# REPORT No. 291

## DRAG OF C-CLASS AIRSHIP HULLS OF VARIOUS FINENESS RATIOS

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49296—29——17

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### 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.

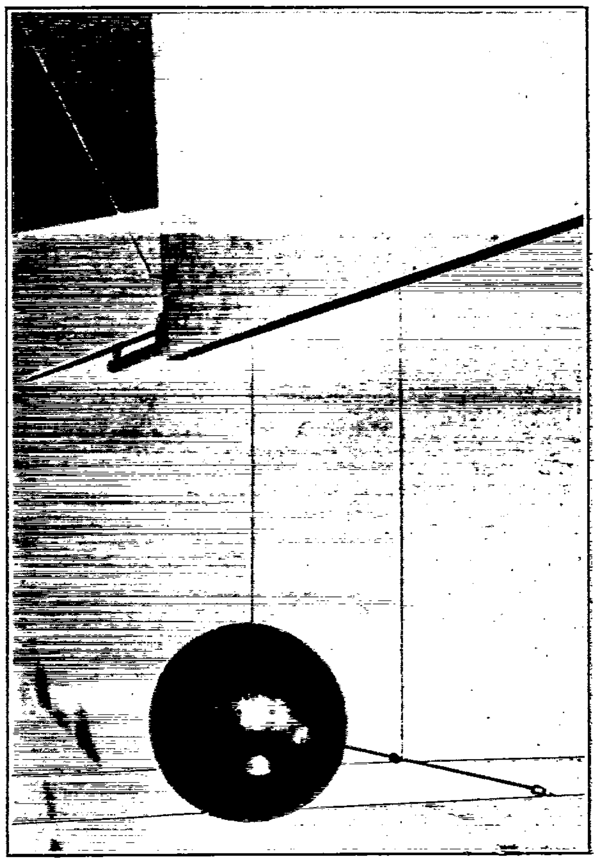

Fig. 1.—Model of C-class airship, fineness ratio 1, mounted on bifilar balance

### 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.

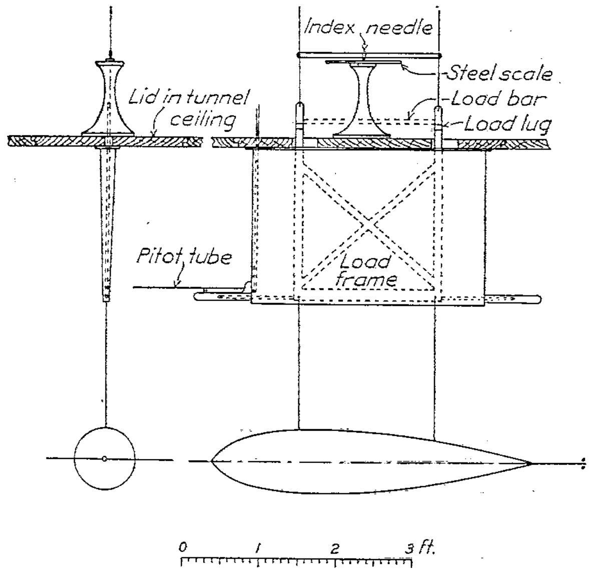


FIG. 2.—Diagrammatic sketch of bifilar balance

## 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

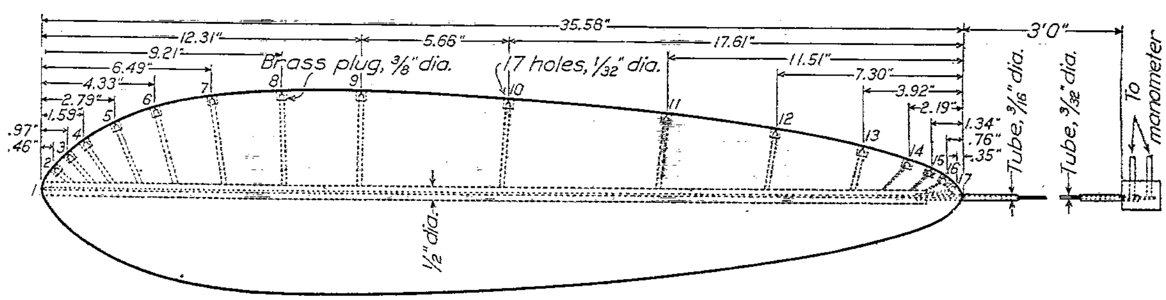


FIG. 3.—Pressure collector on C-class airship model with fineness ratio of 4.62

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 $Cs = 2R/\rho\ (\text{Vol.})^{2/3}\ V^2$ gives $C_C = 2aV^{n-2}/\rho\ (\text{Vol.})^{2/3}$ which on logarithmic paper is a straight line since the air density $\rho$ 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, $Cs = .028$. 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, $P = KV^n$.

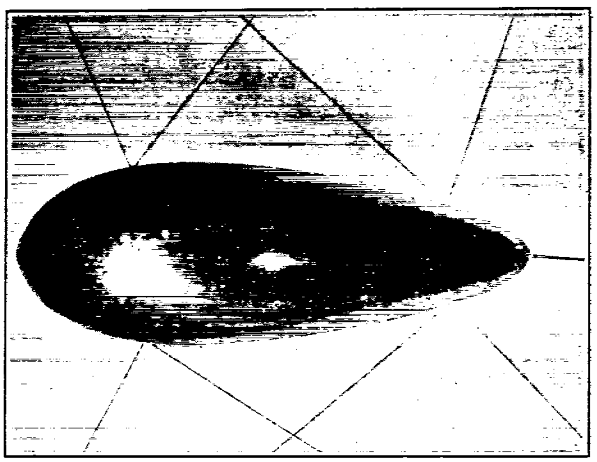

FIG. 4.—Model of C-class airship, fineness ratio 4.62, mounted for pressure distribution test

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.

## 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

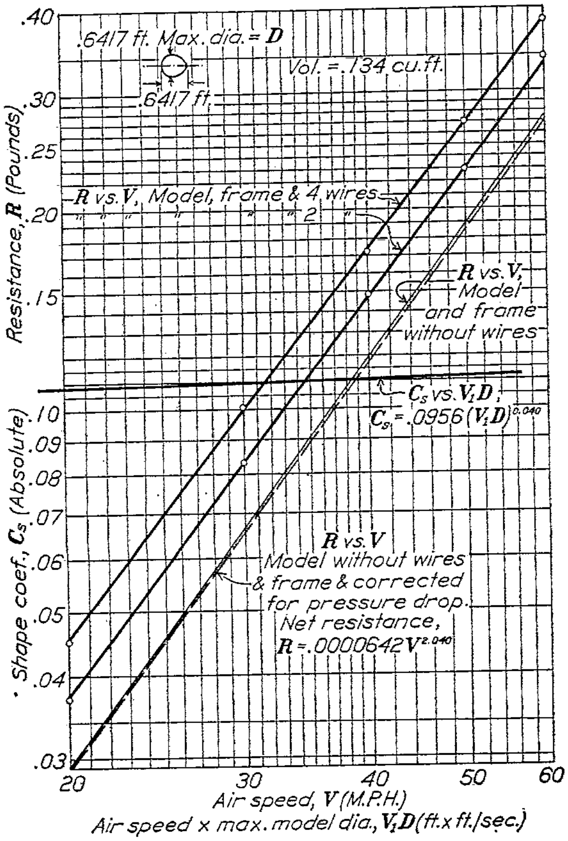


FIG. 5.—Fineness ratio=1

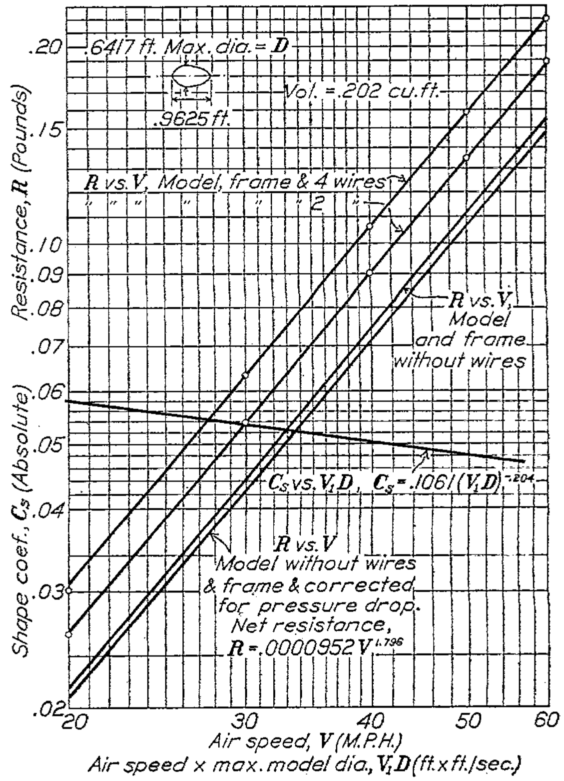


FIG. 6.—Fineness ratio=1.5

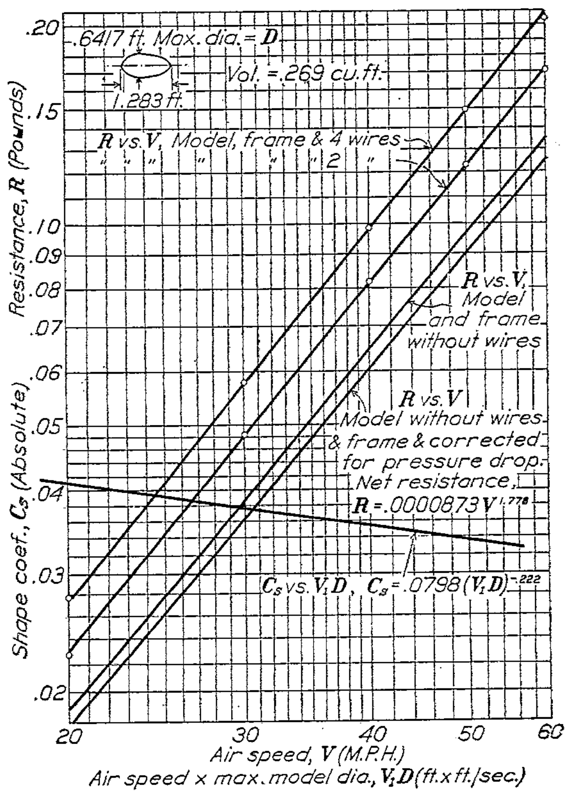


FIG. 7.—Fineness ratio=2

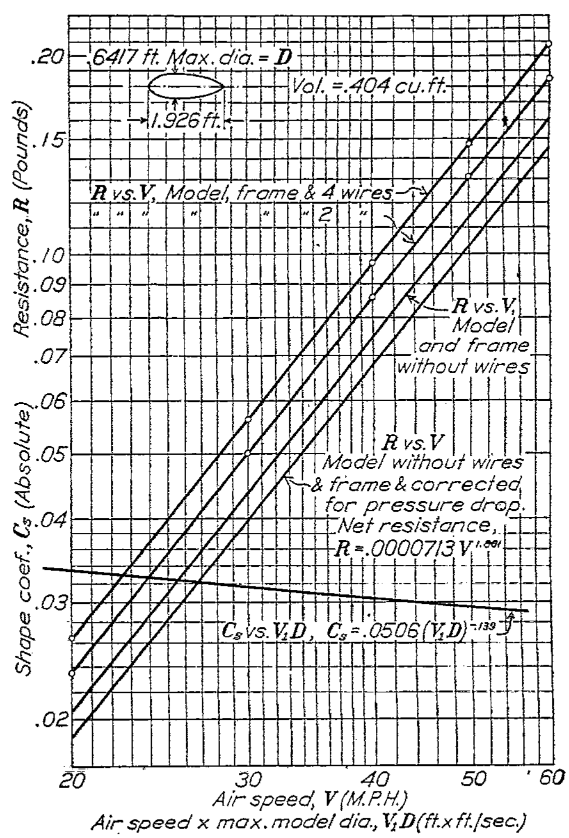


FIG. 8.—Fineness ratio=3

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

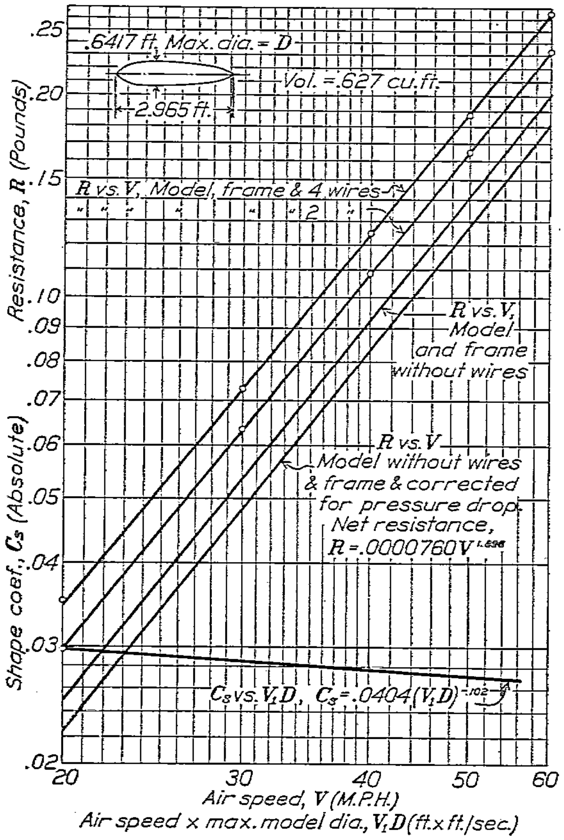


FIG. 9.—Fineness ratio = 4.62

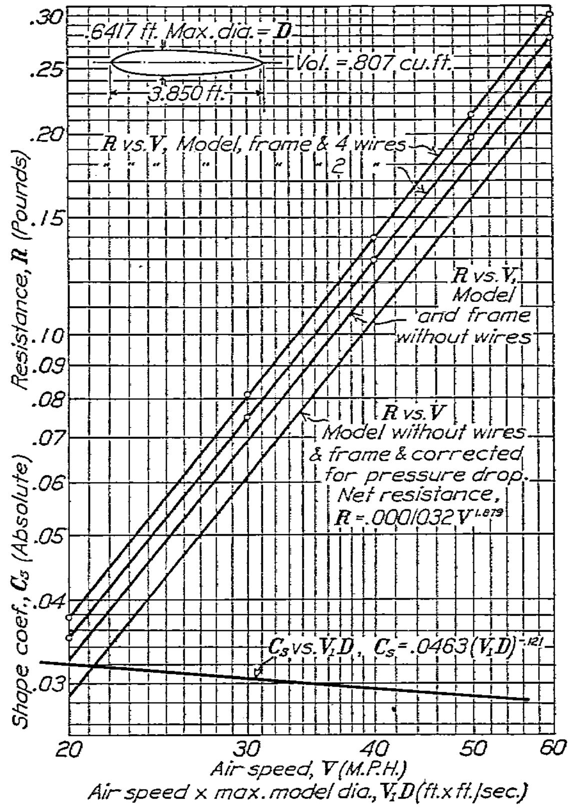


FIG. 10.—Fineness ratio = 6

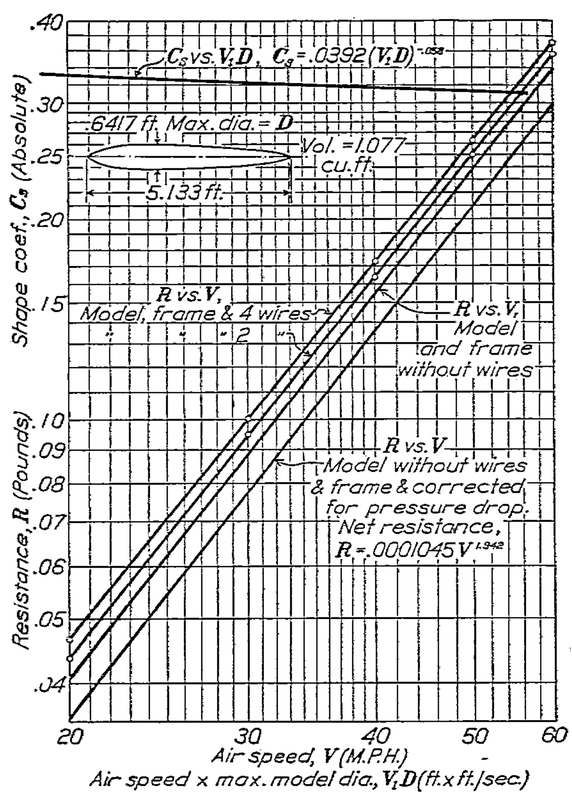


FIG. 11.—Fineness ratio = 8

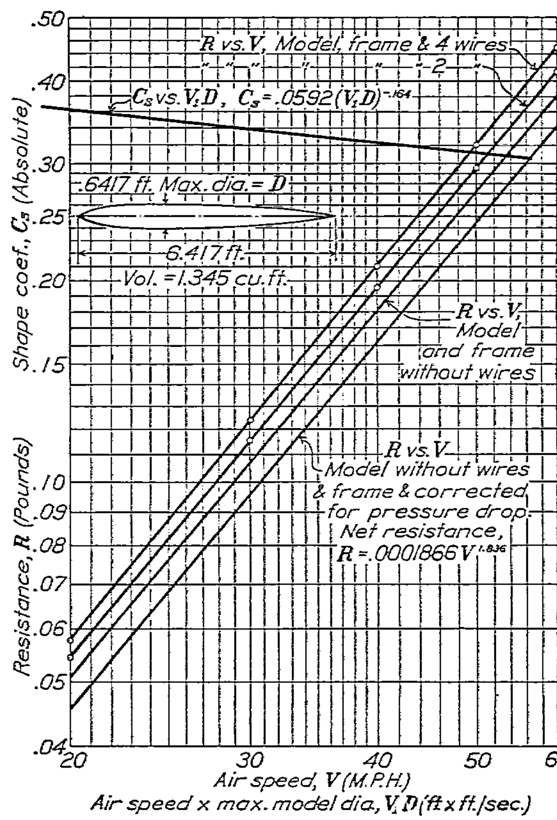


FIG. 12.—Fineness ratio = 10

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

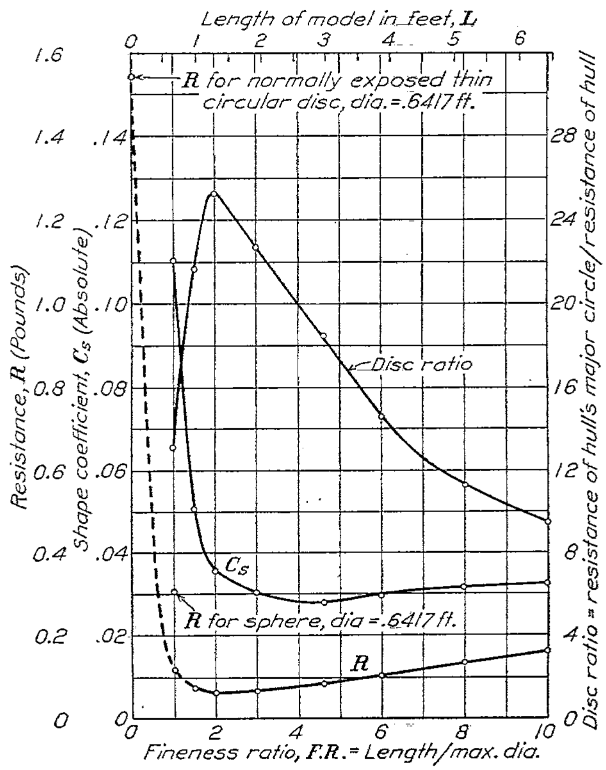


FIG. 13.—C-class airship. Models with various fineness ratios. Air speed 40 M. P. H. Model at 0° pitch and 0° yaw

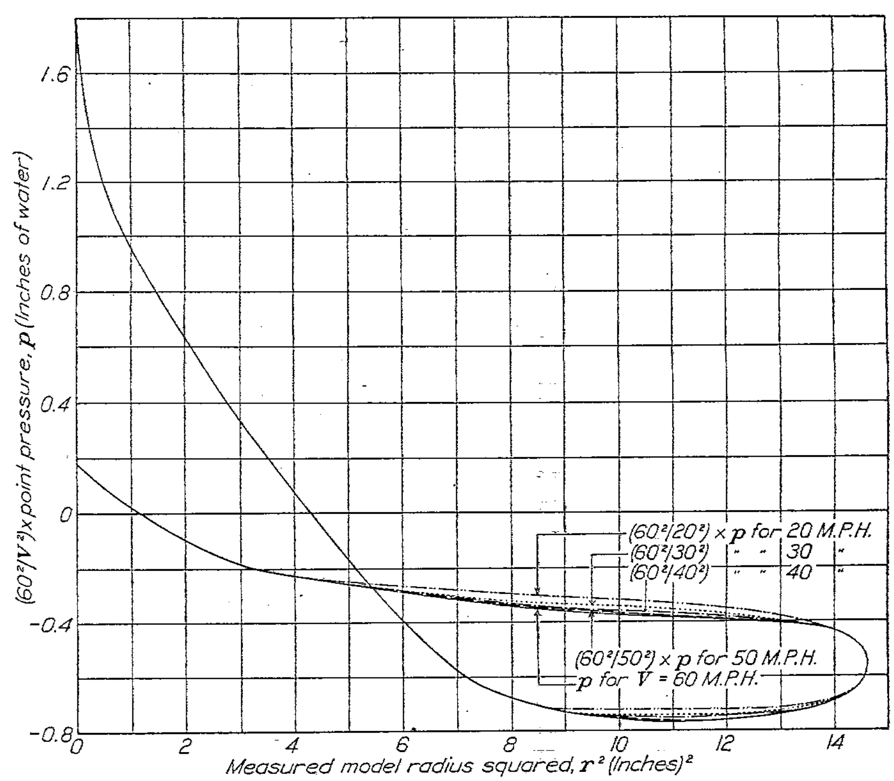


FIG. 16.—C-class airship. Fineness ratio=4.62 Model at 0° pitch and 0° yaw

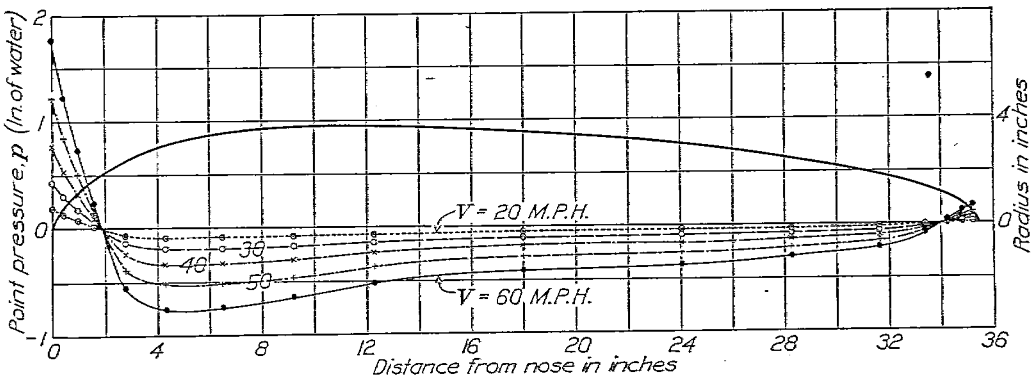

FIG. 14.—C-class airship. Fineness ratio=4.62. Model at 0° pitch and 0° yaw. Air speeds, $V$=20 to 60 M. P. H.

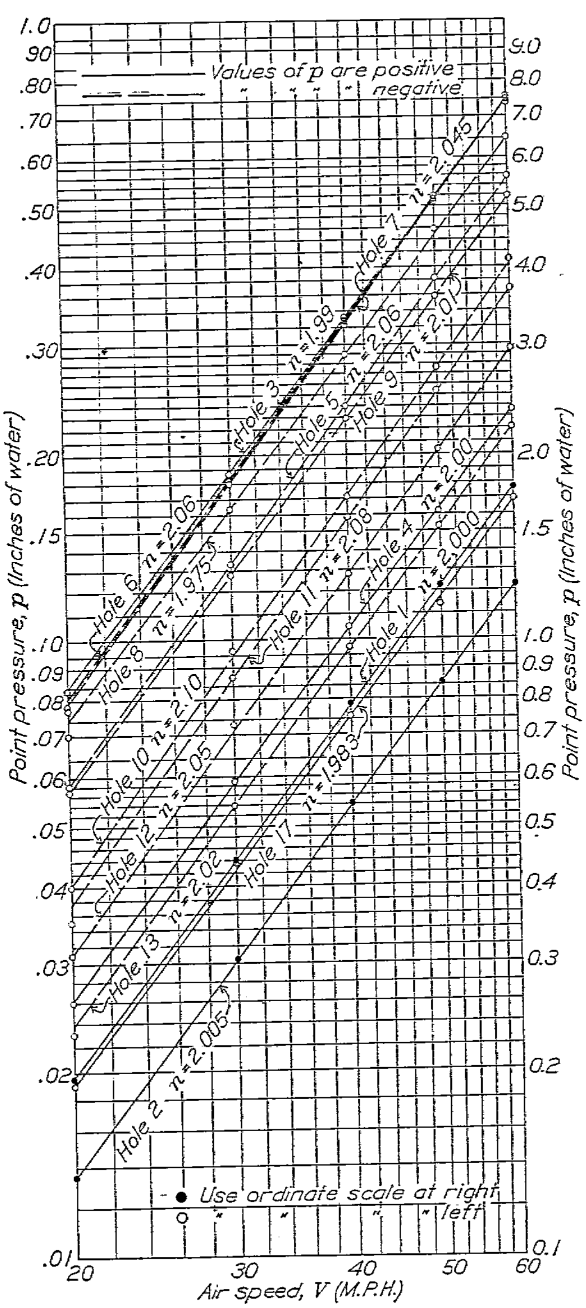

FIG. 15.—C-class airship. Fineness ratio=4.62 Model at 0° pitch and 0° yaw

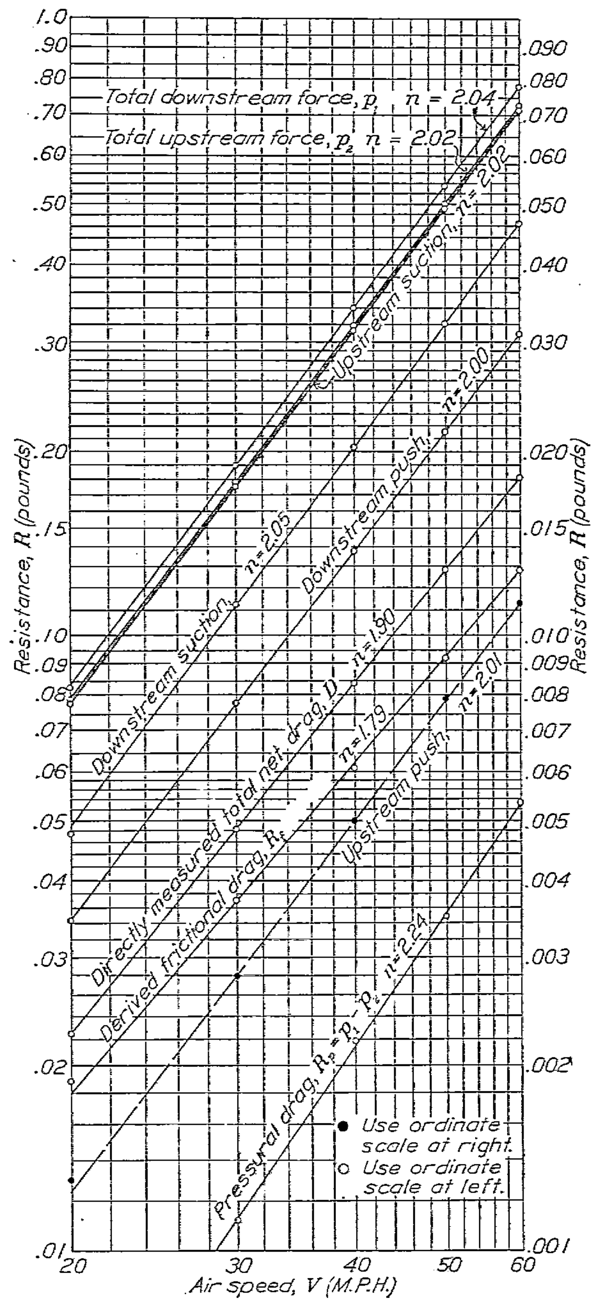

FIG. 17.—C-class airship. Fineness ratio=4.62 Model at 0° pitch and 0° yaw

### 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.

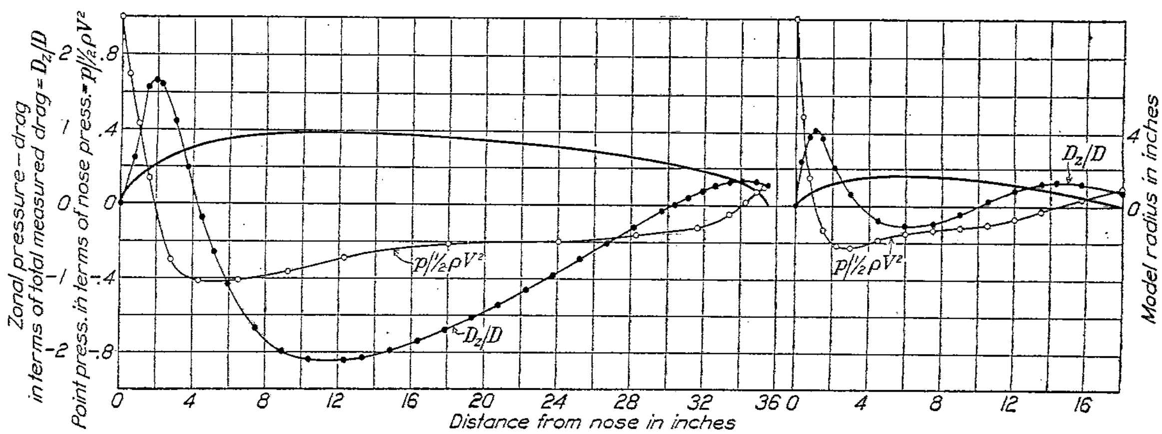


FIG. 18.—At left C-class airship. Fineness ratio=4.62. Air speed 40 M. P. H.
At right Parseval type airship, British test, see R. & M. No. 107. Air speed 40.91 M. P. H.

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, $C_s = 2R/\rho(\mathrm{Vol})^{2/3}V_1^2$ |
|---|---|---|
| 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.
$\rho$ =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.)$=K_DSV^2=1.544$ 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 |

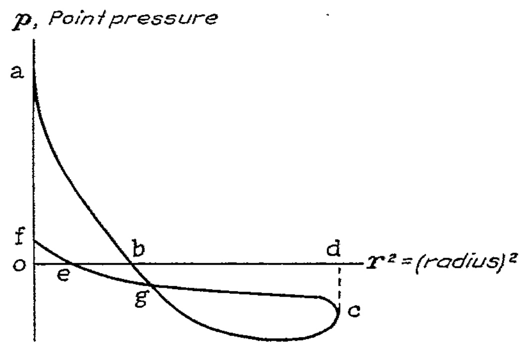


FIG. 19.—
Downstream push ∝ abo
Downstream suction ∝ ced
Upstream push ∝ eof
Upstream suction ∝ bcd
Total area = (abo+ced) − (eof+bcd) = (agf−gcg) ∝ $R_p$

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