

REPORT No. 397

THE DRAG CHARACTERISTICS OF SEVERAL AIRSHIPS DETERMINED BY DECELERATION TESTS

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SUMMARY

The results of deceleration tests conducted for the purpose of determining the drag characteristics of six airships are given herein. The tests were made during the past few years with airships of various shapes and sizes belonging to the Army, the Navy, and the Goodyear-Zeppelin Corporation. In each instance a representative of the National Advisory Committee for Aeronautics cooperated with the organization to which the airship belonged to conduct the tests. Although the deceleration tests with the U. S. S. "Los Angeles" have been previously reported, the final results obtained with that airship are included herein for comparison.

Drag coefficients for the following airships are shown: Army "TC-6," "TC-10," and "TE-2"; Navy "Los Angeles" and "ZMC-2"; Goodyear "Puritan." The coefficients vary from about 0.045 for the small blunt airships to 0.023 for the relatively large slender "Los Angeles." This variation may be due to a combination of effects, but the most important of these is probably the effect of length-diameter ratio.

INTRODUCTION

Deceleration tests have frequently been used for an experimental determination of the drag of full-sized airships. For various reasons, some of which pertain to the test conditions and some to assumptions made in the calculations, the results obtained by this method are often considerably in error. The drag data obtained are valuable, however, owing to the lack of more satisfactory sources of full-scale data.

The National Advisory Committee for Aeronautics, in conjunction with the Nineteenth Airship Company of the Army Air Corps, the Bureau of Aeronautics of the Navy, and the Goodyear-Zeppelin Corporation, has conducted deceleration tests during the past few years to determine the drag characteristics of six airships. In conjunction with these tests, speed trials were also conducted with these airships. The airships represent five different shapes, and vary in volume from 80,000 cubic feet for the Army's nonrigid *TE-2* to 2,760,000 cubic feet for the U. S. S. *Los Angeles*. The results of these tests and of the speed trials conducted with these airships are given herein, together with a description of the general procedure

followed and details of each series of tests except those conducted with the *Los Angeles*. The tests with the latter airship have previously been reported (reference 1), but the final results are included herein for comparison.

The various subjects are treated in the following order:

General Method.

Accuracy.

Los Angeles, Results.

TC-10, Tests and Results.

Puritan, Tests and Results.

ZMC-2, Tests and Results.

TC-6, Tests and Results.

TE-2, Tests and Results.

Discussion of Results.

GENERAL METHOD

The general method is described below. Any deviations from this procedure will be noted in the individual accounts of the details of each series of tests.

Air speed was measured with an N. A. C. A. recording air-speed meter (reference 2) connected by rubber tubing to a suspended Pitot-static head. This air-speed head was suspended below the airship a sufficient distance to insure that it was not appreciably affected by the air flow around the hull. The photographic records of the air-speed recorder were in most cases timed at regular short intervals by means of an N. A. C. A. timer. (Reference 3.) Air temperature and pressure readings were taken for the calculation of air density and true air speed.

In speed trials air-speed measurements were taken at various engine speeds. Records having a duration of 10 or 15 seconds for each speed were usually considered to be sufficient. The results of these trials were used to show the variation of air speed with engine speed. As a curve showing this variation is essentially a straight line, it can be established by relatively few points and can be extrapolated to show with fair accuracy the air speed which would be obtained with somewhat greater engine speeds than those actually used.

In deceleration tests continuous air-speed records were taken while the airship decelerated more or less

smoothly in horizontal flight with the power off. Each run was started with the airship in steady horizontal flight at either cruising or maximum speed. The power was cut off by closing the engine throttles or by opening the ignition switches. Air temperature and pressure readings were taken in most cases at the start and end of each run.

The drag characteristics were calculated from the deceleration data by the method described in reference 1. The symbols used and a description of the calculations follow:

- V —velocity
 v —total air volume of airship
 v_m —virtual volume
 t —time
 s —characteristic length (a linear quantity determined by the drag characteristics of an airship)
 A —drag area of airship ($A = \frac{\text{total drag}}{\text{dynamic pressure}}$)
 A_p —drag area of parts not ordinarily contributing to the drag of the airship
 k_1 —longitudinal coefficient of additional mass
 C_D —drag coefficient (based on $v^{2/3}$)
 ρ —air density (mass per unit volume)

Curves of $\frac{1}{V}$ against t were plotted for the determination of the characteristic length

$$s = \frac{dt}{d\left(\frac{1}{V}\right)}$$

which is constant for any given airship when the resistance is proportional to the square of the velocity. (Reference 1.) As only the slopes of these curves are important, the time may be measured from an arbitrary reference, which is usually the start of the air-speed record.

The drag area and shape coefficient were found by use of the expressions

$$A = \frac{2v_m}{s} - A_p$$

and

$$C_D = \frac{A}{v^{2/3}}$$

The virtual volume v_m is the actual volume of the airship plus an additional amount that allows for the momentum contributed to the decelerating mass by the air that is moved as a result of the airship's motion. The form of the expression for virtual volume is

$$v_m = v(1+k)$$

in which k is the additional mass coefficient for the shape considered.

There is some doubt regarding the proper value to be assigned to k . Theoretical additional mass coefficients for ellipsoids require the assumption that air is inviscid and that the airships are equivalent to

ellipsoids in shape. Actually, owing to viscosity of the air, an airship is accompanied by a boundary layer of air of varying thickness in which the velocity varies with the distance from the hull surface. According to a Goodyear-Zeppelin Corporation report by Klemperer, the momentum of the boundary layer is approximately equivalent to an additional mass coefficient of 0.02 for the *Los Angeles*. With regard to other shapes and sizes, it is stated that, in addition to an expected variation with the inverse of the fifth root of the Reynolds Number, there is some evidence to indicate that the boundary-layer momentum depends upon the shape, being relatively greater for blunt shapes. If the above value of the coefficient for the *Los Angeles* is used as a datum, the coefficients for the small blunt airships are apparently somewhat greater than 0.02. If the effect of Reynolds Number alone is considered upon the basis stated above, the coefficients for these airships would be about 0.03; but because they are relatively blunt, as well as small, the proper value of the coefficient is very uncertain.

As there is considerable uncertainty regarding the equivalent boundary-layer volume for all but one of the airships, and because it is probably small in any event, the virtual volumes are calculated on the basis of theoretical longitudinal mass coefficients alone. The coefficient for each airship is assumed to be the same as that for an ellipsoid having the same volume and either the same diameter or length as the airship.

It is assumed that

$$v_m = v(1+k_1)$$

in which v includes the total air volume of the envelope and all external parts, and k_1 is found from Lamb's additional mass coefficients for ellipsoids. (Reference 4.) For nonrigid airships the actual air volume of the envelope is the theoretical volume plus the increase in volume caused by fabric stretch. This increase in volume is assumed to be 3 per cent for all the nonrigid airships. Although the additional mass coefficients for appendages are probably different from that for the envelope, the volume of these parts is so small relative to the total volume that the error incurred in applying the same coefficient to all parts is negligible.

The quantity A_p that appears in the equation for net drag area is the sum of the equivalent drag areas of the propellers and suspended air-speed head. Although the drag of the air-speed head has been found to be nearly constant at high speed because of variations in curvature of the cable, its drag is approximately equivalent to a drag area of 2 square feet for the speeds encountered in the airship tests. The drag areas of the propellers for each airship were estimated by the application of results obtained in Durand and Lesley's propeller tests. (Reference 5.) The drag areas of stopped propellers were calculated by means of equations given by Diehl (reference 6)

which are based on the above-mentioned propeller tests. These equations are:

$$\text{Negative thrust} = C_D' \frac{\rho}{2} V^2 \left(\frac{b}{D}\right) D^3$$

$$C_D' = 1.16 - 0.44 \frac{p}{D} \quad (\text{for stopped propeller})$$

where V is the forward velocity
 b , maximum blade width
 D , diameter
 p , nominal pitch

The propeller characteristics for the various airships are given in Table I.

ACCURACY

The accuracy with which air speed is measured is, in general, probably within ± 2 per cent.

The manner in which the calculated shape coefficients are affected by various inaccuracies is conveniently shown by the following expression:

$$C_D = \frac{2v^{1/3} (1+k_1)}{s} \frac{A_p}{v^{2/3}}$$

The first term represents the over-all shape coefficient and the last, the correction for drag of the propellers and suspended air-speed head.

The fact that corrections for stretch of the nonrigid airships may be inaccurate is acknowledged, but the effect on C_D of such errors is probably negligible. The accuracy of the first term is therefore considered to be dependent upon the accuracy of the experimentally determined s and assumed k_1 . The accuracy of s depends not only upon exactness in measuring time and velocity, but also upon the exactness with which the actual test conditions conform with those desired or assumed by the deceleration theory. The lack of conformity in this respect is probably the more serious source of error. The value of s obtained by averaging the results of several runs is believed to be subject to an error of the order of ± 5 per cent, and to a somewhat greater error when the results of only one or two runs are available. With regard to the volume factor $(1+k_1)$, it has been previously stated that neglecting the effect of air viscosity probably leads to an error of at least -2 or -3 per cent in this factor. Errors in the second term of the above expression probably do not affect the shape coefficient by more than ± 3 per cent. It appears, therefore, that, in general, C_D is subject to a plus-or-minus error of about 8 per cent, and may be a few per cent low in every case owing to the use of an incorrect volume factor.

"LOS ANGELES" RESULTS

The *Los Angeles* has a hull volume of 2,760,000 cubic feet, a length of 656 feet, a maximum diameter of 90.7 feet, and a length-diameter ratio of 7.23. As the results of the deceleration tests with this airship have

previously been published (reference 1), no description of the tests or no detailed account of the results are given here. It should be noted, however, that the drag coefficient for this airship without water recovery is given as 0.023 herein (Table II) and as 0.0242 in reference 1. The difference is caused by the difference between the methods of calculating virtual volume in the two cases. In the previous case 4 per cent was allowed for the effect of the boundary layer on virtual volume; whereas, in the present case the effect of friction in this respect was neglected, as previously explained. A value of $k_1 = 0.04$ was used in the calculation of virtual volume. This value is the additional mass coefficient for an ellipsoid having a volume and diameter equal to the volume and diameter of the *Los Angeles*.

"TC-10" TESTS

In the fall of 1928 speed and deceleration trials were conducted with the Army airship *TC-10* at Langley Field, Va. These tests were conducted by DeFrance, of the National Advisory Committee for Aeronautics, while he was on reserve duty with the Nineteenth Airship Company.

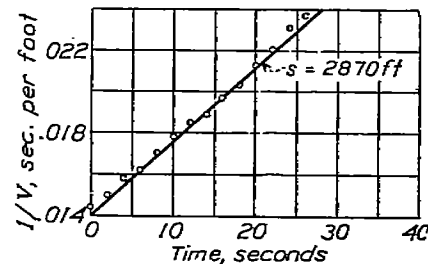


FIGURE 1.—TC-10 deceleration test. Run No. 1

The *TC-10* is a conventional nonrigid airship with an open car and with two engines mounted on outriggers. It has a volume of 200,600 cubic feet, a length of 195.8 feet, a maximum diameter of 44.5 feet, and a length-diameter ratio of 4.4. There are four fins and three movable tail surfaces. The tractor propellers were driven by water-cooled engines that probably developed a maximum of 150 horsepower each.

Two deceleration runs and a series of speed trials were made. The deceleration runs were started by opening the ignition switches with the engines operating at 1,300 r. p. m., which was approximately their maximum speed. For some reason the switches were not opened simultaneously in the first run. In the speed trials records were taken with the airship following a given compass course, the keel level, and the engine speed steady. Level flight was maintained by the aid of an indicating statorscope during the speed and deceleration tests.

"TC-10" RESULTS

The deceleration curves are shown in Figures 1 and 2 and the results of the speed trials in Figure 3.

The average characteristic length is

$$s = 2,835 \text{ feet}$$

The total air volume of this airship is calculated to be 207,700 cubic feet, and the value of k_1 for an ellipsoid of equivalent volume and length is 0.07. The calculated virtual volume is, therefore,

$$v_m = 207,700 \times 1.07 = 222,300 \text{ cubic feet}$$

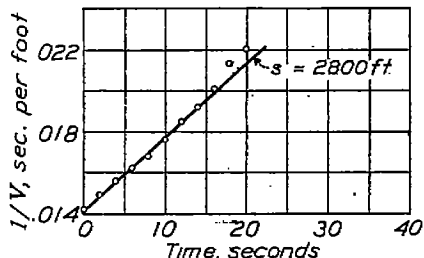


FIGURE 2.—TC-10 deceleration test. Run No. 2

The drag area of the propellers is calculated for the stopped condition, although they actually continued to rotate for about 10 seconds after the switches were opened. The total drag area of the two propellers and the suspended air-speed head is

$$A_p = 14 + 2 = 16 \text{ square feet}$$

The net drag area is

$$A = \frac{2 \times 222,300}{2,835} - 16 = 141 \text{ square feet}$$

and the shape coefficient

$$C_D = \frac{141}{(207,700)^{2/3}} = 0.040$$

The maximum full-throttle speed attained was 49.5 m. p. h. The value of ρ for the speed trials was 0.00226. Although the engine speed for this air speed was not recorded, it was found to be 1,330 r. p. m. by extrapolation of the curve in Figure 3.

"PURITAN" TESTS

Two series of performance tests with the *Puritan* airship were conducted at Akron, Ohio, in the latter part of 1928 by the Goodyear-Zeppelin Corporation, assisted by DeFrance, of the National Advisory Committee for Aeronautics. The results of the speed and deceleration runs made during these tests are given herein. In each series several speed trials and deceleration runs were made.

The *Puritan* is a nonrigid airship having a volume of 85,870 cubic feet, a length of 127.5 feet, a maximum diameter of 36.4 feet, and a length-diameter ratio of 3.5. It has a closed cabin which is attached directly to the envelope. Power is supplied by two radial air-

cooled engines having a rated power of 67 horsepower at 1,690 r. p. m. The engines are mounted on outriggers on either side of the cabin. The propellers rotated in opposite directions during the first series of tests. Before the second series of tests one of the engines was replaced by a new engine having a direction of rotation opposite to that of the one replaced. Consequently a new propeller was required, and both propellers rotated in the same direction during the second series of tests.

Power was cut off in the deceleration runs by opening the ignition switches. Four deceleration runs were made in the first series of tests and three in the second. Three windows were out in the first series and the airship was slightly heavy to the extent that it lost altitude at the rate of about 200 feet per minute. The deceleration runs in the second series of tests were started with the engines developing a full-throttle speed of 1,690 r. p. m., whereas in the first series this engine speed could not be attained, and the starting speed was consequently slightly lower. Rate-of-climb and inclinometer observations in the first series of deceleration trials indicate that fairly level keel was maintained, but that the airship descended slightly

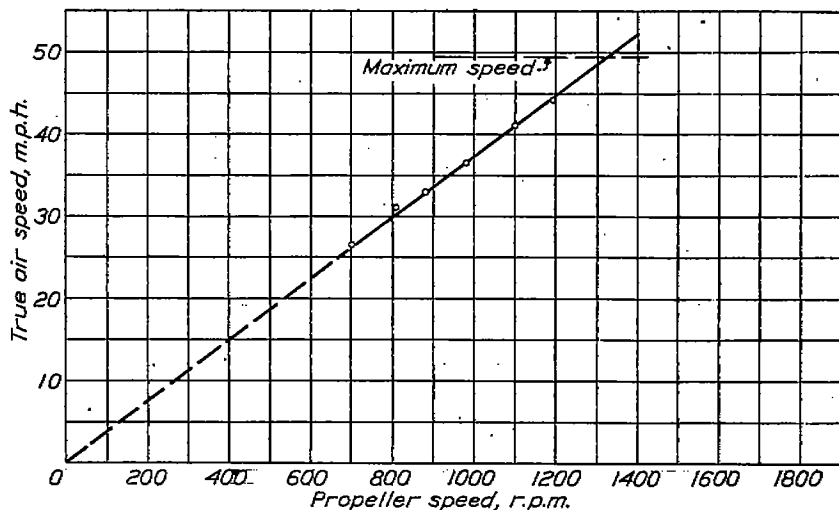


FIGURE 3.—TC-10 airship speed trials. True air speed versus propeller r. p. m.

because of heaviness. In the second series constant altitude was maintained.

"PURITAN" RESULTS

The curves obtained from the deceleration runs are shown in Figures 4 to 10 and the results of the speed trials in Figure 11. The average characteristic lengths are

$$s = 1,990 \text{ feet (first series)}$$

and

$$s = 1,800 \text{ feet (second series)}$$

The calculated total air volume v for the *Puritan* is 89,300 cubic feet. The value of k_1 for an ellipsoid of equivalent volume and length is 0.10. Therefore

$$v_m = 89,300 \times 1.10 = 98,200 \text{ cubic feet}$$

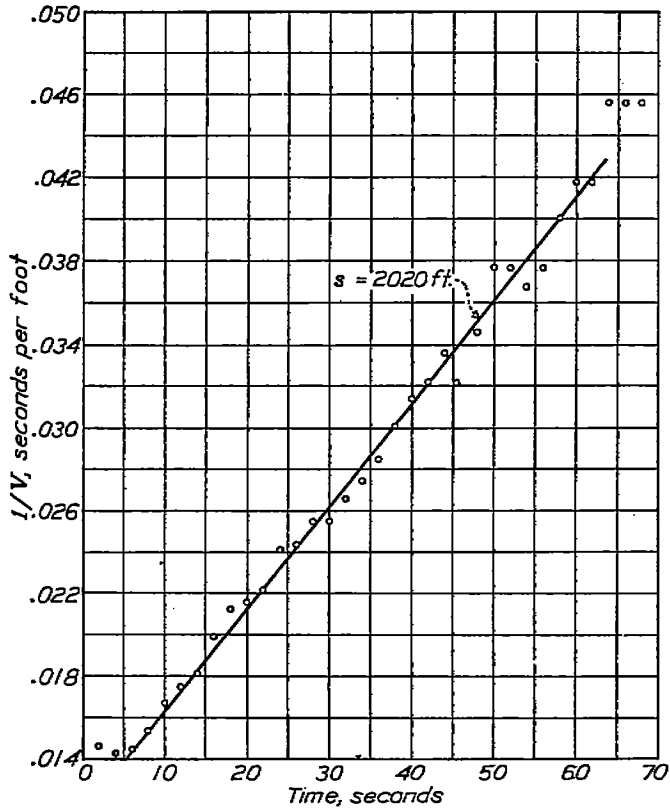


FIGURE 4.—Puritan deceleration test. Run No. 1

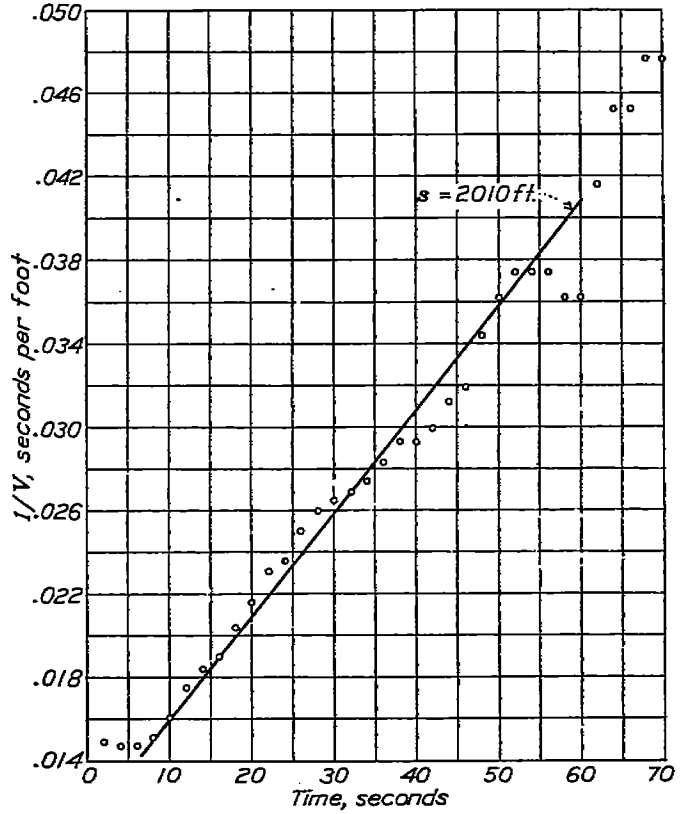


FIGURE 6.—Puritan deceleration test. Run No. 3

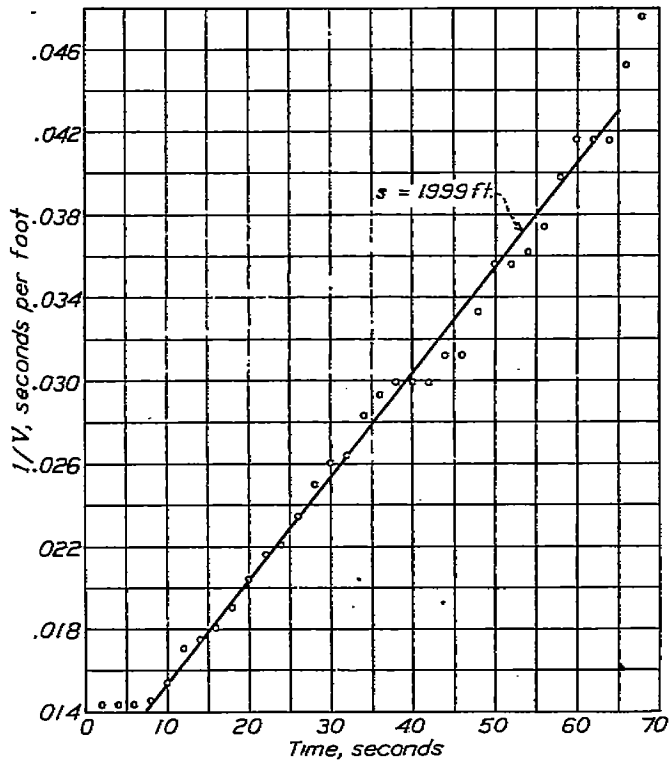


FIGURE 5.—Puritan deceleration test. Run No. 2

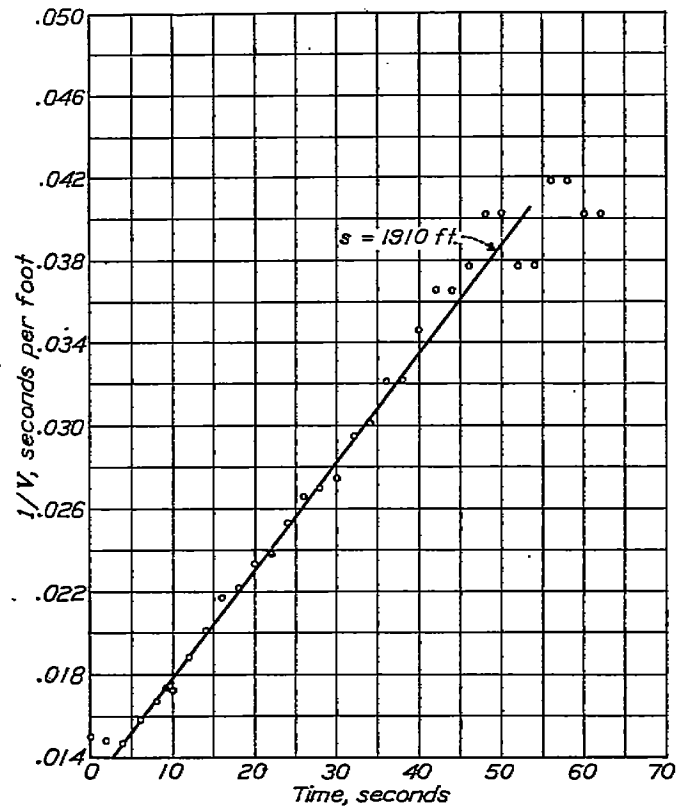


FIGURE 7.—Puritan deceleration test. Run No. 4

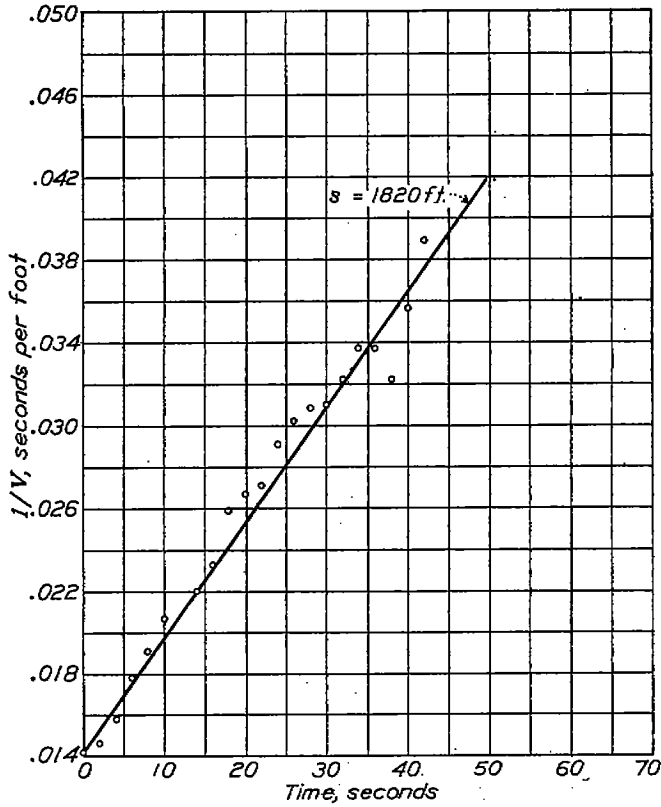


FIGURE 8.—Puritan deceleration test. Run No. 1. (2d series)

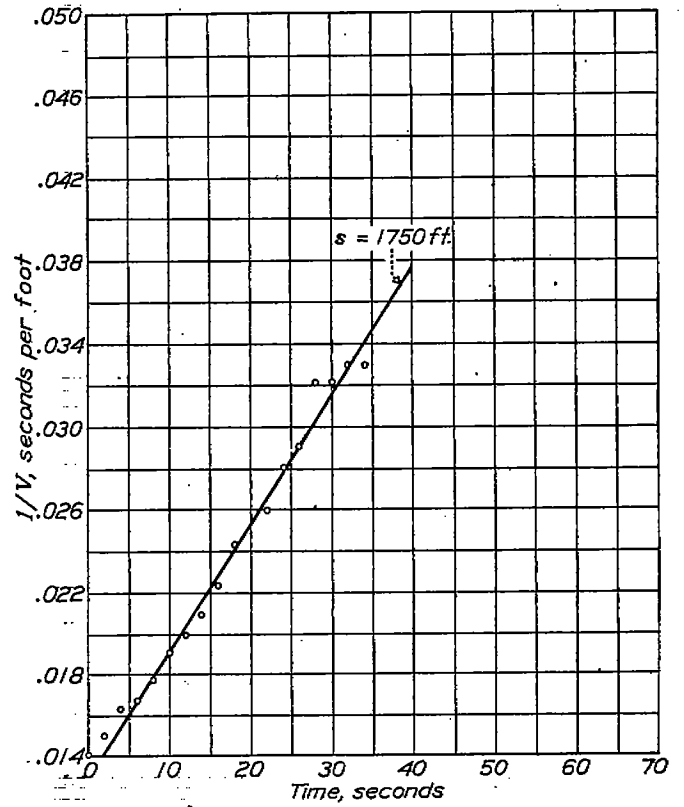


FIGURE 10.—Puritan deceleration test. Run No. 3. (2d series)

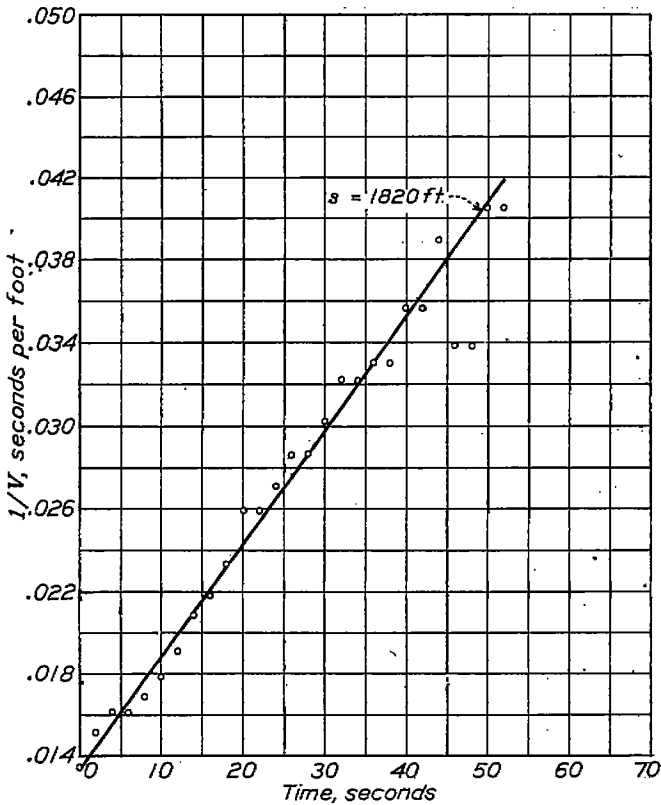


FIGURE 9.—Puritan deceleration test. Run No. 2. (2d series)

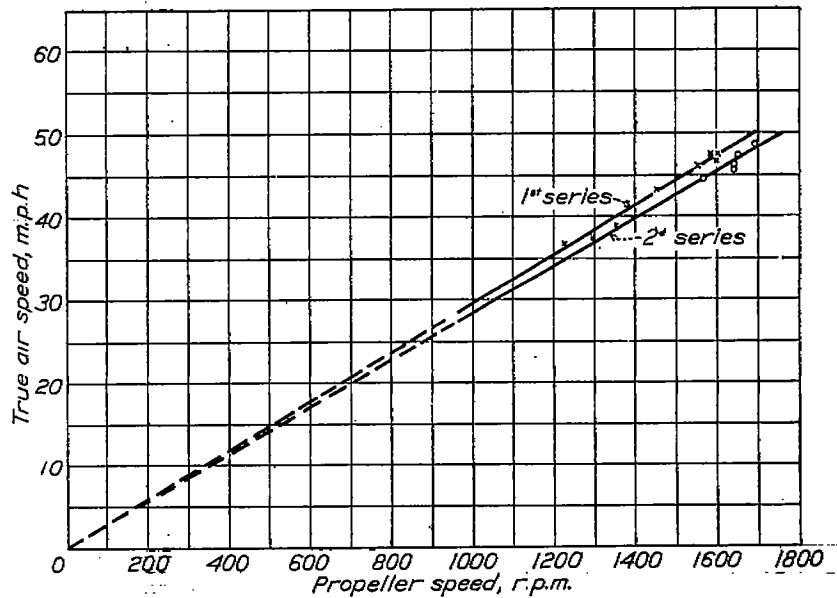


FIGURE 11.—Puritan airship speed trials. True air speed versus propeller r. p. m.

The equivalent drag area of the propellers, considered as stopped, was calculated to be 10 square feet, which, added to the drag area of the suspended air-speed head, gives

$$A_p = 10 + 2 = 12 \text{ square feet}$$

Thus, for the net drag areas we have

$$A = \frac{2 \times 98,200}{1,990} - 12 = 87 \text{ square feet (first series)}$$

$$\text{and } A = \frac{2 \times 98,200}{1,800} - 12 = 97 \text{ square feet (second series)}$$

The shape coefficients for the two cases are

$$C_D = \frac{87}{(89,300)^{2/3}} = 0.044 \text{ (first series)}$$

$$\text{and } C_D = \frac{97}{(89,300)^{2/3}} = 0.049 \text{ (second series)}$$

The values of ρ for the speed trials were 0.00233 for the first series and 0.00237 for the second. Figure 11 shows the maximum speeds attained to be 47.5 m. p. h. and 48.5 m. p. h. for the first and second series of tests, respectively. These air speeds did not occur at the same engine speeds, however. In the first series the engines developed a maximum of 1,600 r. p. m., whereas in the second series the maximum engine speed attained was 1,690 r. p. m. For a given engine speed the curve for the first series of tests shows a higher air speed than that for the second series. The difference in these curves indicates a change in the drag coefficient of the airship that is in agreement with that found from the deceleration tests. However, the fact that one of the propellers was changed puts the issue in doubt as, in addition to the change in direction of rotation of the second propeller, the characteristics of this propeller may not have been identical with those of the propeller replaced.

"ZMC-2" TESTS

Speed and deceleration tests were made with the *ZMC-2* airship at Lakehurst, N. J., November 7, 1929. They were conducted by the National Advisory Committee for Aeronautics at the request of and in conjunction with the Bureau of Aeronautics of the Navy. One series of speed trials and five deceleration runs were made.

The *ZMC-2* is the all-metal airship constructed by the Aircraft Development Corporation for the Navy Department. It has a volume of 202,200 cubic feet, a length of 149.4 feet, a maximum diameter of 52.7 feet, and a length-diameter ratio of 2.83, which is unusually small for present-day airships. The forward portion of the hull is an ellipsoid and the after portion a hyperboloid. It is circular in section and is constructed of smooth aluminum alloy sheets joined with gas-tight riveted seams. It has eight fins and movable tail surfaces equally spaced around the hull. Four of the movable surfaces act as elevators. Of the remaining four movable surfaces the

lower pair act as ordinary rudders. The upper pair may be used either as "automatic" rudders or as fins if locked. At the time of the tests they were in the latter condition. The control car is attached directly to the hull. Power is furnished by two 220-horsepower radial air-cooled engines supported by faired outriggers which also contain the air scoops. In general, the airship is much cleaner than the service types of nonrigid airships.

The usual instruments were used in the tests on this airship. The air-speed head was suspended approximately 60 feet below the control car. Deceleration tests were made with the engine switches open, and the time required for the propellers to stop rotating was obtained with a stop watch.

The tests were made over water at altitudes varying from a few hundred feet for the deceleration runs to about 2,000 feet for the speed trials. The air was remarkably smooth throughout the flight. Before starting the deceleration tests the airship was placed in buoyant equilibrium and was trimmed longitudinally to a nearly even keel. The static nose heaviness of the airship could not be entirely overcome, however, even at a very low altitude. Deceleration runs were started from steady flight with both engines at 1,550 r. p. m. The two engine switches were opened simultaneously with the starting of the air-speed recorder. Approximate level keel was maintained by the use of considerable elevator control. In the speed trials records were taken over 5 to 10 second intervals during steady level flight at the desired engine speeds. In all the tests the car windows were closed, with the exception of the first deceleration run in which two side windows were inadvertently left open.

The static nose heaviness of the airship augmented by the drag of the car and engines made it necessary to use about 10° up elevator in the deceleration runs. In the speed trials the deflection was varied from up at low speeds to down at maximum speed, with the neutral position at cruising speed. The airship's inclinometer was used to indicate the angle of trim in both cases. Since this instrument is affected by longitudinal deceleration, the airship was probably inclined with the nose up slightly in the deceleration runs. The calculated magnitude of this error varies from about 3° at the start to 1° at the end of the runs. The actual pitch, however, was probably very small, as the airship climbed appreciably during each run.

"ZMC-2" RESULTS

The results of the deceleration tests are given in Figures 12 to 16, inclusive, in which the reciprocals of the measured velocities are plotted against time. From these curves the average characteristic length was found to be

$$s = 2,816 \text{ feet}$$

The total air volume v is 203,300 cubic feet, and the longitudinal mass coefficient k_1 for an equivalent ellipsoid based on length and volume is 0.13. Therefore,

$$v_m = 1.13 \times 203,300 = 229,800 \text{ cubic feet}$$

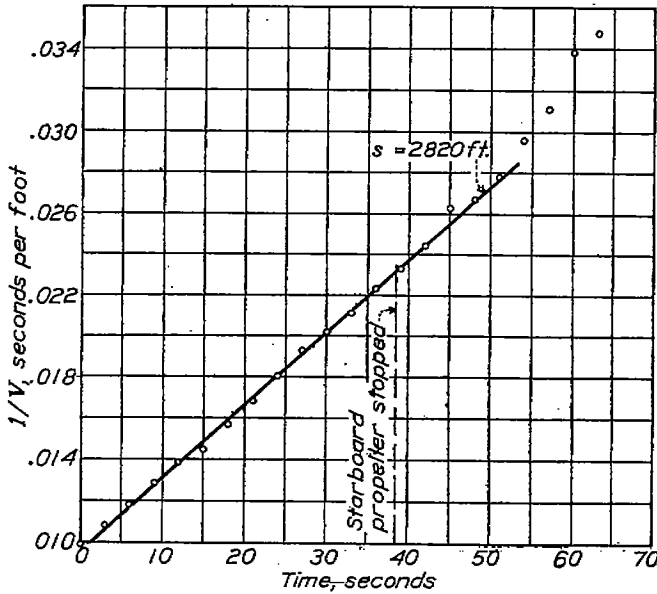


FIGURE 12.—ZMC-2 deceleration test. Run No. 1

Although the propellers actually rotated for about 40 seconds after the switches were opened, the deceleration curves show no appreciable change in slope

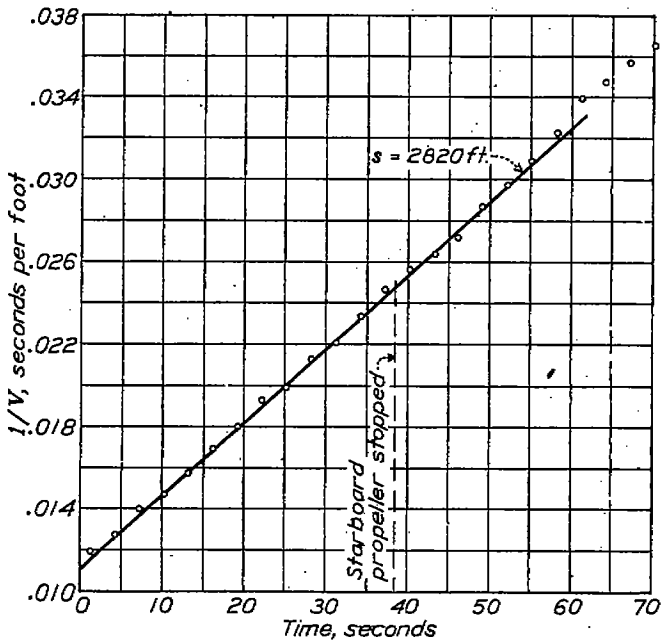


FIGURE 13.—ZMC-2 deceleration test. Run No. 2

as the result of this condition. The drag area of the propellers was therefore calculated for the stopped condition and was found to be about 12 square feet. This amount, plus the drag of the suspended instrument, gives

$$A_p = 12 + 2 = 14 \text{ square feet}$$

Therefore, the net drag area is

$$A = \frac{2 \times 229,800}{2,816} - 14 = 149 \text{ square feet}$$

and

$$C_D = \frac{149}{(203,300)^{2/3}} = 0.043$$

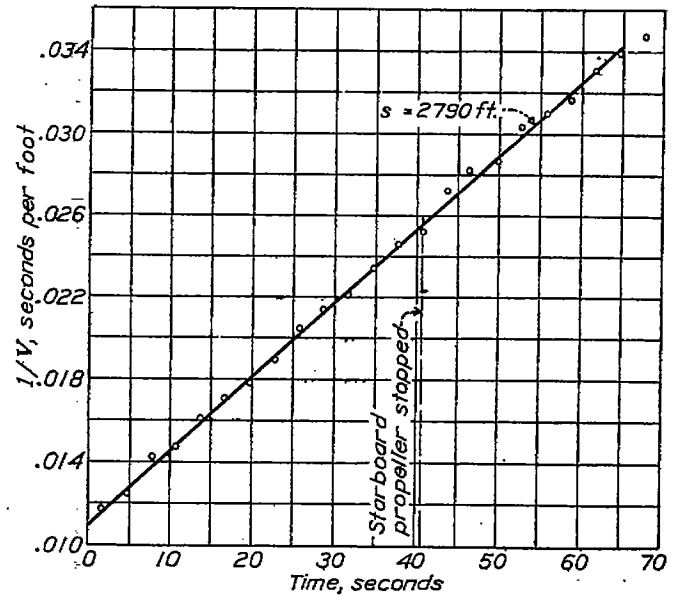


FIGURE 14.—ZMC-2 deceleration test. Run No. 3

The results of the speed trials with the ZMC-2 airship are shown in Figure 17. The value of ρ for these trials was 0.00225. A maximum air speed of 70.7 m. p. h. was attained at full throttle. The fact

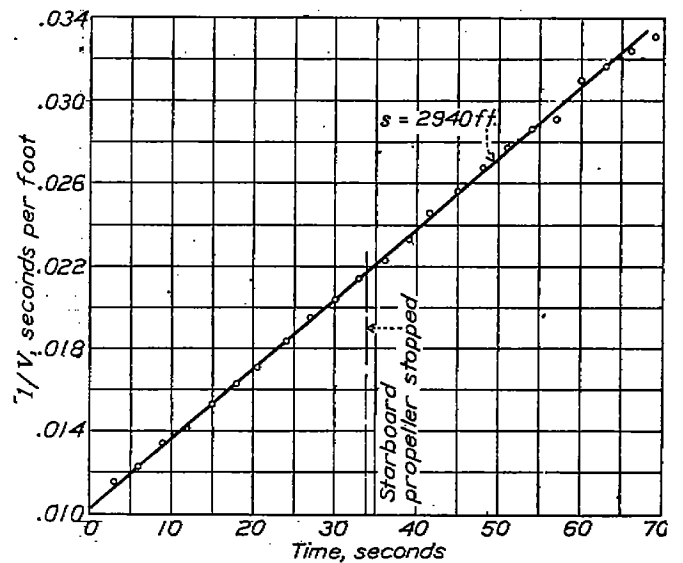


FIGURE 15.—ZMC-2 deceleration test. Run No. 4

that this air-speed point is not so close to the curve as the other points can be attributed to an error in the tachometer readings as logically as to an error in air speed. The accuracy of the tachometers is unknown, as calibrations of these instruments were not available.

“TC-6” TESTS

Speed trials were made with the Army airship TC-6 at Langley Field, Va., during October of 1929. Deceleration tests with this airship were made during

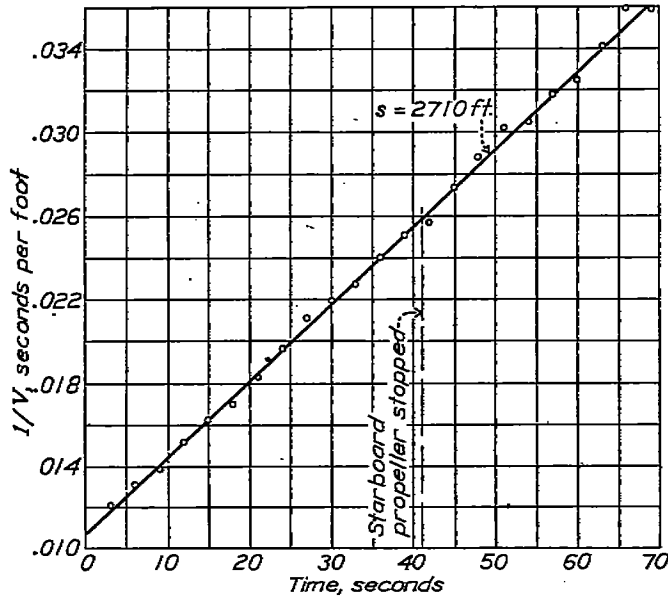


FIGURE 16.—ZMC-4 deceleration test. Run No. 5

February of 1930. Both these investigations were conducted by the National Advisory Committee for Aeronautics with the cooperation of the Nineteenth Airship Company.

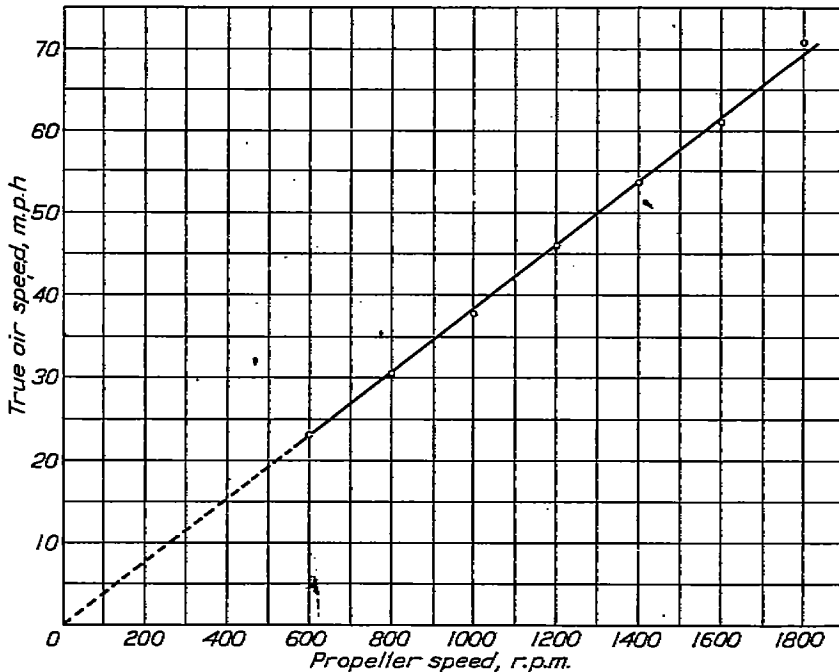


FIGURE 17.—ZMC-4 airship speed trials. True air speed versus propeller r. p. m.

The TC-6 was similar to the TC-10, except that the car was about 1 foot closer to the bag and air-cooled radial engines were used instead of water-cooled engines. The rated power of these engines is about 190 horsepower at 1,600 r. p. m.

The N. A. C. A. fight-path-angle and air-speed recorder with a suspension length of about 90 feet was utilized during the speed trials because the suspended air-speed head usually employed was not available. As the air was fairly bumpy during the speed trials a large number of runs were made. Four deceleration runs were made, but only two were satisfactory

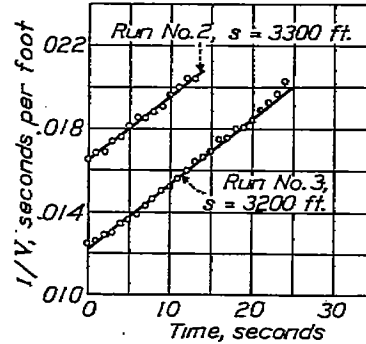


FIGURE 18.—TC-6 deceleration test. Run Nos. 2 and 3

because of difficulties experienced with the air-speed recorder.

Before each deceleration run the airship was put in equilibrium with the tail slightly heavy while the engines were operating at half speed. The negative pitching moment caused by the drag of the car and engines was thereby overcome without the use of elevators. The deceleration trials were started from different speeds. Level keel was maintained by sighting on the horizon.

“TC-6” RESULTS

The results obtained in the two satisfactory deceleration runs are shown in Figure 18. The average characteristic length derived from these curves is

$$s = 3,250 \text{ feet}$$

Since the shape and volume of the TC-6 are the same as for the TC-10, it follows that

$$v = 207,700 \text{ cubic feet}$$

and $v_m = 222,300 \text{ cubic feet}$

The drag area of the propellers stopped was calculated to be 11 square feet, and since the drag area of the suspended air-speed head is about 2 square feet, it follows that:

$$A_p = 11 + 2 = 13 \text{ square feet}$$

The net drag area is:

$$A = \frac{2 \times 222,300}{3,250} - 13 = 124 \text{ square feet}$$

and

$$C_D = \frac{124}{(207,700)^2} = 0.035$$

The results of the speed trials are shown in Figure 19. The value of ρ for these tests was 0.00224. The maximum full-throttle air speed attained was 59.4 m. p. h. and the engine speed for this air speed was 1,595 r. p. m. It will be noted that three curves of air speed against engine speed were obtained. The reason for the difference between the curves is unknown. The results were obtained in two flights on the same day at practically identical atmospheric conditions. The fact that the air was somewhat rough does not explain the discrepancies nor can they be logically attributed to instrument errors. Although the airship was supposedly on an even keel in these tests, the possibility that it was pitched by varied amounts appears to be the only logical explanation of the observed discrepancies.

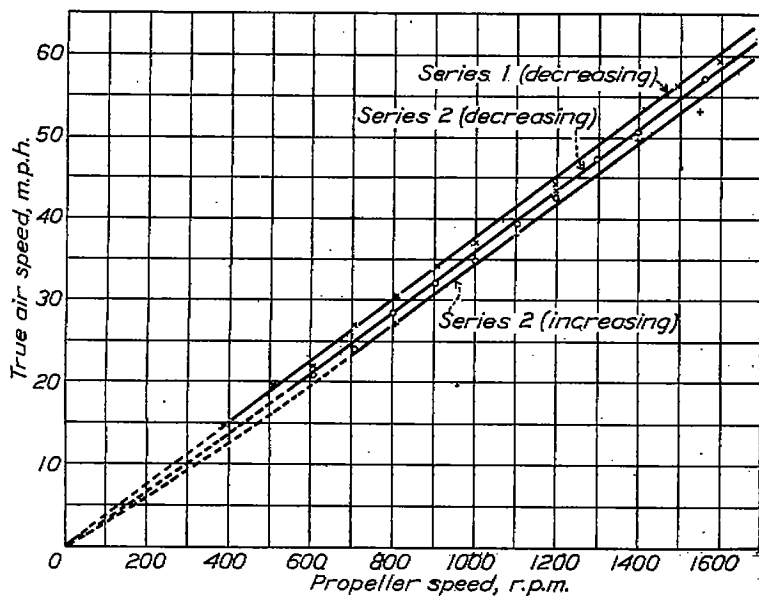


FIGURE 19.—TC-6 airship speed trials. True air speed versus propeller r. p. m.

"TE-2" TESTS

Deceleration tests with the Army *TE-2* airship were made at Langley Field, Va., in October, 1930. These tests were conducted by the National Advisory Committee for Aeronautics with the cooperation of the Nineteenth Airship Company.

The *TE-2* airship has a volume of 80,200 cubic feet, a length of 136 feet, a maximum diameter of 34 feet, and a length-diameter ratio of 4.0. The car is open and is provided with a landing wheel which facilitates the handling of the airship on the ground. Power is supplied by two 3-cylinder air-cooled engines mounted on outriggers. These engines operate two wooden pusher propellers. The rated full-throttle power of these engines is 38.5 horsepower at 1,400 r. p. m.

It was not advisable to stop the engines in flight because starting them required the use of directly connected hand cranks. Consequently power was shut off in the deceleration runs by throttling the engines to a speed of about 300 r. p. m. Four runs were made. The first and last were started with the

engines at their full-throttle speed of 1,400 r. p. m. The engine speeds at the start of the second and third runs were 1,350 and 1,300 r. p. m., respectively. The third was very unsatisfactory, and the results for this run are not included. Level keel was maintained by sighting on the horizon while decelerating.

Separate speed trials were not made, but the relationship between air speed and engine speed was determined approximately by values recorded at the start of the decelerations. This procedure was made possible by the fact that the air-speed records were started slightly before the engines were throttled.

"TE-2" RESULTS

The deceleration curves obtained in the three satisfactory runs are shown in Figures 20 to 22, and a

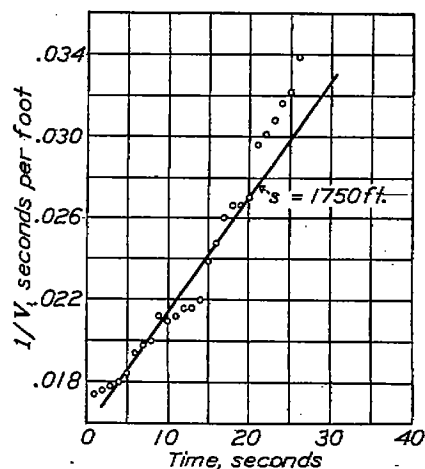


FIGURE 20.—TE-2 deceleration test. Run No. 1

curve of air speed against engine r. p. m., in Figure 23. The average of the three values for characteristic length is:

$$s = 1,740 \text{ feet}$$

The calculated total air volume v is 82,900 cubic feet. The longitudinal mass coefficient k_1 is 0.08 for an ellipsoid having a volume and length equal to that of the airship. Therefore,

$$v_m = 1.08 \times 82,900 = 89,500 \text{ cubic feet}$$

The drag of the propellers idling at 300 r. p. m. was calculated to be equivalent to a drag area of 15 square feet. The total drag area correction is, therefore,

$$A_p = 15 + 2 = 17 \text{ square feet}$$

From the above values, the net drag area was calculated to be

$$A = \frac{2 \times 89,500}{1,740} = 86 \text{ square feet}$$

and the shape coefficient,

$$C_D = \frac{86}{(82,900)^{2/3}} = 0.045$$

The curve of Figure 23 shows that at the full-throttle engine speed of 1,400 r. p. m. the air speed was 38.3 m. p. h. The value of ρ for the test conditions was 0.00227.

DISCUSSION OF RESULTS

The principal results are summarized in Table II and a comparison of the shapes and shape coefficients of the six airships is shown in Figure 24. The Reynolds Numbers given for these airships were calculated on the basis of over-all length and the average velocity used for the determination of curves of

The probable magnitude of the effect of Reynolds Number is of considerable interest. If it were sufficiently large it would cause the curves of $\frac{1}{V}$ against t to bend upward perceptibly with increasing $\frac{1}{V}$. The fact that a consistent curvature of this nature

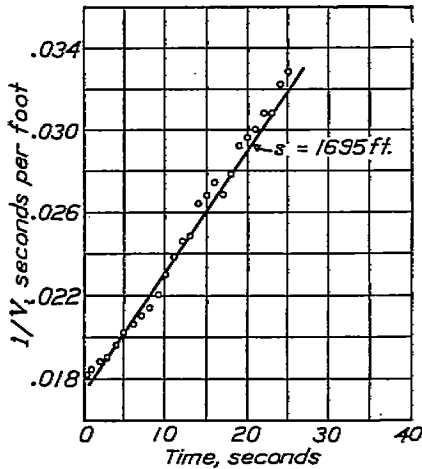


FIGURE 21.—TE-2 deceleration test. Run No. 2

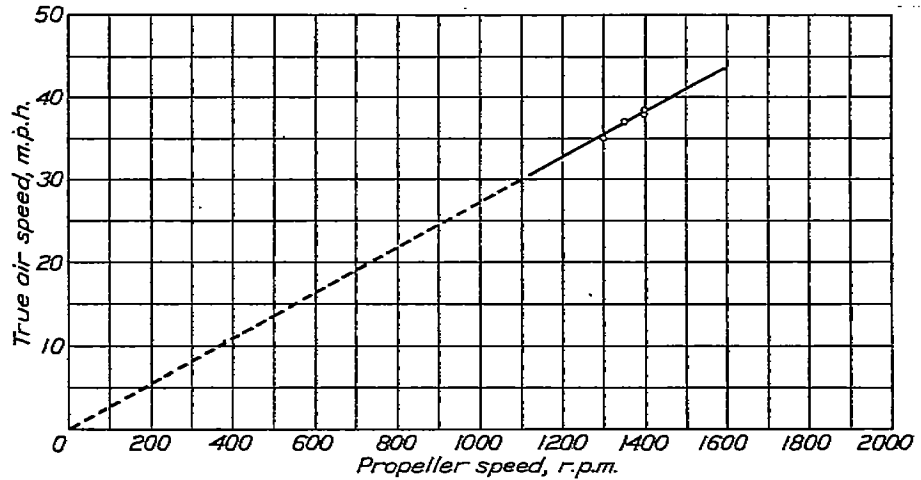


FIGURE 23.—TE-2 airship speed trials. True air speed versus propeller r. p. m.

$\frac{1}{V}$ versus t . The drag coefficients vary from 0.023 for the *Los Angeles* to about 0.045 for the *TE-2*, *Puritan*, and *ZMC-2* airships. Although the variation in coefficients appears to be an irregular but pronounced variation with the inverse of the length-diameter ratio, a comparison of the coefficients on the basis of a single variable is not entirely justified,

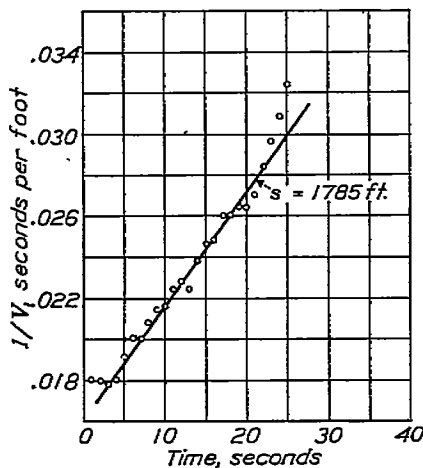


FIGURE 22.—TE-2 deceleration test. Run No. 4

because of the probable effect of such factors as differences in appendages, envelope curvature, and Reynolds Number. The Reynolds Numbers decrease approximately in the same order as the length-diameter ratios, and the variation in Reynolds Number would be expected to account, to some extent, for the general increase in coefficients with decreased length-diameter ratio.

can not be detected indicates that the effect is no greater than the effect of inaccuracies in the data. The same conclusion results from a consideration of Figure 25. This figure shows the variation of total drag coefficient with Reynolds Number determined from tests in the variable density wind tunnel with a bare-hull airship model of length-diameter ratio 5.9. The experimental points represent the values obtained in two tests with this model. All the experimental points obtained are not shown, as several of them practically coincide with those plotted. For the straight portion of the curve $C_D \propto R^n$ where n has a value of about -0.12 . Although the curve has been extrapolated, it probably provides the best indication of the effect of Reynolds Number on the resistance of airship shapes that is now available. Between $R=350 \times 10^6$ and $R=35 \times 10^6$, which is the approximate range covered in the flight tests, the variation in C_D is 0.0048. Such a change in the drag coefficient of the *Los Angeles* would increase it from 0.023 to about 0.028 at the Reynolds Numbers of the small short airships.

The propulsive efficiency E and the propulsive coefficient K for an airship can be calculated by the use of the following expressions:

$$E = \frac{\rho A V^3}{2 \times 550 \times \text{hp}}$$

$$K = \frac{\rho V^4}{550 \times \text{hp}} = \frac{2E}{C_D}$$

The horsepower that appears in these expressions is the power developed by the engines at the air speed V , and thus at the engine speed at which V occurs. In the present case the rated full-throttle power of the engines for the maximum engine speed attained

is known, but it is probable that the actual power delivered in tests was considerably different from the rated power. Owing to the uncertainty regarding the horsepower developed and the fact that errors in V^3 are about three times as great as errors in V , the use of the above expressions would probably lead to ques-

deceleration runs with an airship deliberately pitched by varied amounts would throw some light on this subject. Then, too, there is need for data which will clarify the issue on virtual volume, particularly for blunt shapes. These data could probably be obtained by boundary-layer measurements on an airship of

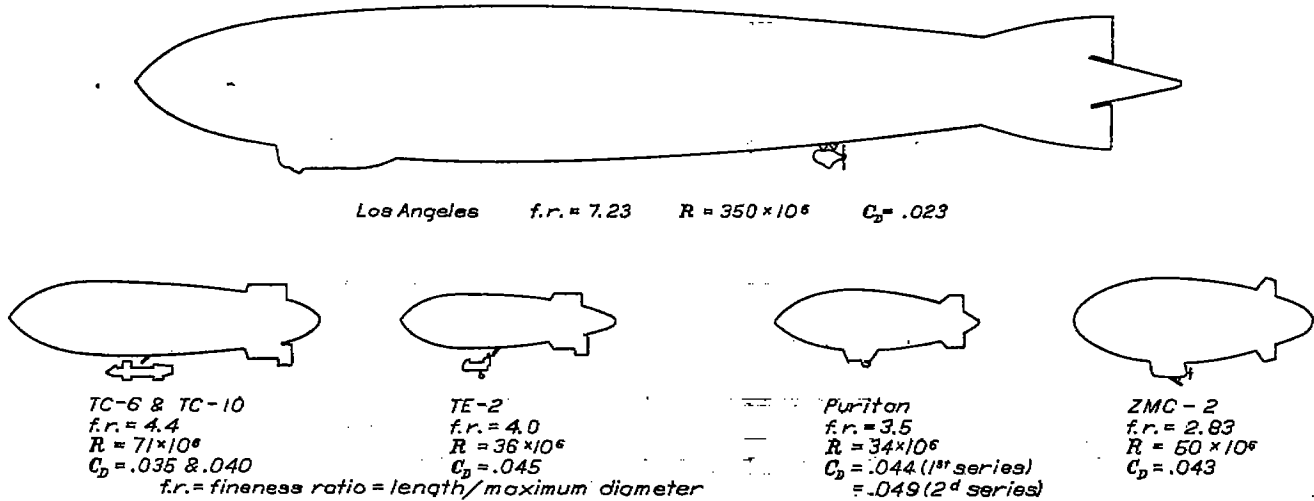


FIGURE 24.—Comparison of airship shapes and drag coefficients

tionable and misleading results. Therefore calculated values of E and K are not included herein.

A consideration of the results impresses one with the fact that there are certain unexplained discrepancies. For instance, the fact that the shape coefficients found for the *Puritan* on different days differ by about 10 per cent and that each series of speed trials with the *TC-6* gave different results has not been explained. Furthermore, it is evident that there is something, a slight pitch or yaw perhaps, that often

small length-diameter ratio. As a solution to the whole problem of accuracy in measuring drag by deceleration tests, it has been proposed that towing tests be conducted with one airship towing another. If such tests could be conducted with the required accuracy, a much needed check on the over-all accuracy of the deceleration method could be obtained.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Langley Field, Va., March 2, 1931.

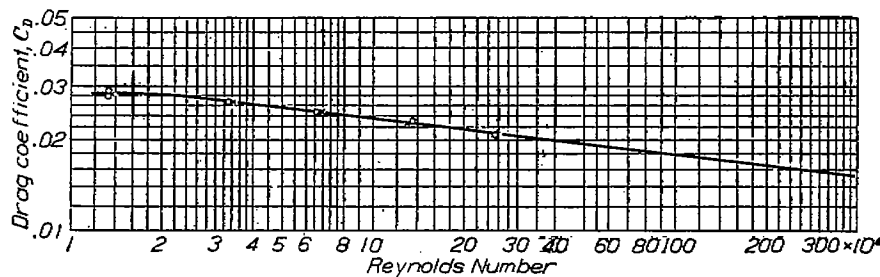


FIGURE 25.—Drag coefficient versus Reynolds Number for a bare-bull airship model. (Length-diameter ratio=5.0)

causes a series of deceleration runs to give widely different results. In fact, in some cases at least one deceleration differed so widely from the average of several more or less consistent runs that it was considered advisable to exclude it in calculating the shape coefficient. Apparently there is need for an investigation of the cause for these discrepancies. It is believed, for instance, that a series of speed trials and

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TABLE I
PROPELLER CHARACTERISTICS

Airship	Number of propellers	Propeller diameter, D (feet)	Nominal pitch, p	p/D	Maximum blade width, b (feet)	b/D	Total drag area, (square feet)
Los Angeles.....	5	11.88	5.44	0.460	0.864	0.0730	39
TC-10.....	2	8.69	5.14	.588	.630	.1083	14
Puritan.....	2	8.25	3.25	.394	.617	.0748	10
ZMC-2.....	2	9.25	4.68	.506	.660	.0713	12
TC-6.....	2	8.60	5.54	.652	.780	.0888	10
TE-2.....	2	7.04	3.92	.567	.718	.1020	15

TABLE II
AIRSHIP CHARACTERISTICS

Airship	Hull volume, cubic feet	Total air volume, cubic feet	Length, feet	Diameter, feet	Length-diameter ratio	k_1	Virtual volume V_v , cubic feet	Drag area A_d , square feet	Drag coefficient C_D
Los Angeles.....	2,760,000	2,840,000	656	90.7	7.23	0.04	2,955,000	463	0.023
TC-10.....	200,600	207,700	195.8	44.5	4.40	.07	222,300	141	.040
Puritan, first test.....	85,870	89,300	127.5	36.4	3.50	.10	98,200	87	.044
Puritan, second test.....	85,870	89,300	127.5	36.4	3.50	.10	98,200	87	.049
ZMC-2.....	202,200	203,300	149.4	52.7	2.83	.13	229,800	149	.043
TC-6.....	200,600	207,700	195.8	44.5	4.40	.07	222,300	124	.035
TE-2.....	80,200	82,900	136	34.0	4.00	.08	89,500	86	.045