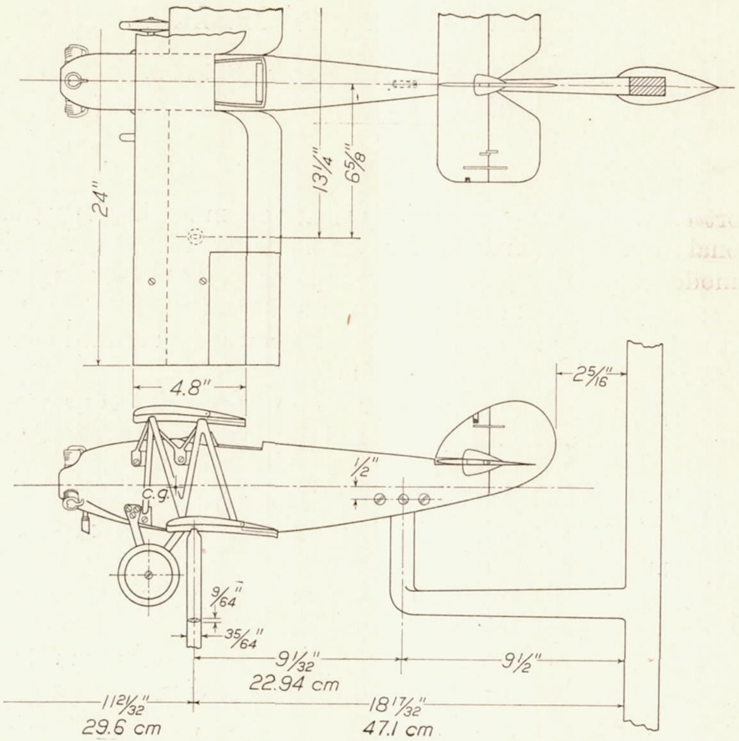


FIG. 1.—Original Sperry Messenger model set up in variable density wind tunnel

METHOD OF TESTING

The original model of the Sperry Messenger as supplied by the Army Air Service was a geometrically similar replica of the airplane so far as the main dimensions were concerned, but many minor parts and details, including the propeller, were omitted in order to simplify the model construction. The original model, therefore, fairly represented the average wind-tunnel model in the amount of detail used.

During the tests the model was attached to the balance in the variable density wind tunnel by means of two vertical "stilts" of ordinary stream-line wire which were hinged at their upper ends to the wings and rigidly connected at their lower ends to the balance. The model was also connected to a vertical shielded balance bar on the down-stream side by means of a short skid which was hinged at the fuselage and rigidly attached to the bar. This arrangement allows the angle of attack to be changed readily. (Figs. 1 and 2.)

During a test run the tank pressure was held constant, and readings of the air forces and moments taken for various angles of attack. The drag and interference corrections for the attachments were determined by separate runs.

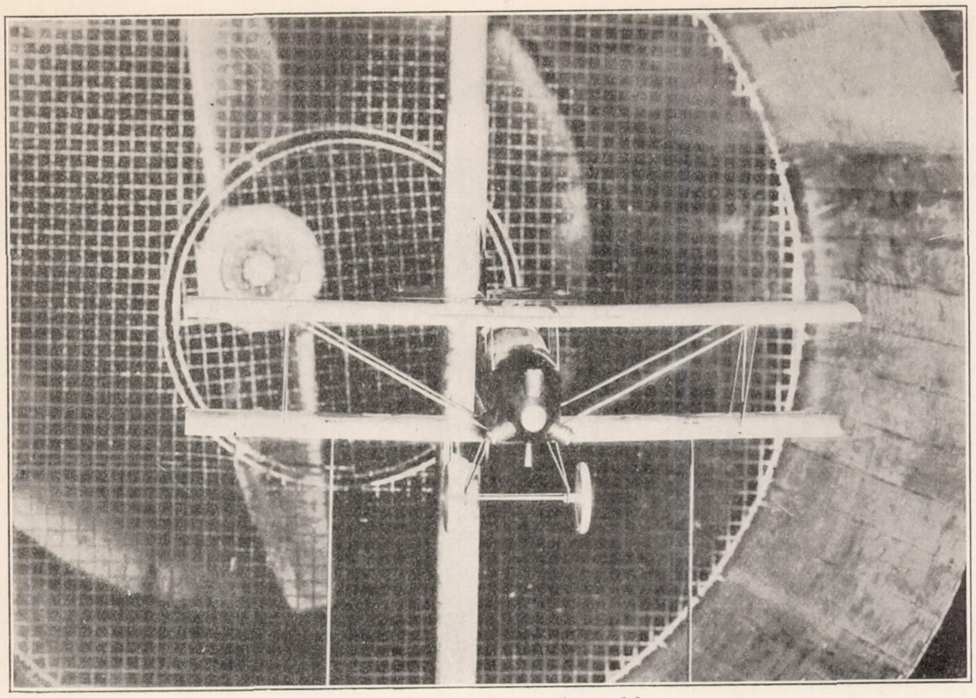


FIG. 2.—Method of supporting model

RESULTS OF THE TESTS

After completing a series of five runs on the original model it was decided to add to it as much detail as practicable in order to get a more exact geometrical similarity. Accordingly 31 changes were made as follows (figs. 3 and 4):

1. New air intake added to carbureter.
2. Oil filler cap added.
3. Fuel tank drain cock added.
4. Oil valve and drain cock added.
5. Pan built up on under side of fuselage.
6. Brass plates added to the sides and bottom of fuselage to approximate bomb rack supports.
7. Chain and sprockets added to side of fuselage.
8. Strips added along top longeron of fuselage.
9. Control cables, horns, and wires added to horizontal tail surfaces.
10. Hole made in under side of fuselage near tail skid.
11. Holes made in stabilizer for control wires.
12. Small fin removed from rudder and fin.
13. Aileron horns and inter aileron struts and with wires running into wing.
14. Cross wires and shock absorbers added to landing gear.
15. Cross wires added in center section above fuselage.
16. Pilot tube added on outer strut.
17. Trailing edge of upper wing altered at center section and hand holes added.
18. Edges of wing changed from round to straight at center section.
19. Angle of attack bomb and cable with rack for bomb added.
20. New engine constructed with fins and valve gear.
21. Length of cockpit changed and hollowed out.
22. Height of wind shield changed.
23. Bump added on top of the fuselage forward as in the full-size airplane.
24. Groove added in ailerons at top and bottom for hinge gap.
25. Wires added to fuselage sides near nose to approximate hinges on cowling.
26. Nose of fuselage hollowed out behind the propeller.
27. Ball bearing propeller hub added.
28. Ailerons fastened in position with screws at ends.
29. Ends of tie struts beveled off at fuselage.
30. Brace wires added between stabilizer and fin.
31. Turnbuckles on all wires approximated by twisting the ends.

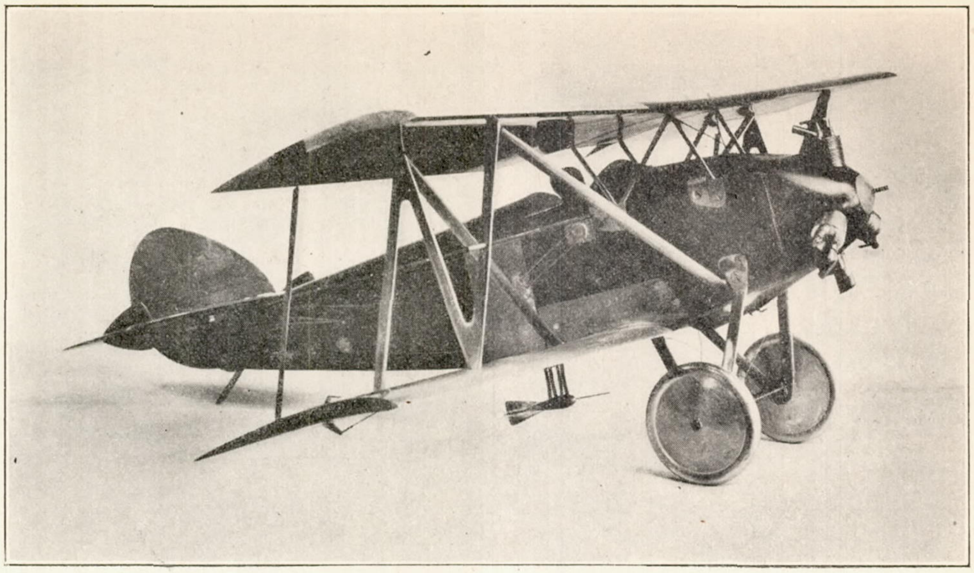


FIG. 3.—View of modified model

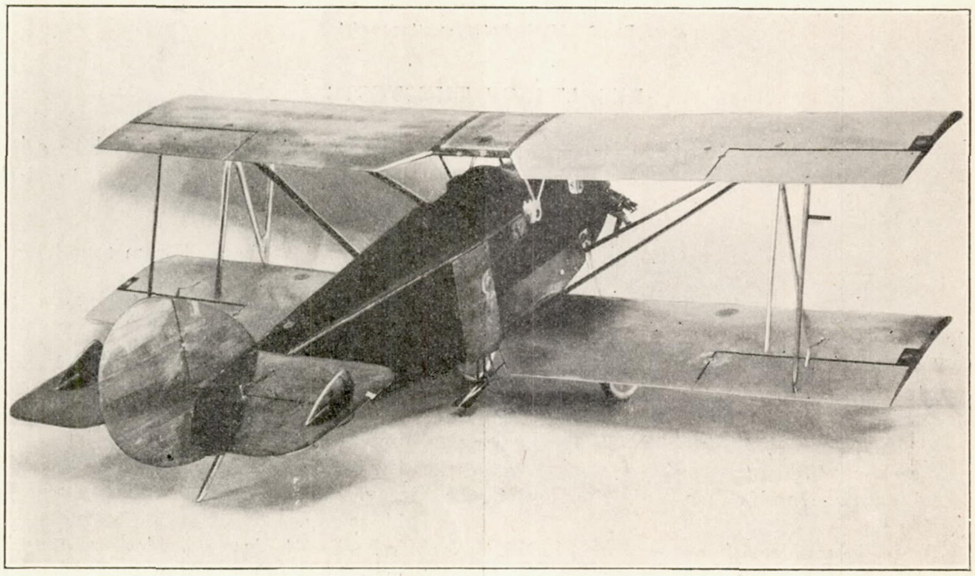


FIG. 4.—Three-quarter rear view of model

Upon completion of these changes a series of three runs was made on the modified model. The results of the two series of tests are given in Tables I to VIII and on Figures 5, 6, and 7. The lift coefficient C_L and the drag coefficient C_D are computed by dividing the measured lift or drag by the wing area and the dynamic pressure. The moment coefficient is computed by

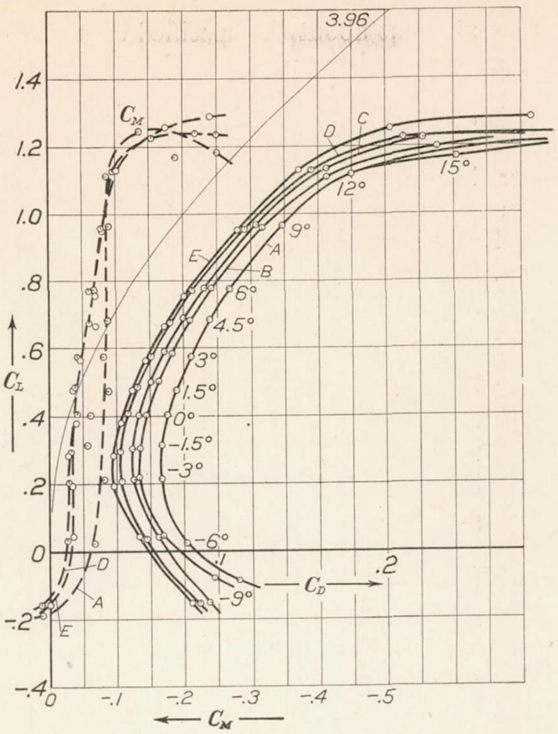


FIG. 5.—Sperry Messenger Original, U. S. A. 5 wings

	Tank pressure atmosphere	Dynamic pressure q=kg/m²	Reynolds number
Curve A	1.00	27.9	189,000
Curve B	2.82	80.5	482,000
Curve C	4.83	140.0	820,000
Curve D	10.00	297.0	1,670,000
Curve E	19.86	619.0	3,400,000

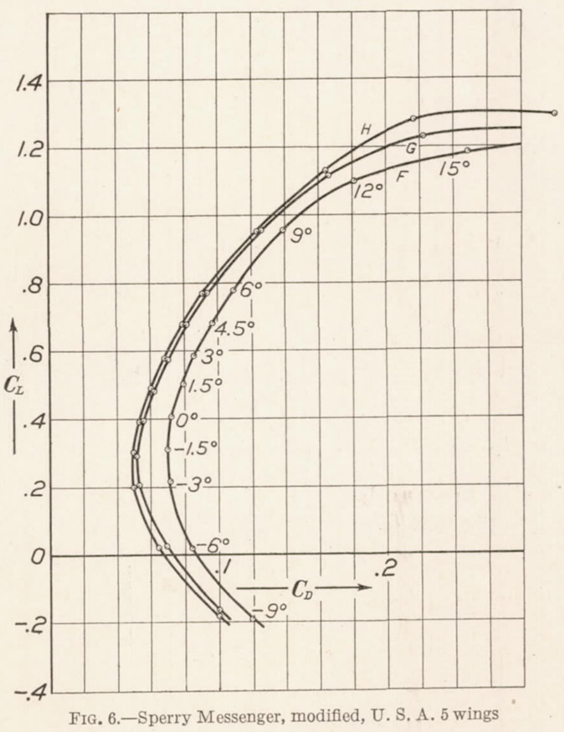


FIG. 6.—Sperry Messenger, modified, U. S. A. 5 wings

	Tank pressure atmospheres	Dynamic pressure q=kg/m²	Reynolds number
Curve F	1.00	26.85	165,000
Curve G	10.30	290.00	1,600,000
Curve H	20.80	637.00	3,450,000

dividing the observed pitching moment about the specified center of gravity by the product of the wing area, the dynamic pressure and the wing chord. That is,

$$C_L=\frac{L}{qS},\quad C_D=\frac{D}{qS},\quad \text{and} \quad C_M=\frac{M_{c.g.}}{qCS}$$

The angle of attack is measured from the line of thrust. The Reynolds number has been computed in the usual way, taking the wing chord as the characteristic length of the model.

An inspection of the test data shows that the scale effect on lift is negligible everywhere except at and near the maximum lift, the maximum effect being of the order of a 4 per cent increase in lift in passing from the Reynolds number of an ordinary wind tunnel test to the full scale value.

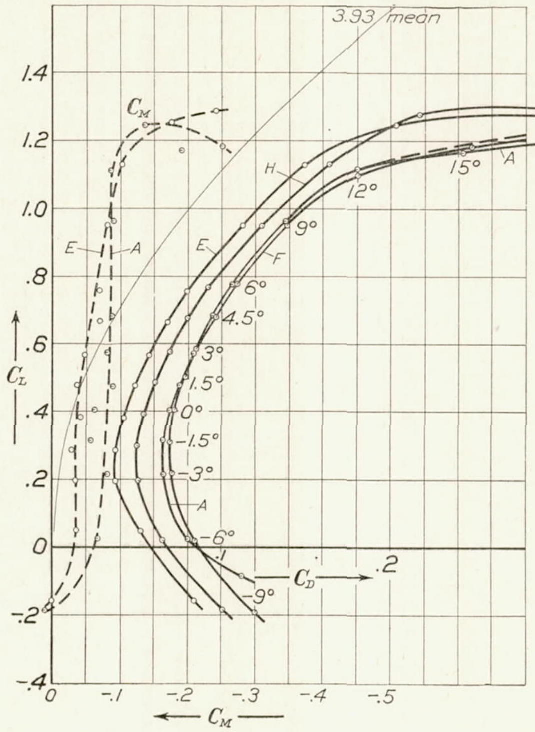


FIG. 7.—Sperry Messenger, U. S. A. 5 wings

	Tank pressure atmosphere	Dynamic pressure q=kg/m²	Reynolds number
Curve A original	1.00	27.90	189,000
Curve E original	19.86	619.00	3,400,000
Curve F modified	1.00	26.85	165,000
Curve H modified	20.80	637.00	3,450,000

Figure 8 has been prepared to bring out the effect of scale on drag by plotting logarithmically the drag coefficient at a given angle of attack against Reynolds number. In each case, for the original model, it is found that the experimental points lie on a straight line, showing that the drag varies as $\left(\frac{Vl}{\nu}\right)^n$. For the modified model only three points are available at each angle of attack, but these points also lie on straight lines, which appear to be justified by the more complete data in the first series. The value of the exponent n varies with angle of attack as follows:

Angle of attack α	Original model n	Modified model n
−6°	−0.17	−0.10
0°	−.15	−.09
6°	−.11	−.06
12°	−.07	−.045
18°	−.07	−.045

The absolute decrease in drag in passing from the lowest to the highest Reynolds number appears to be substantially independent of angle of attack except at the highest angle $-18°$. These differences are as follows:

Angle of attack α	Original model			Modified model		
	C_D at		ΔC_D	C_D at		ΔC_D
	R. N.= 189,000	R. N.= 3,400,000		R. N.= 165,000	R. N.= 3,450,000	
−6°	0.0811	0.0530	0.0281	0.0846	0.0648	0.0198
0°	.0701	.0423	.0278	.0725	.0539	.0186
+6°	.1075	.0800	.0275	.1088	.0916	.0172
12°	.1800	.1495	.0305	.1808	.1635	.0173
18°	.3551	.2875	.0676	.3434	.3002	.0432

The great increase at 18° is no doubt due to the change in type of flow which is beginning to occur at this angle. At lower angles the scale effect apparently agrees very closely in form with that predicted by Diehl (reference 1) from his study of test data at low Reynolds numbers.

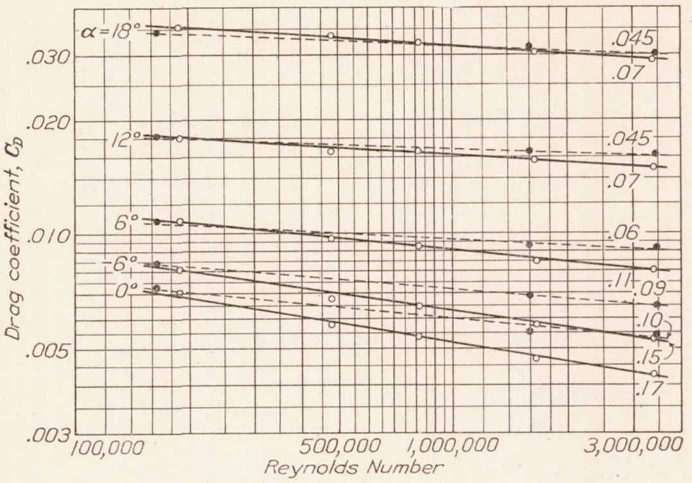


FIG. 8.—Variation of drag coefficient with Reynolds number for Sperry Messenger model. Variable Density Wind Tunnel

The differences between the absolute drags and the exponents for the original and modified models can not be entirely accounted for at this time. A study of the list of changes will show that while some tend to increase the drag and others reduce it, there is a preponderance in favor of an increase in drag. It is possible, of course, that the drag of some of the added parts, when measured on the model with the mutual interferences present, may increase more rapidly than the square of the Reynolds number. The curves of the drag coefficient against Reynolds number for such parts could slope upward to the right on the logarithmic plot, and partially explain not only the lower exponents for the modified model but also close agreement between the drag of the two models at low Reynolds number.

The research on the Sperry Messenger airplane has not progressed far enough to make possible a complete comparison between the model and full scale data. Based on the free flight data at hand the conclusion is reached that the modified model gives results which are not only substantially correct and in better agreement with free flight than those given by the original model but that the differences are in the same direction. That is, it would appear that the more exact a model is made the more nearly will the test data obtained in the variable density wind tunnel agree with full scale.

These results have a direct bearing on the tests of airplane models made at low values of Reynolds number in atmospheric wind tunnels, in that they show the common practice of using simplified models to be unjustified and the test data without meaning unless corrections are applied not only for the omitted parts but also for the scale effect. At present the scale effect correction is rather uncertain, but the variable density wind tunnel will be able eventually to supply the necessary information. A preliminary study indicates that a large part of the scale effect may be due to the model struts and wires, in which case a partial scale effect correction may be readily applied with data now available. Too much emphasis can not be laid on the unsoundness of the assumption that test data obtained on a simplified model can be used without corrections to predict full-scale performance.

CONCLUSIONS

Owing to the preliminary nature of this report, it is impractical to draw any but the most general conclusions, as follows:

1. The scale effect on lift appears negligible except at the maximum lift where a 4 per cent increase was obtained by a twenty-fold increase in Reynolds number. This effect probably varies with the wing section and arrangement.

2. The scale effect on drag is represented by an exponential variation with Reynolds number. That is, Drag$\propto\left(\frac{Vl}{\nu}\right)^n$ where the exponent n is probably of the order of -0.10.

3. A model must represent the full size airplane as accurately as possible if the data obtained from tests in the variable density wind tunnel are to be valid.

4. The test data appear to justify the principle of the variable density wind tunnel, which now offers an extremely valuable means not only of supplying data free from scale effect but also of studying scale effect and similar design problems.

5. The common assumption that data obtained on simplified airplane models at low Reynolds numbers can be used without corrections to predict full scale performance is unsound and may lead to absurd results in certain cases.

More test data are required along the lines covered by this report before final conclusions can be drawn. It is recommended in particular that the effect of the major changes made on the original Sperry Messenger model be investigated one at a time in order to find the cause or causes for the very slight effect of the changes at low Vl. It is also recommended that a similar research be made on another airplane of a different type, for example, a bomber or a very simple monoplane.

BIBLIOGRAPHY

1. Diehl, W. S. The Variation of Aerofoil Lift and Drag Coefficients with Changes in Size and Speed. 1921. N. A. C. A. Technical Report No. 111.

TABLE I

SPERRY MESSENGER MODEL (ORIGINAL)

Span, 24 inches (61 cm); area, 0.139 m².
Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient, C_L	Drag coefficient, C_D	Moment coefficient,[1] C_M	$\frac{C_L}{C_D}$
−9.0	27.8	−0.186	0.1121	+0.012	−1.66
−6.0	28.0	.023	.0811	−.066	2.84
−3.0	28.2	.212	.0667	−.083	3.17
−1.5	27.8	.313	.0668	−.057	4.68
0.0	27.8	.406	.0701	−.062	5.79
1.5	28.2	.472	.0757	−.088	6.23
3.0	28.0	.572	.0840	−.081	6.80
4.5	28.0	.683	.0952	−.087	7.17
6.0	28.0	.775	.1075	−.067	7.21
9.0	28.1	.962	.1393	−.090	6.90
12.0	28.0	1.115	.1800	−.086	6.20
15.0	28.1	1.168	.2424	−.184	4.82
18.0	27.8	1.244	.3551	−.136	3.50
21.0	27.4	1.181	.4572	−.250	2.58

[1] Moments taken about the center of gravity.

Average temperature, 20° C.; average tank pressure, 1 atmosphere; average Reynolds number, 189,000.

TABLE II

SPERRY MESSENGER MODEL (ORIGINAL)

Span, 24 inches (61 cm); area, 0.139 m².
Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient, C_L	Drag coefficient, C_D	$\frac{C_L}{C_D}$
−9.0	79.7	−0.139	0.0978	−1.42
−6.0	80.0	+.048	.0675	0.71
−3.0	80.6	.219	.0535	4.08
−1.5	80.6	.305	.0540	5.64
0.0	81.3	.402	.0579	6.93
1.5	81.0	.498	.0653	7.62
3.0	81.0	.583	.0735	7.93
4.5	81.5	.681	.0839	8.11
6.0	81.5	.775	.0965	8.03
9.0	81.5	.957	.1272	7.51
12.0	81.5	1.107	.1657	6.68
15.0	81.4	1.197	.2308	5.18
18.0	79.8	1.225	.3357	3.65
21.0	79.8	1.191	.4380	2.72

Average temperature, 23° C.; average tank pressure, 2.82 atmospheres; average Reynolds number, 482,000.

TABLE III

SPERRY MESSENGER MODEL (ORIGINAL)

Span, 24 inches (61 cm); area, 0.139 m². Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient C_L	Drag coefficient C_D	Moment coefficient[1] C_M	$\frac{C_L}{C_D}$
−9.0	140	−0.151	0.0943	−0.007	−1.60
−6.0	140	+.041	.0646	−.015	0.63
−3.0	140	.213	.0500	−.043	4.26
−1.5	142	.306	.0492	−.049	6.21
0.0	140	.402	.0535	−.055	7.48
1.5	140	.498	.0602	−.055	8.28
3.0	142	.590	.0684	−.077	8.62
4.5	141	.690	.0799	−.069	8.62
6.0	140	.779	.0922	−.097	8.45
9.0	139	.966	.1234	−.075	7.76
12.0	139	1.134	.1651	−.075	6.87
15.0	138	1.224	.2223	−.161	5.52
18.0	138	1.220	.3222	−.187	3.79
21.0	136	1.189	.4272	−.238	2.78

[1] Moments taken about the center of gravity.

Average temperature, 26° C.; average tank pressure, 4.83 atmospheres; average Reynolds number, 820,000.

TABLE IV

SPERRY MESSENGER MODEL (ORIGINAL)

Span, 24 inches (61 cm); area, 0.139 m². Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient C_L	Drag coefficient C_D	Moment coefficient[1] C_M	$\frac{C_L}{C_D}$
−9.0	292	−0.158	0.0888	+0.013	−1.78
−6.0	298	+.035	.0573	−.026	+0.61
−3.0	295	.207	.0428	−.029	4.83
−1.5	298	.297	.0421	−.032	7.05
0.0	293	.409	.0468	−.042	8.75
1.5	298	.487	.0529	−.038	9.20
3.0	298	.575	.0608	−.043	9.45
4.5	298	.676	.0719	−.060	9.39
6.0	298	.770	.0849	−.061	9.07
9.0	299	.952	.1166	−.078	8.17
12.0	298	1.127	.1562	−.096	7.22
15.0	298	1.225	.2112	−.154	5.81
18.0	298	1.237	.3023	−.219	4.09
21.0	293	1.233	.4148	−.250	2.97

[1] Moments taken about the center of gravity.

Average temperature, 34° C.; average tank pressure, 10 atmospheres; average Reynolds number, 1,670,000.

TABLE V

SPERRY MESSENGER MODEL (ORIGINAL)

Span, 24 inches (61 cm); area, 0.139 m². Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient, C_L	Drag coefficient, C_D	Moment coefficient[1] C_M	$\frac{C_L}{C_D}$
−9.0	616	−0.158	0.0841	+0.001	−1.88
−6.0	617	.024	.0530	−.034	+0.45
−3.0	621	.193	.0380	−.034	5.08
−1.5	619	.284	.0380	−.028	7.47
0.0	622	.380	.0423	−.041	8.98
1.5	621	.475	.0490	−.036	9.71
3.0	621	.563	.0573	−.047	9.83
4.5	622	.664	.0684	−.068	9.71
6.0	623	.754	.0800	−.069	9.42
9.0	621	.949	.1124	−.080	8.44
12.0	619	1.130	.1495	−.102	7.57
15.0	619	1.253	.2033	−.175	5.68
18.0	611	1.285	.2875	−.241	4.47

Moments taken about the center of gravity of full scale airplane.

Average temperature, 35° C.; average tank pressure, 19.86 atmospheres; average Reynolds number, 3,400,000.

TABLE VI

SPERRY MESSENGER MODEL (MODIFIED)

Span, 24 inches (61 cm); area, 0.1377 m². Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient, C_L	Drag coefficient, C_D	$\frac{C_L}{C_D}$
−9.0	26.6	−0.191	0.1203	−1.59
−6.0	26.7	.019	.0846	0.22
−3.0	26.9	.216	.0707	3.05
−1.5	26.9	.310	.0699	4.43
0.0	26.9	.405	.0725	5.74
1.5	26.9	.500	.0787	6.35
3.0	26.7	.582	.0850	6.85
4.5	26.8	.679	.0967	7.01
6.0	26.8	.776	.1088	7.14
9.0	26.8	.952	.1393	6.83
12.0	26.8	1.098	.1808	6.08
15.0	26.8	1.184	.2478	4.78
18.0	26.8	1.225	.3434	3.57
21.0	26.7	1.238	.4528	2.73

Average temperature, 25° C.; average tank pressure, 1 atmosphere; average Reynolds number, 165,000.

TABLE VII

SPERRY MESSENGER MODEL (MODIFIED)

Span, 24 inches (61 cm); area, 0.1377 m ².
Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient C_L	Drag coefficient C_D	$\frac{C_L}{C_D}$
−9.0	290	−0.167	0.1001	−1.67
−6.0	293	+.024	.0687	+0.35
−3.0	292	.204	.0526	3.78
−1.5	291	.293	.0509	5.76
0.0	290	.396	.0550	7.19
1.5	290	.486	.0614	7.91
3.0	290	.575	.0698	8.23
4.5	290	.679	.0808	8.40
6.0	290	.773	.0930	8.31
9.0	290	.954	.1251	7.75
12.0	290	1.114	.1651	6.75
15.0	290	1.228	.2214	5.55
18.0	286	1.244	.3144	3.96
21.0	285	1.223	.4216	2.90

Average temperature, 44° C.; average tank pressure, 10.3 atmospheres; average Reynolds number, 1,600,000.

TABLE VIII

SPERRY MESSENGER MODEL (MODIFIED)

Span, 24 inches (61 cm); area, 0.1377 m ².
Chord, 4.8 inches (12.2 cm); U. S. A. 5 airfoil.

Angle of attack, degrees	Dynamic pressure, q=kg/m²	Lift coefficient C_L	Drag coefficient C_D	$\frac{C_L}{C_D}$
−9.0	628	−0.183	0.1005	−1.82
−6.0	634	+.019	.0648	+0.29
−3.0	637	.196	.0504	3.88
−1.5	637	.300	.0501	5.99
0.0	634	.390	.0539	7.24
1.5	639	.487	.0610	7.98
3.0	635	.575	.0689	8.34
4.5	644	.675	.0796	8.48
6.0	643	.767	.0916	8.36
9.0	648	.951	.1236	7.71
12.0	638	1.128	.1635	6.90
15.0	630	1.279	.2166	5.92
18.0	632	1.293	.3002	4.31

Average temperature, 39° C.; average tank pressure, 20.8 atmospheres; average Reynolds number, 2,450,000.

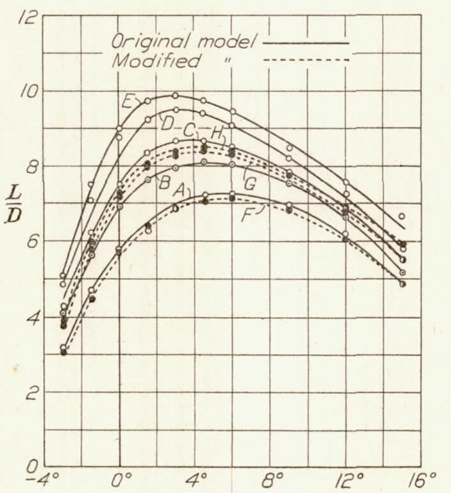
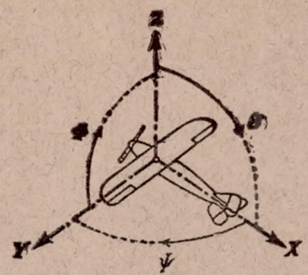


FIG. 9.—Variation of L/D with Reynolds number

	Tank pressure atmospheres	Reynolds number
A	1.00	189,000
B	2.82	482,000
C	4.83	820,000
D	10.00	1,670,000
E	19.86	3,400,000
F	1.00	165,000
G	10.30	1,600,000
H	20.80	3,450,000

O



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

Diameter, D

Pitch (a) Aerodynamic pitch, p_a

(b) Effective pitch, p_e

(c) Mean geometric pitch, p_g

(d) Virtual pitch, p_v

(e) Standard pitch, p_s

Pitch ratio, p/D

Inflow velocity, V'

Slipstream velocity, V_s

Thrust, T.

Torque, Q.

Power, P.

(If "coefficients" are introduced all units used must be consistent.)

Efficiency $\eta = T\,V/P$.

Revolutions per sec., n; per min., N.

Effective helix angle $\Phi=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

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.