NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 291

DRAG OF C-CLASS AIRSHIP HULLS OF VARIOUS FINENESS RATIOS

By A. F. ZAHM, R. H. SMITH, and F. A. LOUDEN

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

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.

REPORT No. 291

DRAG OF C-CLASS AIRSHIP HULLS OF VARIOUS FINENESS RATIOS

By A. F. ZAHM, R. H. SMITH, and F. A. LOUDEN
Aerodynamical Laboratory, Bureau of Construction and Repair
United States Navy

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

[An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. It consists of 12 members who are appointed by the President, all of whom serve as such without compensation.]

REPORT No. 291

DRAG OF C-CLASS AIRSHIP HULLS OF VARIOUS FINENESS RATIOS

By A. F. Zahm, R. H. Smith, and F. A. Louden

PREFACE

This report presents the results of wind-tunnel tests on eight C-class airship hulls with various fineness ratios, conducted in the Navy Aerodynamic Laboratory, Washington. The purpose of the tests was to determine the variation of resistance with fineness ratio, and also to find the pressure and friction elements of the total drag for the model having the least shape coefficient.

Seven C-class airship hulls with fineness ratios of 1.0, 1.5, 2.0, 3.0, 6.0, 8.0, and 10.0 were made and verified. These models and also the previously constructed original C-class hull, whose fineness ratio is 4.62, were then tested in the 8 by 8 foot tunnel for drag at 0° pitch and yaw, at various wind speeds. The original hull, which was found to have the least shape coefficient, was then tested for pressure distribution over the surface at various wind speeds.

This account is a slightly revised form of Report No. 335, prepared in the Bureau of Construction and Repair for the Bureau of Aeronautics, May 14, 1927, and by it submitted for publication to the National Advisory Committee for Aeronautics. A summary of conclusions and a comparison with previous data are given at the end of the text.

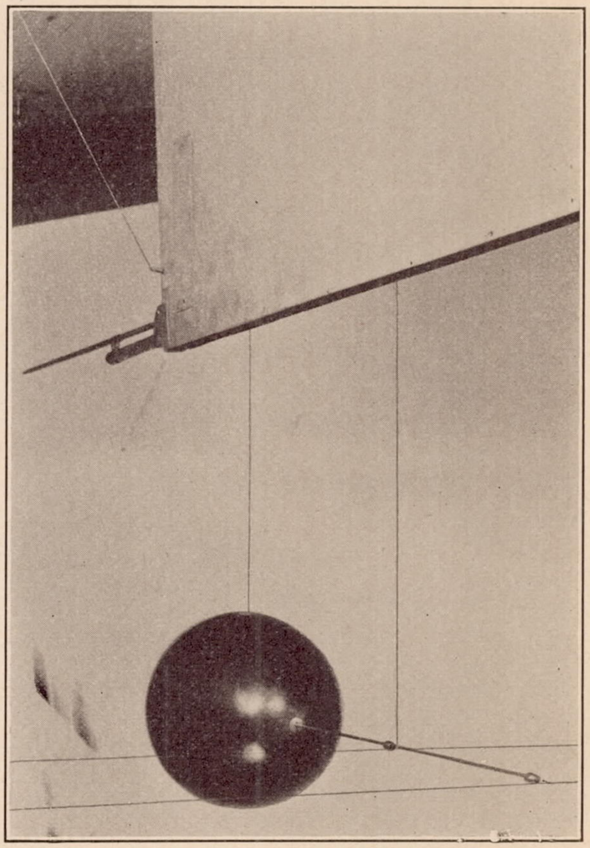


Fig. 1.—Model of C-class airship, fineness ratio 1, mounted on bifilar balance

DESCRIPTION OF MODELS

The eight models, the smallest of which is shown in Figure 1, and hull outlines of which are shown in the sketches of Figures 5 to 12, were all 7.7 inches in their specified maximum diameter. The specified and measured offsets and the length and volume of the various models are given in Table I. The models were made of laminated pine and varnished.

The original C-class hull, previously described in References 1 and 2, was fitted with 17 pressure-collecting holes as shown in Figure 3. The pressure leads, one running from a hole in the nose and the other successively from each surface hole, were connected to an inclined-tube manometer outside the tunnel.

METHOD OF TESTING

The drag of the hulls was measured with the bifilar balance, which is shown in Figure 2. The models with a fineness ratio of 4.62 and greater were mounted as indicated in Figure 2;

the models with fineness ratios of 1.0, 1.5, 2.0, and 3.0 were mounted as shown in Figure 1. The provisions, method, and precision of such tests are discussed in Reference 3.

The pressure distribution measurements were made on the original C-class hull which was mounted in the tunnel at 0° pitch and 0° yaw as shown in Figure 4. The difference of pressure between the nose and each of the holes aft of the nose was determined successively. To do this all the surface holes were plugged except one which was joined to one pressure lead, while the nose hole was joined to the other lead. The wind speed was then varied from 20 to 60 miles an hour, by 10-mile intervals, and the differential pressure was measured on an alcohol manometer having a 1 to 10 slope. These pressure differences could be read in all cases to within 0.005″ vertical of alcohol.

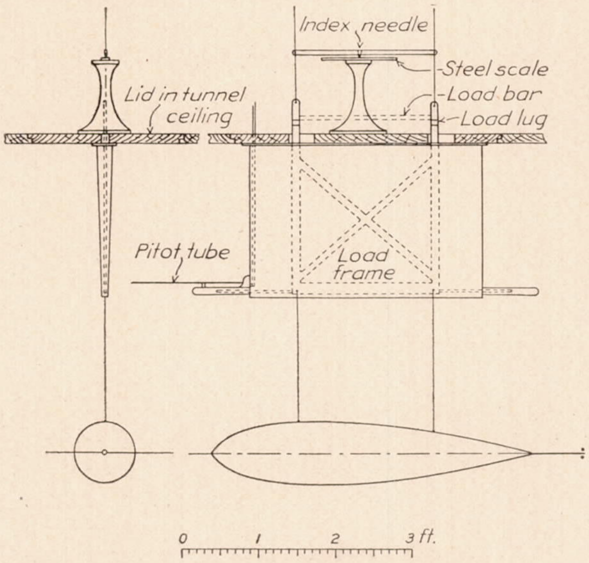


FIG. 2.—Diagrammatic sketch of bifilar balance

RESULTS OF DRAG MEASUREMENTS

Table II gives the gross and net drags for all the models, as found for the various conditions; Table III gives the derived shape coefficients and values of $V_1\ D$ where V_1 is the air speed in feet per second and D the maximum model diameter in feet; Table IV gives values of the disk ratio for the various models at 40 miles an hour. The drag of a normally exposed thin disk with a diameter equal to that of the hull's major circle was found to be 0.00298 SV^2 pounds at V miles an hour, where S is the area of the disk in square feet. The ratio of this force to the actual head-on drag of the hull is called the "disk ratio."

In Figures 5 to 12 the gross and net drags are plotted against air speed in individual graphs, to illustrate the various experimental corrections; the shape coefficient is plotted against $V_1\ D$. Figure 13 gives plots at 40 miles an hour, of the drag, shape coefficient, and disk ratio versus

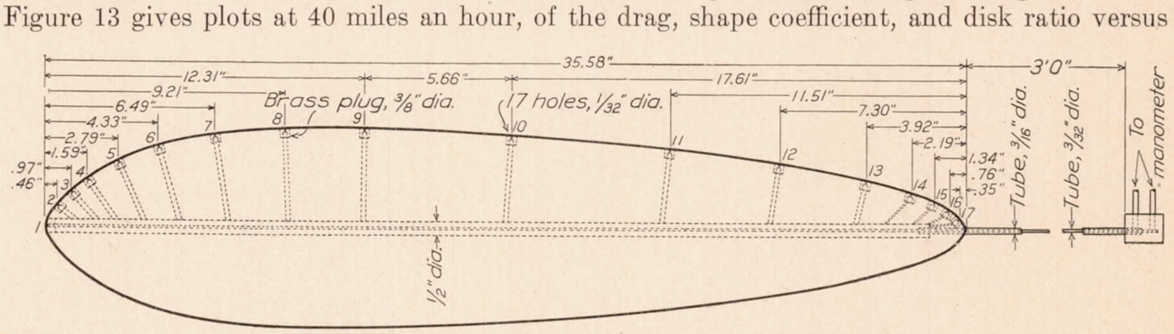


FIG. 3.—Pressure collector on C-class airship model with fineness ratio of 4.62

fineness ratio; the resistance of a sphere and of a disk each with a diameter equal to the maximum diameter of the various hulls is also shown.

One sees from Figures 5 to 12 that, for the present speed range, the net resistance of all the models is of the form $R = aV^n$, where a and n are numerical constants. Substituting this empirical value of R in the equation of the shape coefficient $C_S = 2R/\rho\ (\text{Vol.})^{2/3}\ V^2$ gives $C_C = 2aV^{n-2}/\rho\ (\text{Vol.})^{2/3}$ which on logarithmic paper is a straight line since the air density ρ is constant. Values of n for all the models are slightly less than 2 except that for the smallest model with a fineness ratio of 1.0, $n = 2.04$.

Figure 13 indicates that, at 40 miles an hour, the model of least resistance and greatest disk ratio, 25.31, has a fineness ratio of 2.0; the model with a fineness ratio of 4.62 has the smallest shape coefficient, $C_S = .028$. The resistance of a sphere with a diameter equal to the maximum model diameter is almost three times as great, at 40 miles an hour, as that of the model with a fineness ratio of 1.0.

RESULTS OF PRESSURE DISTRIBUTION MEASUREMENTS

The differential pressure measurements made on the model of best shape coefficient, viz, fineness ratio = 4.62, are presented in Table V. Table VI gives the point pressure at the several holes, found by subtracting the differential pressure from the nose pressure. These data are plotted in Figures 14 and 15. Table VII gives the point pressure in terms of the nose pressure. The graphs of the faired values of point pressure multiplied by $(60/V)^2$ to make them comparable are shown in Figure 16. The integrals of each pressure graph, giving the elements of pressure drag, and the summation of these, or the resultant pressure-drag, are given in Table VIII and plotted in Figure 17. With them are shown the total drag and the resultant friction. The order of graphic integration here used to find the force $\pi \int p.\ d(r)^2$, where r is the radius of the model at any point along its axis, over the various portions of the surface of the model, is detailed in Figure 19.

One sees from Figure 14 that the point pressure at all speeds decreases from full impact $\frac{1}{2}\rho V^2$ at the nose of the model to zero at a distance of 5.4 per cent of the model length from the nose; the maximum suction occurs at about one-seventh of said length, and is equal to about 43 per cent of the nose pressure. There is another point of zero pressure at 4.4 per cent of the model length from the stern; aft of this point the pressure is positive. Figure 15 shows that the pressure at each hole varies nearly as the square of the velocity. n indicates exponent in equation, $P = KV^n$.

From Figure 17 it is seen that the total drag and its elements vary as V^n for the range of speeds used. The difference between the curves of total drag and pressure drag, giving the frictional drag, varies as $V^{1.79}$. n indicates exponent in equation, $R = KV^n$.

Figure 18 gives, for the present perforated model and a Parseval model tested in England, the point pressure and zonal pressure-drag for various zone[1] lengths. The point pressure is in terms of the nose pressure; the zonal drag is in terms of the whole measured model drag, comprising pressure and friction. The whole drag of the Navy model is seen to be 26 per cent pressural, hence 74 per cent frictional; the drag of the other is 20 per cent pressural and 80 per cent frictional. The pressure graphs for the British model were plotted from the tabulated data of Reference 4.

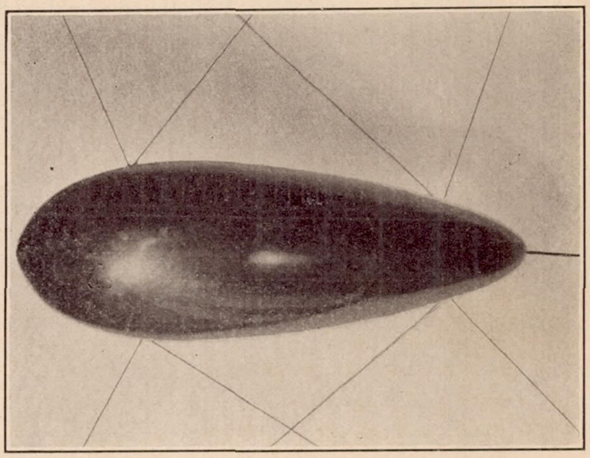


FIG. 4.—Model of C-class airship, fineness ratio 4.62, mounted for pressure distribution test

CONCLUSIONS

Figures 5 to 12 indicate that the drag of each of the C-class models of various fineness ratio varies as V^n, where n is less than 2.0, except for the smallest model with a fineness ratio of 1.0, for which $n = 2.04$.

Figure 13 shows that at 40 miles an hour the model with a fineness ratio of 2.0 has the least drag and the greatest disk ratio, 25.31; the model whose fineness ratio is 4.62 has the smallest shape coefficient, $C_s = 2R/\rho(\text{Vol.})^{2/3} V_1^2 = .028$.

Figure 17 indicates that, at 20 to 60 M. P. H., all the elements of the total drag of the model whose fineness ratio equals 4.62 vary as V^n. At 40 miles an hour, the total downstream pressure is 408 per cent of the total measured drag; the total upstream pressure, 382 per cent; the resultant pressural drag, 26 per cent; the frictional drag, 74 per cent.

The graph of total drag versus model length, Figure 13, is a smooth continuous curve for all lengths from 0 upward, indefinitely.

[1] A zone is a part of the surface bounded by two planes normal to V. Usually one plane is assumed tangent to the surface at its upstream end

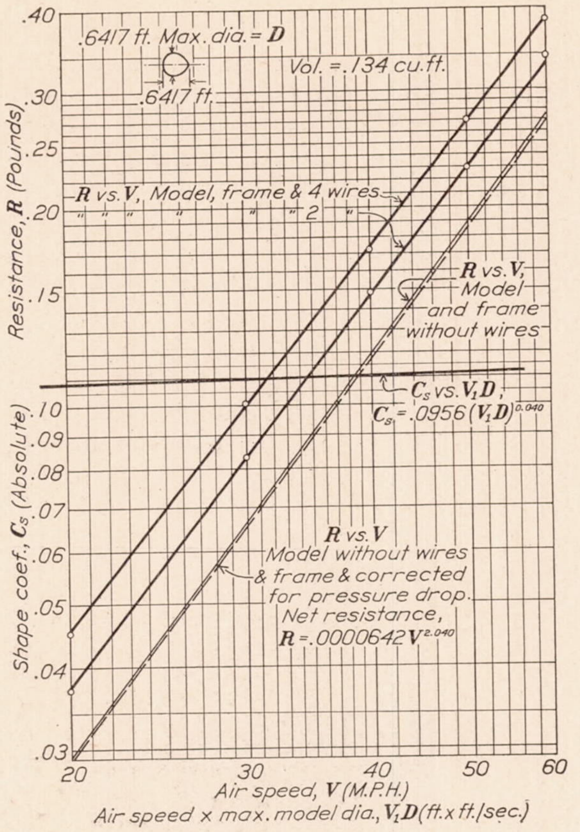


FIG. 5.—Fineness ratio = 1

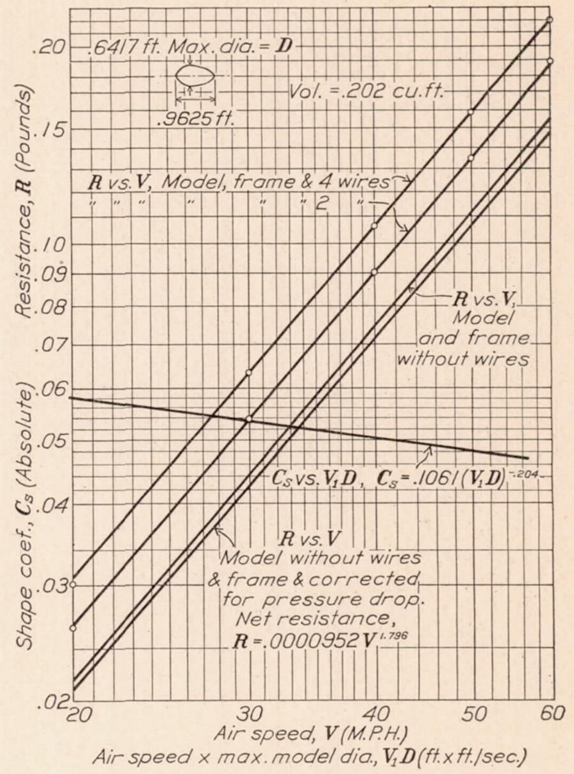


FIG. 6.—Fineness ratio = 1.5

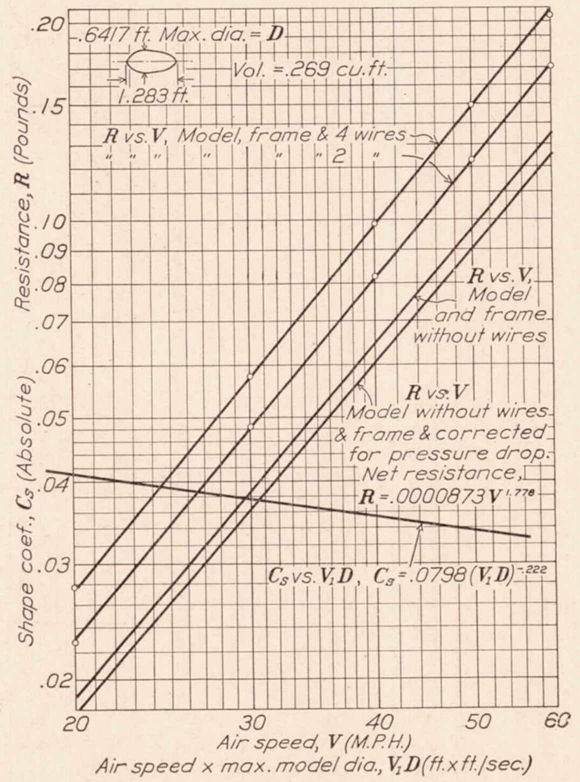


FIG. 7.—Fineness ratio = 2

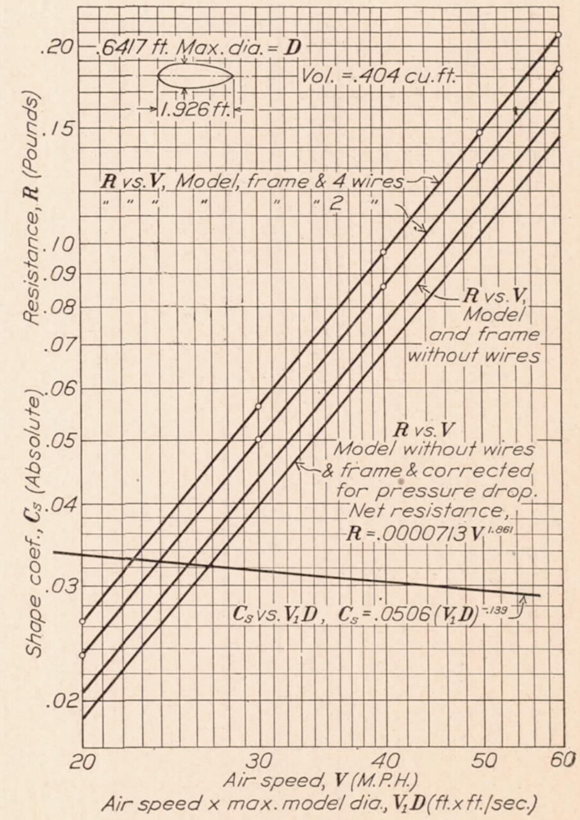


FIG. 8.—Fineness ratio = 3

C-class airship. Model at 0° pitch and 0° yaw

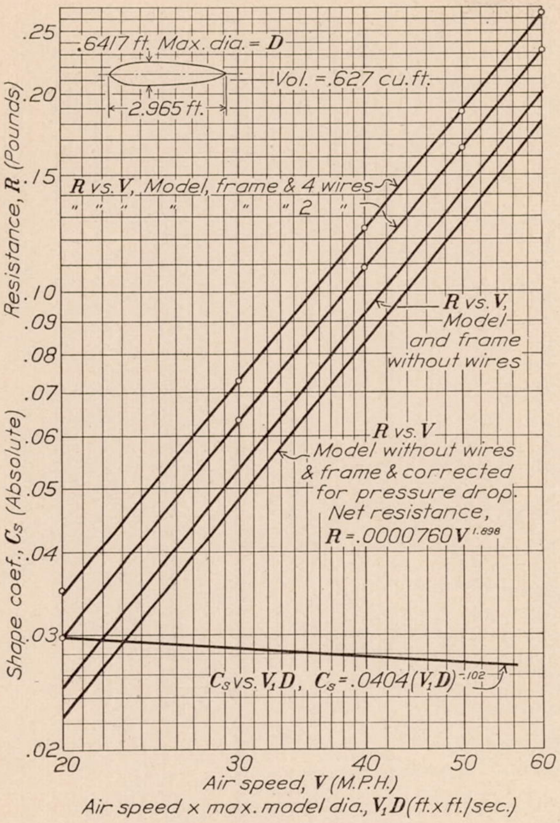


FIG. 9.—Fineness ratio=4.62

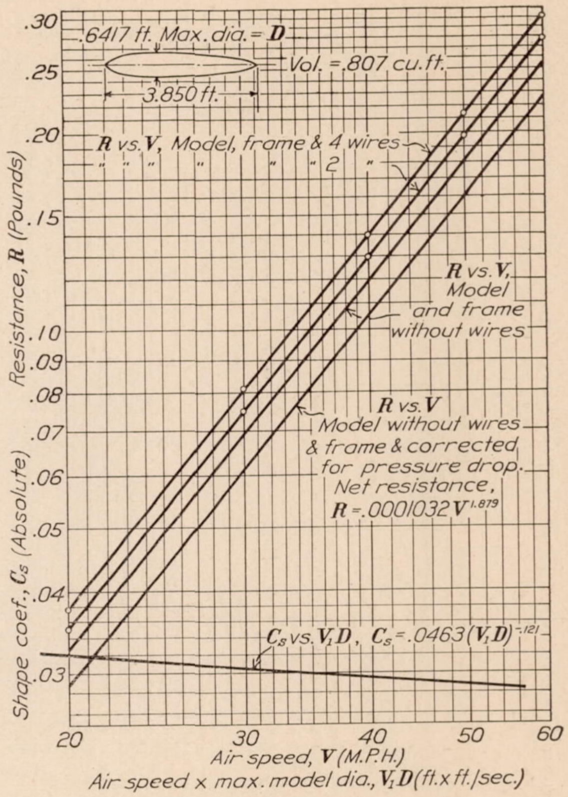


FIG. 10.—Fineness ratio=6

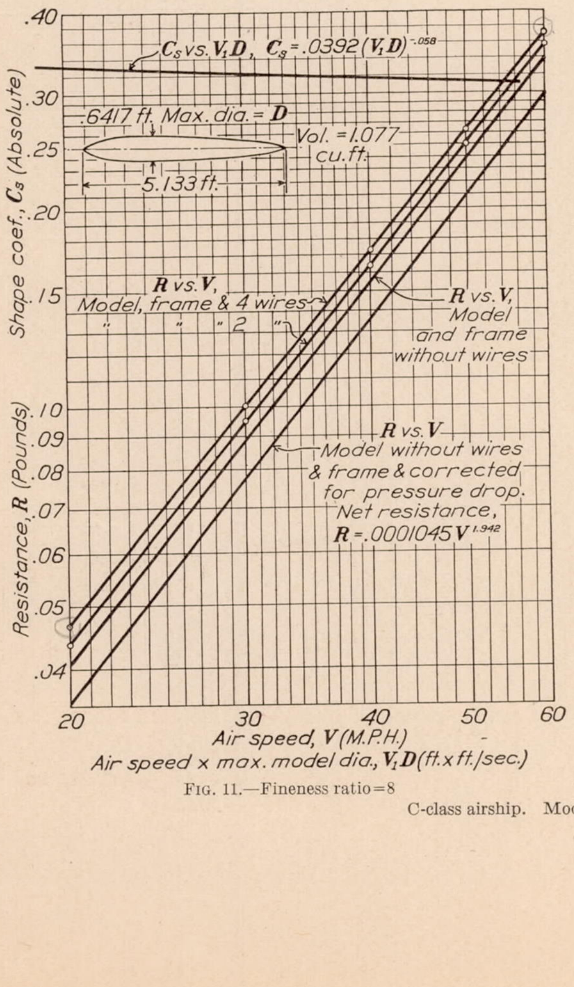


FIG. 11.—Fineness ratio=8

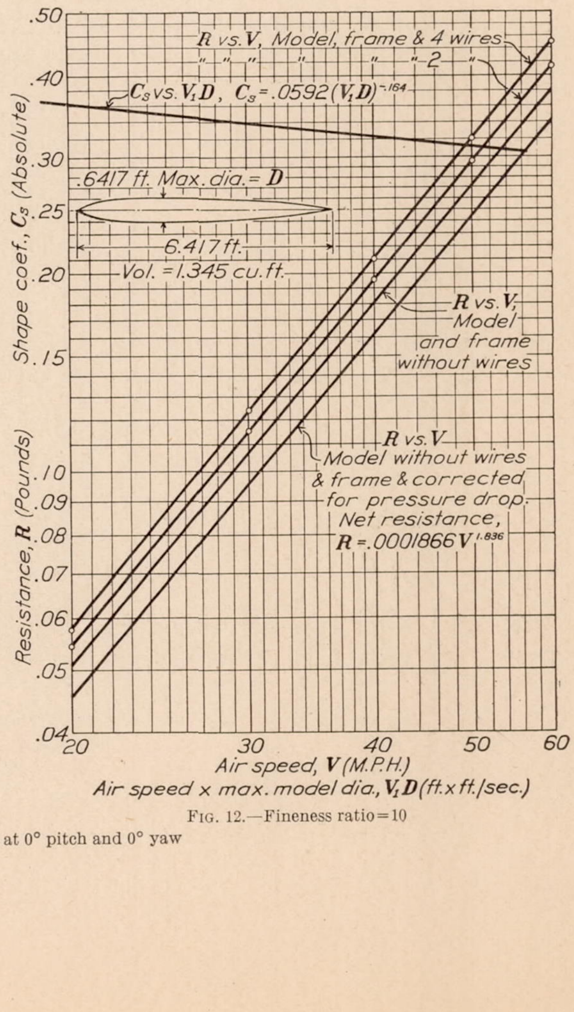


FIG. 12.—Fineness ratio=10

C-class airship. Model at 0° pitch and 0° yaw

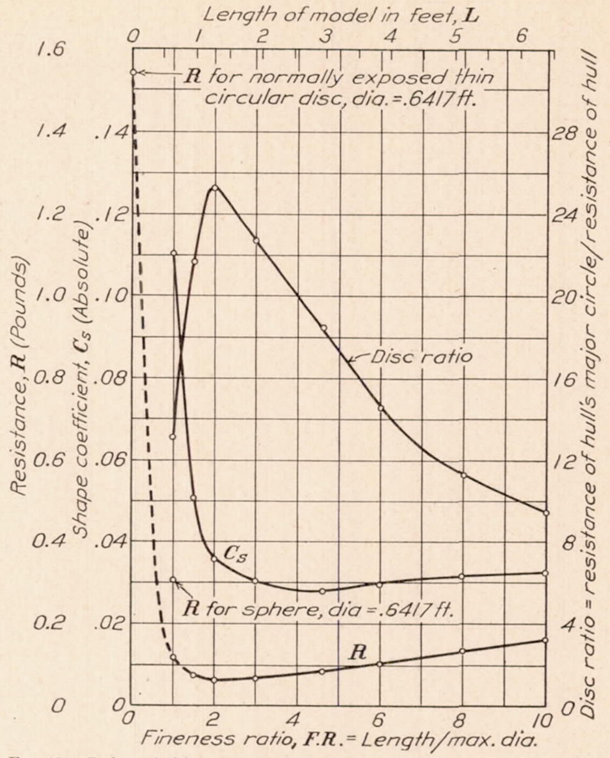


FIG. 13.—C-class airship. Models with various fineness ratios. Air speed 40 M. P. H. Model at 0° pitch and 0° yaw

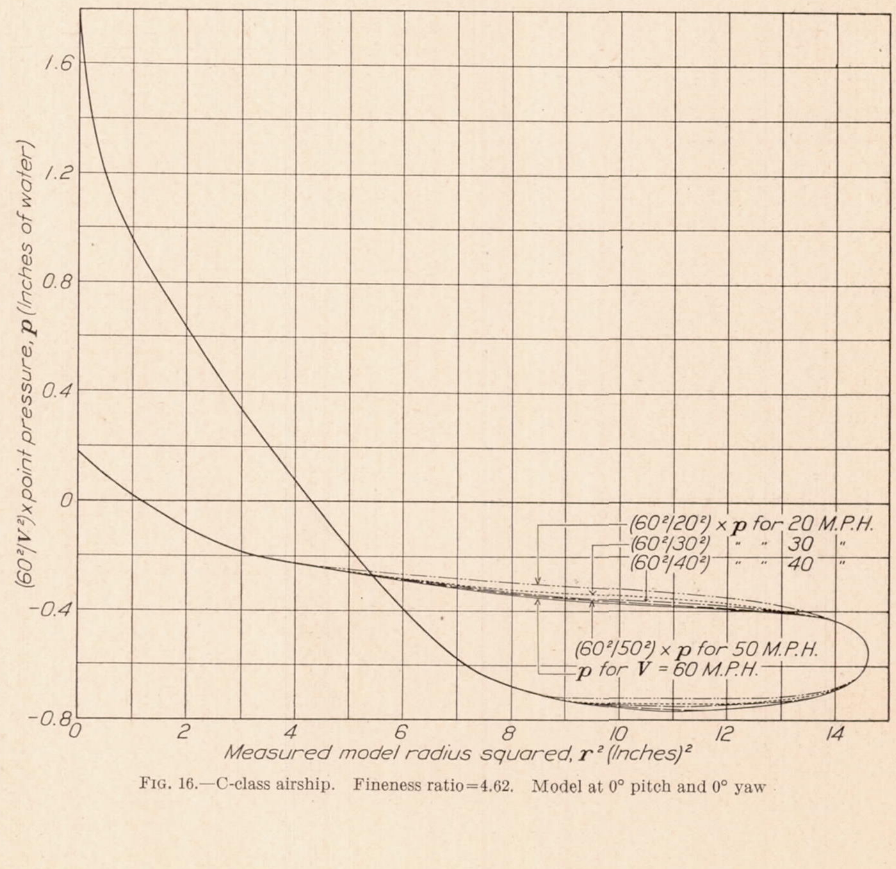


FIG. 16.—C-class airship. Fineness ratio = 4.62. Model at 0° pitch and 0° yaw

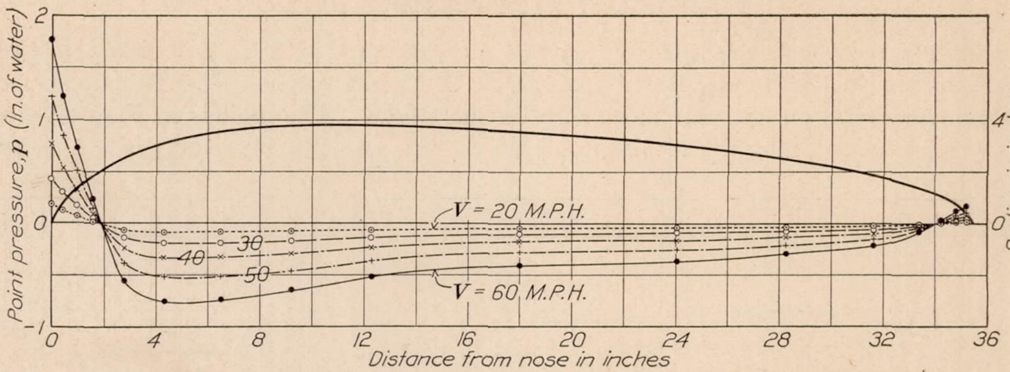


FIG. 14.—C-class airship. Fineness ratio=4.62. Model at 0° pitch and 0° yaw. Air speeds, V=20 to 60 M. P. H.

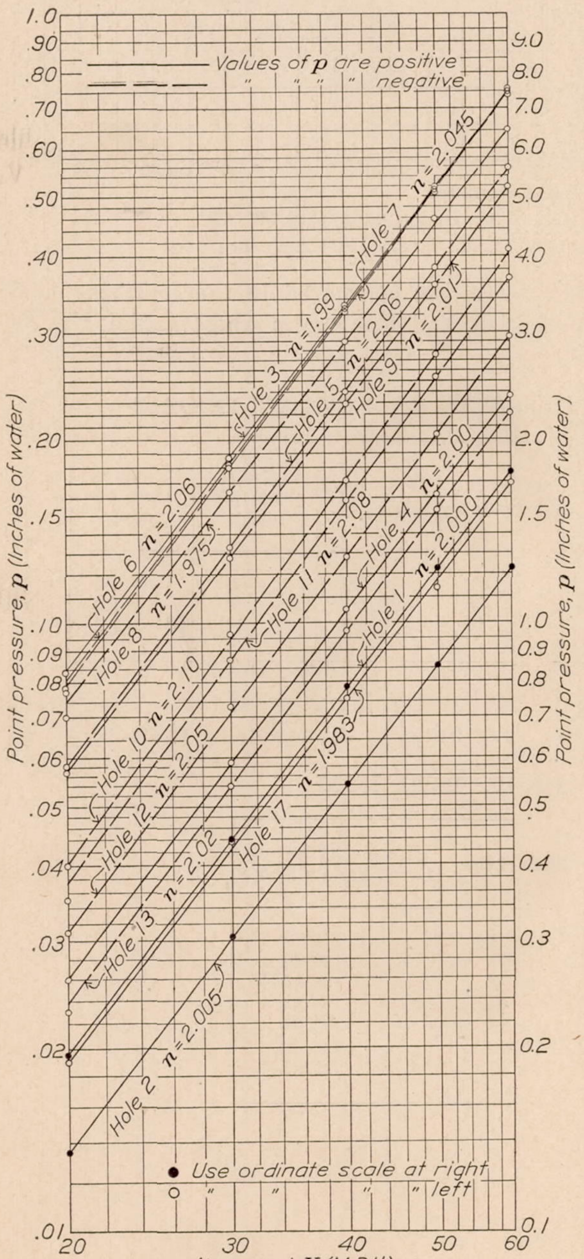


FIG. 15.—C-class airship. Fineness ratio=4.62
Model at 0° pitch and 0° yaw

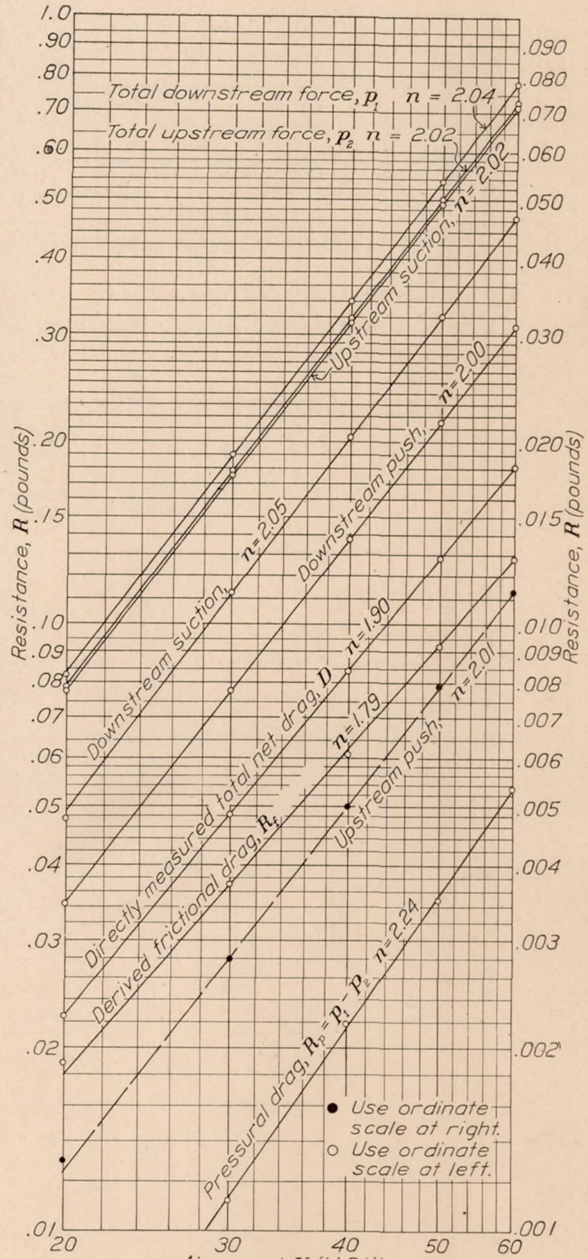


FIG. 17.—C-class airship. Fineness ratio=4.62
Model at 0° pitch and 0° yaw

COMPARISON WITH PREVIOUS DATA

For any ellipsoid or simple quadric, fixed at any attitude in a uniform infinite stream of inviscid liquid, it can be shown, Reference 5, that the zonal pressure-drag is upstream on the fore part; downstream on the rear part; zero on the whole. The models in Figure 18 exhibit these properties except that the resultant pressure-drag, owing to viscosity, is not quite zero.

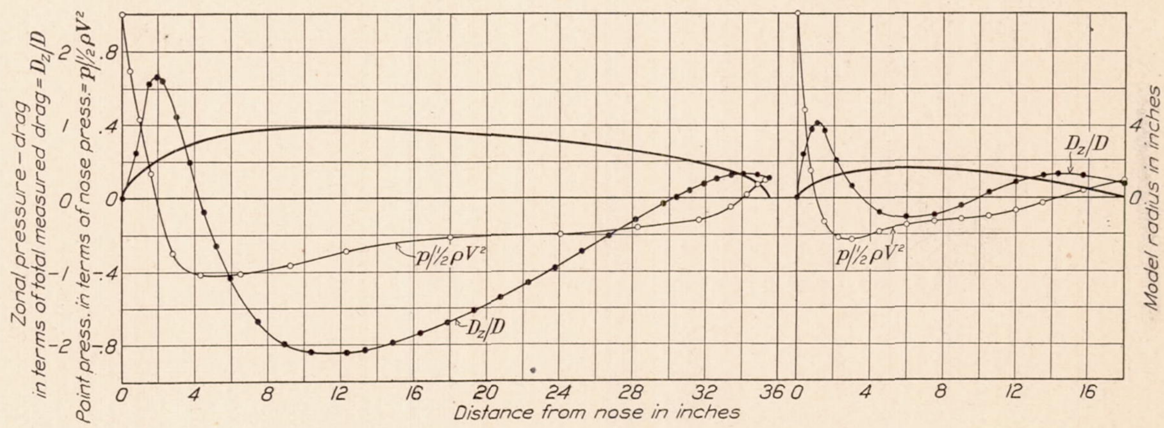


FIG. 18.—At left C-class airship. Fineness ratio=4.62. Air speed 40 M. P. H. At right Parseval type airship, British test, see R. & M. No. 107. Air speed 40.91 M. P. H.

The pressure-drag and friction-drag for the C-class are compared in the following table with those of the Parseval model, tested by the British, and Fuhrmann's best model, No. IV, in Reference 6.

DRAG ELEMENTS OF FUHRMANN, PARSEVAL, AND C-CLASS MODELS

	Length, inches	Major diameter, inches	Fineness ratio	Test speed M. P. H.	Pressural drag, per cent	Frictional drag, per cent
Navy C-class	35. 58	7. 7	4. 62	40. 00	26	74
Parseval	18. 00	3. 17	5. 68	40. 91	20	80
Fuhrmann No. IV	45. 43	7. 4	6. 14	22. 37	63	37

The disk ratio and shape coefficient, as found at 40 miles an hour, are given for the present C-class model of fineness ratio = 4.62 and for some other hulls, in the following table:

COEFFICIENTS FOR VARIOUS BARE HULLS

Model	Disk ratio	Shape coefficient, $C_s=2R/\rho(\text{Vol})^{2/3}V_1^2$
Long ZR–1	10. 71	0. 03077
Short ZR–1	11. 07	. 03122
Goodrich B	16. 22	. 03090
F-class	16. 48	. 02984
I. E	17. 16	. 03098
E. P	18. 28	. 02932
C-class	18. 47	. 02795

C–Class Airship, Various Fineness Ratios

TABLE I

PRINCIPAL DIMENSIONS

Station number [1]	Specified radius (inches)	Measured radius in inches for fineness ratio of—							
		1.00	1.50	2.00	3.00	4.62	6.00	8.00	10.00
0	0	0	0	0	0	0	0	0	0
1	1. 001			1. 000	1. 01	1. 05	1. 01	1. 05	1. 003
2	1. 747			1. 750	1. 75	1. 75	1. 76	1. 75	1. 747
3	2. 286		2. 272	2. 300	2. 29	2. 28	2. 32	2. 28	2. 278
4	2. 688		2. 688	2. 688	2. 71	2. 66	2. 71	2. 67	2. 682
5	2. 982	2. 989	2. 982	2. 973	3. 01	2. 95	3. 00	2. 98	2. 989
6	3. 204	3. 200	3. 205	3. 189	3. 24	3. 18	3. 23	3. 21	3. 207
7	3. 379	3. 379	3. 380	3. 350	3. 40	3. 35	3. 40	3. 38	3. 379
8	3. 511	3. 505	3. 512	3. 495	3. 54	3. 49	3. 52	3. 51	3. 513
10	3. 683	3. 680	3. 691	3. 660	3. 71	3. 69	3. 69	3. 68	3. 693
12	3. 779	3. 780	3. 792	3. 760	3. 81	3. 79	3. 80	3. 77	3. 791
14	3. 830	3. 831	3. 845	3. 801	3. 86	3. 82	3. 84	3. 81	3. 833
16	3. 849	3. 853	3. 860	3. 820	3. 87	3. 83	3. 87	3. 82	3. 847
16. 6	3. 850	3. 856	3. 864	3. 822	3. 87	3. 85			3. 851
18	3. 840	3. 844	3. 854	3. 810	3. 86	3. 81	3. 86	3. 80	3. 854
20	3. 797	3. 802	3. 810	3. 780	3. 83	3. 77	3. 82	3. 77	3. 826
22	3. 738	3. 740	3. 745	3. 720	3. 76	3. 70	3. 76	3. 73	3. 761
24	3. 659	3. 659	3. 660	3. 650	3. 67	3. 62	3. 69	3. 65	3. 674
26	3. 558	3. 570	3. 563	3. 550	3. 58	3. 52	3. 53	3. 55	3. 581
28	3. 443	3. 465	3. 453	3. 440	3. 47	3. 41	3. 48	3. 44	3. 456
30	3. 318	3. 343	3. 322	3. 312	3. 34	3. 29	3. 34	3. 31	3. 328
32	3. 170	3. 196	3. 186	3. 170	3. 19	3. 13	3. 18	3. 16	3. 195
34	3. 005	3. 024	3. 020	3. 006	3. 02	2. 97	3. 01	3. 01	3. 024
36	2. 817	2. 853	2. 827	2. 819	2. 84	2. 78	2. 82	2. 82	2. 835
38	2. 608	2. 628	2. 611	2. 615	2. 62	2. 56	2. 61	2. 60	2. 624
40	2. 369	2. 386	2. 376	2. 370	2. 38	2. 32	2. 36	2. 36	2. 379
41	2. 236	2. 264	2. 241	2. 240	2. 24	2. 19	2. 25	2. 22	2. 244
42	2. 098	2. 116	2. 101	2. 100	2. 10	2. 04	2. 10	2. 09	2. 098
43	1. 945	1. 961	1. 952	1. 956	1. 94	1. 86	1. 95	1. 93	1. 938
44	1. 766	1. 782	1. 772	1. 782	1. 77	1. 66	1. 77	1. 75	1. 758
45	1. 554	1. 560	1. 564	1. 561	1. 56	1. 44	1. 55	1. 54	1. 542
46	1. 281	1. 291	1. 286	1. 290	1. 31	1. 18	1. 26	1. 27	1. 292
47	. 912	. 919	. 900	. 991	. 96	. 85	. 87	. 90	. 878
48	0	0	0	0	0	0	0	0	0

[1] Station 0 is at nose of model, Station 48 is at stern

Fineness ratio	Interval along model axis between stations (inches)	Length of model (inches)	Volume of model (cubic feet)
1. 00	0. 16042	7. 700	0. 134
1. 50	. 24063	11. 550	. 202
2. 00	. 32083	15. 400	. 269
3. 00	. 48125	23. 100	. 404
4. 62	. 74125	35. 580	. 627
6. 00	. 96250	46. 200	. 807
8. 00	1. 28333	61. 600	1. 077
10. 00	1. 60417	77. 000	1. 345

C-Class Airship, Various Fineness Ratio

TABLE II

RESISTANCE OF C-CLASS AIRSHIP MODELS

[Models at 0° pitch and 0° yaw]

Air speed (M. P. H.)	Displacement due to model and 4 wires (inches)	Corresponding resistance (pounds)	Displacement due to model and 2 wires (inches)	Corresponding resistance (pounds)	Resistance of model without wires (from curves) (pounds)	Resistance due to frame (pounds)	Resistance due to pressure drop (pounds)	Net total resistance R (pounds)
Fineness ratio=1.0								
20	0. 500	0. 0451	0. 410	0. 0369	0. 0292	−0. 0001	0. 0005	0. 0288
30	1. 120	. 1009	. 925	. 0833	. 0664	0	. 0011	. 0653
40	1. 910	. 1721	1. 650	. 1486	. 1205	+. 0005	. 0018	. 1182
50	3. 000	. 2703	2. 540	. 2289	. 1895	. 0010	. 0027	. 1858
60	4. 250	. 3829	3. 750	. 3379	. 2760	+. 0018	. 0037	. 2705
Fineness ratio=1.5								
20	0. 436	0. 0301	0. 374	0. 0258	0. 0213	−0. 0001	0. 0008	0. 0206
30	. 921	. 0635	. 782	. 0540	. 0444	0	. 0017	. 0427
40	1. 542	. 1064	1. 308	. 0903	. 0746	+. 0005	. 0027	. 0714
50	2. 296	. 1584	1. 956	. 1350	. 1116	. 0010	. 0040	. 1066
60	3. 200	. 2208	2. 746	. 1895	. 1552	+. 0018	. 0055	. 1479
Fineness ratio=2.0								
20	0. 550	0. 0277	0. 453	0. 0228	0. 0187	−0. 0001	0. 0011	0. 0177
30	1. 150	. 0578	. 961	. 0483	. 0387	0	. 0022	. 0365
40	1. 954	. 0983	1. 629	. 0819	. 0653	+. 0005	. 0037	. 0610
50	2. 965	. 1491	2. 452	. 1233	. 0972	. 0010	. 0054	. 0908
60	4. 073	. 2049	3. 390	. 1705	. 1349	+. 0018	. 0074	. 1257
Fineness ratio=3.0								
20	0. 320	0. 0266	0. 283	0. 0235	0. 0206	−0. 0001	0. 0019	0. 0188
30	. 679	. 0564	. 604	. 0501	. 0438	0	. 0040	. 0398
40	1. 173	. 0974	1. 035	. 0859	. 0752	+. 0005	. 0066	. 0681
50	1. 780	. 1477	1. 590	. 1320	. 1144	. 0010	. 0099	. 1035
60	2. 510	. 2083	2. 223	. 1845	. 1607	+. 0018	. 0135	. 1454
Fineness ratio=4.62								
20	0. 378	0. 0351	0. 321	0. 0298	0. 0249	−0. 0001	0. 0026	0. 0224
30	. 785	. 0729	. 681	. 0633	. 0536	0	. 0052	. 0484
40	1. 343	. 1248	1. 167	. 1084	. 0926	+. 0005	. 0085	. 0836
50	2. 014	. 1871	1. 775	. 1649	. 1415	. 0010	. 0125	. 1280
60	2. 850	. 2648	2. 513	. 2335	. 2005	+. 0018	. 0172	. 1815
Fineness ratio=6.0								
20	0. 275	0. 0376	0. 256	0. 0350	0. 0324	−0. 0001	0. 0038	0. 0287
30	. 598	. 0817	. 551	. 0753	. 0695	0	. 0081	. 0614
40	1. 024	. 1399	. 950	. 1298	. 1196	+. 0005	. 0133	. 1058
50	1. 569	. 2143	1. 445	. 1974	. 1810	. 0010	. 0197	. 1603
60	2. 210	. 3019	2. 038	. 2784	. 2549	+. 0018	. 0271	. 2260

C-CLASS AIRSHIP, VARIOUS FINENESS RATIO—Continued

TABLE II—Continued

RESISTANCE OF C-CLASS AIRSHIP MODELS—Continued

Air speed (M. P. H.)	Displacement due to model and 4 wires (inches)	Corresponding resistance (pounds)	Displacement due to model and 2 wires (inches)	Corresponding resistance (pounds)	Resistance of model without wires (from curves) (pounds)	Resistance due to frame (pounds)	Resistance due to pressure drop (pounds)	Net total resistance R (pounds)
Fineness ratio=8.0								
20	0. 279	0. 0465	0. 261	0. 0435	0. 0405	−0. 0001	0. 0051	0. 0355
30	. 604	. 1006	. 575	. 0957	. 0885	0	. 0108	. 0777
40	1. 040	. 1732	. 985	. 1640	. 1545	+. 0005	. 0177	. 1363
50	1. 581	. 2632	1. 503	. 2502	. 2373	. 0010	. 0263	. 2100
60	2. 234	. 3720	2. 149	. 3578	. 3361	+. 0018	. 0361	. 3000
Fineness ratio=10.0								
20	0. 313	0. 0576	0. 296	0. 0544	0. 0508	−0. 0001	0. 0055	0. 0454
30	. 675	. 1241	. 631	. 1160	. 1066	0	. 0111	. 0955
40	1. 145	. 2106	1. 065	. 1959	. 1810	+. 0005	. 0181	. 1624
50	1. 746	. 3211	1. 609	. 2959	. 2720	. 0010	. 0267	. 2443
60	2. 440	. 4487	2. 251	. 4140	. 3800	+. 0018	. 0367	. 3415

C–CLASS AIRSHIP, VARIOUS FINENESS RATIOS

TABLE III

SHAPE COEFFICIENT AND CORRESPONDING VALUES OF $V_1 D$

[Symbols defined below]

Air speed V (M. P. H.)	$V_1 D$ (ft × ft/sec.)	Shape coefficient $C_s=2R/\rho(\text{Vol.})^{2/3} V_1^2$ (absolute)							
		$F. R.=1$	$F. R.=1.5$	$F. R.=2$	$F. R.=3$	$F. R.=4.62$	$F. R.=6$	$F. R.=8$	$F. R.=10$
20	18. 80	0. 10804	0. 05867	0. 04161	0. 03390	0. 02996	0. 03243	0. 03323	0. 03661
30	28. 23	. 10863	. 05393	. 03805	. 03182	. 02870	. 03076	. 03225	. 03415
40	37. 67	. 11047	. 05066	. 03573	. 03059	. 02795	. 02978	. 03179	. 03263
50	47. 04	. 11137	. 04851	. 03411	. 02982	. 02735	. 02894	. 03141	. 03148
60	56. 47	. 11250	. 04670	. 03277	. 02906	. 02691	. 02831	. 03113	. 03053

R = Resistance of model in pounds.
ρ = Air density = 0.00237 slugs per cubic foot.
Vol. = Volume of model in cubic feet.
V = Air speed in miles per hour.
V_1 = Air speed in feet per second.
D = Maximum model diameter in feet = 0.6417.
$F. R.$ = Fineness ratio = Length of model/D.

C-Class Airship, Various Fineness Ratios

TABLE IV

DISK RATIO AT 40 M. P. H.

Fineness ratio of model	Net resistance of model R (pounds)	Disk ratio $R_{Disk}*/R$
1.00	0.1182	13.06
1.50	.0714	21.62
2.00	.0610	25.31
3.00	.0681	22.67
4.62	.0836	18.47
6.00	.1058	14.59
8.00	.1363	11.33
10.00	.1624	9.51

*R_{Disk} = Resistance of a normally exposed thin circular disk whose diameter is equal to the diameter of the hull's major circle (0.6417 ft.) $= K_D S V^2 = 1.544$ lb. at $V = 40$ M. P. H.
$K_D = 0.00298$ lb. /ft.^{2}/mi.^{2}/hr.^{2}

C-Class Airship. Fineness Ratio = 4.62

TABLE V

OBSERVED DIFFERENCE IN PRESSURE BETWEEN NOSE AND HOLES AFT OF NOSE, dp

$$dp = \frac{1}{2}\rho V^2 - p$$

[Model at 0° pitch and 0° yaw]

Number of hole	Air speed in miles per hour				
	20	30	40	50	60
dp in inches of alcohol on 1 to 10 slope and 0.819 specific gravity					
1	0	0	0	0	0
2	.73	1.65	2.95	4.59	6.65
3	1.36	3.09	5.53	8.67	12.58
4	2.04	4.68	8.31	12.95	18.56
5	3.09	7.05	12.50	19.57	28.27
6	3.33	7.65	13.55	21.14	30.60
7	3.32	7.63	13.51	21.07	30.49
8	3.23	7.45	13.08	20.50	29.34
9	3.07	6.98	12.28	19.26	27.78
10	2.82	6.60	11.66	18.25	26.46
11	2.80	6.48	11.52	18.02	25.95
12	2.75	6.33	11.15	17.40	25.05
13	2.65	6.08	10.76	16.77	24.15
14	2.45	5.70	10.06	15.66	22.60
15	2.38	5.41	9.44	14.70	21.17
16	2.20	5.06	8.92	13.93	19.97
17	2.14	4.88	8.68	13.54	19.40
dp converted to inches of water [1]					
1	0	0	0	0	0
2	.061	.137	.244	.377	.543
3	.113	.255	.452	.708	1.032
4	.170	.383	.680	1.064	1.530
5	.254	.575	1.025	1.610	2.326
6	.274	.624	1.113	1.740	2.518
7	.273	.622	1.109	1.735	2.508
8	.266	.606	1.074	1.688	2.414
9	.253	.570	1.014	1.585	2.287
10	.233	.538	.956	1.501	2.177
11	.231	.529	.944	1.479	2.135
12	.227	.515	.913	1.430	2.061
13	.219	.496	.882	1.379	1.987
14	.203	.464	.824	1.287	1.860
15	.197	.435	.773	1.207	1.741
16	.182	.413	.731	1.143	1.643
17	.177	.398	.710	1.112	1.597

[1] *dp* was changed to inches of water by employing the manometer's calibration curve.

C-Class Airship. Fineness Ratio=4.62

TABLE VI

POINT PRESSURE, p, IN INCHES OF WATER AT THE 17 HOLES $p=\frac{1}{2}\rho V^2-dp$

[Model at 0° pitch and 0° yaw]

Number of hole	Air speed in miles per hour				
	20	30	40	50	60
1	+0. 196	+0. 442	+0. 785	+1. 226	+1. 766
2	. 135	. 305	. 541	. 849	1. 223
3	. 083	. 187	. 333	. 518	. 734
4	+. 026	+. 059	+. 105	+. 162	+. 236
5	−. 058	−. 133	−. 240	−. 384	−. 560
6	−. 078	−. 182	−. 328	−. 514	−. 752
7	−. 077	−. 180	−. 324	−. 509	−. 742
8	−. 070	−. 164	−. 289	−. 462	−. 648
9	−. 057	−. 128	−. 229	−. 359	−. 521
10	−. 040	−. 096	−. 171	−. 275	−. 411
11	−. 035	−. 087	−. 159	−. 253	−. 369
12	−. 031	−. 073	−. 128	−. 204	−. 295
13	−. 023	−. 054	−. 097	−. 153	−. 211
14	−. 007	−. 022	−. 039	−. 061	−. 094
15	+. 002	+. 007	+. 012	+. 019	+. 025
16	. 014	. 029	. 054	. 083	. 123
17	+. 019	+. 044	+. 075	+. 114	+. 169

C-Class Airship. Fineness Ratio=4.62

TABLE VII

POINT PRESSURE IN TERMS OF NOSE PRESSURE, $p/\frac{1}{2}\rho V^2$

[Model at 0° pitch and 0° yaw]

Number of hole	Air speed in miles an hour				
	20	30	40	50	60
1	+1. 000	+1. 000	+1. 000	+1. 000	+1. 000
2	. 689	. 690	. 689	. 692	. 693
3	. 423	. 423	. 424	. 423	. 416
4	+. 133	+. 133	+. 134	+. 132	+. 134
5	−. 296	−. 301	−. 306	−. 313	−. 317
6	−. 398	−. 412	−. 418	−. 419	−. 426
7	−. 393	−. 407	−. 413	−. 415	−. 420
8	−. 357	−. 371	−. 368	−. 377	−. 367
9	−. 291	−. 290	−. 292	−. 293	−. 295
10	−. 204	−. 217	−. 218	−. 224	−. 233
11	−. 179	−. 197	−. 203	−. 206	−. 209
12	−. 158	−. 165	−. 163	−. 166	−. 167
13	−. 117	−. 122	−. 124	−. 125	−. 119
14	−. 036	−. 050	−. 050	−. 050	−. 053
15	+. 010	+. 016	+. 015	+. 015	+. 014
16	. 071	. 066	. 069	. 068	. 070
17	+. 097	+. 100	+. 096	+. 093	+. 096

C-Class Airship. Fineness Ratio = 4.62

TABLE VIII

ALONG-STREAM FORCES EXPRESSED IN POUNDS AND IN TERMS OF TOTAL DRAG

[Model at 0° pitch and 0° yaw]

Air speed M. P. H.	Downstream			Upstream			Pressural drag $R_p = P_1 - P_2$	Frictional drag R_f	Total drag $R = R_p + R_f$
	Push	Suction	Total P_1	Push	Suction	Total P_2			
	Pounds								
20	0.0344	0.0476	0.0820	0.0013	0.0771	0.0784	0.0036	0.0188	0.0224
30	.0775	.1123	.1898	.0028	.1758	.1786	.0112	.0372	.0484
40	.1377	.2033	.3410	.0050	.3141	.3191	.0219	.0617	.0836
50	.2151	.3216	.5367	.0079	.4938	.5017	.0350	.0930	.1280
60	.3098	.4681	.7779	.0113	.7131	.7244	.0535	.1280	.1815
	Per cent of total drag								
20	154	212	366	6	344	350	16	84	100
30	160	232	393	6	364	370	23	77	100
40	165	243	408	6	376	382	26	74	100
50	168	251	419	6	386	392	27	73	100
60	171	258	429	6	393	399	30	70	100

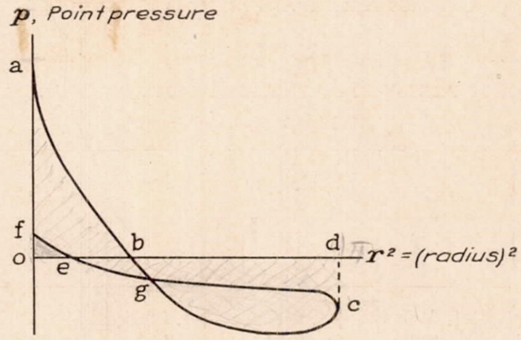


Fig. 19.—
Downstream push ∝ abo
Downstream suction ∝ ced
Upstream push ∝ eof
Upstream suction ∝ bcd
Total area = (abo + ced) − (eof + bcd) = (agf − gcg) ∝ R_p

REFERENCES

Reference 1.—Aeronautics Staff, "Resistance of Airship Hulls C-Class and S. S. T. Enlarged," C. & R. Aeronautical Report No. 128, April, 1919.

Reference 2.—Aeronautics Staff, "Lift, Drag, $N\psi$ and N_r for C-Class Airship Hull," C. & R. Aeronautical Report No. 162, November, 1920.

Reference 3.—A. F. Zahm and R. H. Smith, "Drag of Two NPL Airship Models," C. & R. Aeronautical Report No. 206, November, 1922.

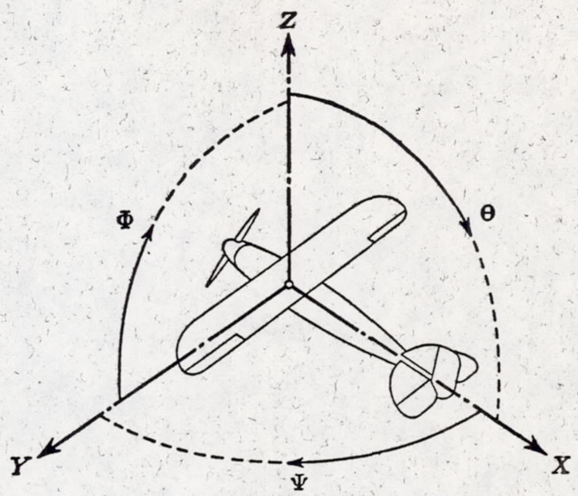
Reference 4.—A. Fage and W. J. Stern, Advisory Committee for Aeronautics, Reports and Memoranda No. 107, May, 1914. (British.)

Reference 5.—A. F. Zahm, "Flow and Drag Formulas for Simple Quadrics," N. A. C. A. Technical Report No. 253, 1926.

Reference 6.—G. Furhmann, "Theoretische und experimentalle Untersuchungen an Ballon-Modellen," Yahrbuch der Motorluftschiff-Studiengesellschaft, Fünfter Band, 1911–12.

Aerodynamical Laboratory,
Bureau of Constuction and Repair,
Navy Yard, Washington, D. C., *May 7, 1927.*

○



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

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

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 $=TV/P$.
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