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 0.046 for the small blunt airships to 0.083 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.
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
- \( v_0 \) — virtual volume
- \( t \) — time
- \( s \) — characteristic length (a linear quantity determined by the drag characteristics of an airship)
- \( A \) — drag area of airship (\( A = \frac{1}{\rho} \) total drag)
- \( A_p \) — 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 \( \frac{v_0}{\rho} \))
- \( \rho \) — air density (mass per unit volume)

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

\[
\frac{1}{V} = \frac{dt}{d\left( \frac{1}{V} \right)}
\]

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

\[
A = \frac{2v_0}{v} - A_p
\]

and

\[
C_D = \frac{A}{v_0 \rho}
\]

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

\[
v_m = \frac{v_0 + k}{v_0 + k}
\]

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

\[
v_m = \frac{v_0}{v_0 + k}
\]

in which \( v \) includes the total air volume of the envelope and all external parts, and \( k \) 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 \( A \) 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:

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

\[ C_D' = 1.16 - 0.445 \frac{p}{D} \]

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 \( \pm 2 \) per cent.

The manner in which the calculated shape coef-
ficients are affected by various inaccuracies is con-
veniently shown by the following expression:

\[ C_D = \frac{2\pi R^2}{s} \left( 1+k_l \right) \frac{A_p}{\varphi s^2} \]

The first term represents the over-all shape coef-
ficient and the last, the correction for drag of the pro-
pellers 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 \( k_l \). 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 \( \pm 5 \) 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
\((1+k_l)\), 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 \( \pm 3 \)
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 fric-
tion in this respect was neglected, as previously
explained. A value of \( k_l = 0.04 \) was used in the calcu-
lation 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 *TGIO* 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.

The *TGIO* is a conventional nonrigid airship with
an open car and with two engines mounted on outrig-
gers. 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 operat-
ing 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 follow-
ing a given compass course, the keel level, and the
engine speed steady. Level flight was maintained by
the aid of an indicating statoscope 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 \( k_l \) for an ellipsoid of equivalent volume and length is 0.07. The calculated virtual volume is, therefore,

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

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

\[ A_D = 14 + 2 = 16 \text{ square feet} \]

The net drag area is

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

and the shape coefficient

\[ C_D = \frac{141}{(207,700)^{1/3}} = 0.040 \]

The maximum full-throttle speed attained was 49.5 m. p. h. The value of \( \rho \) 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 89,300 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 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

\[ s = 1,900 \text{ feet (first series)} \]

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 \( k_l \) 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 8.—Puffin deceleration test. Run No. 1. (2d series)

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

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

FIGURE 11.—Puffin 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

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

and

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

The shape coefficients for the two cases are

$$C_D = \frac{87}{(89,300)^{1/4}} = 0.044 \text{ (first series)}$$

and

$$C_D = \frac{97}{(89,300)^{1/4}} = 0.049 \text{ (second series)}$$

The values of $\rho$ 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,

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

Therefore, the net drag area is

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

and

$$C_D = \frac{149}{(203,300)^{1/2}} = 0.043$$

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

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

The results of the speed trials with the ZMG-3 airship are shown in Figure 17. The value of $\rho$ for these trials was 0.00225. A maximum air speed of 70.7 m. p. h. was attained at full throttle. The fact 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.
DRAG CHARACTERISTICS OF SEVERAL AIRSHIPS DETERMINED BY DECELERATION TESTS

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

The N. A. C. A. flight-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 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 largely 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

\[ C_d = \frac{124}{(207,700)^{1/2}} = 0.035 \]

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 1,800 r. p. m.
The results of the speed trials are shown in Figure 19. The value of $p$ 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.

![Graph: TO-9 airship speed trials. True air speed versus propeller r. p. m.](image)

**"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 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,

\[ v_n = 1.08 \times 82,900 = 89,500 \text{ cubic feet} \]

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,

\[ C_D = \frac{86}{(82,900)0.045} \]

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 \( p \) 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 can not be detected indicates that the effect is no greater than the effect of inaccuracies in the data.

The Reynolds Numbers decrease approximately in the same order as the length-diameter ratios, and the Reynolds Numbers of the small short airships.

Figure 21—TE-4 deceleration test. Run No. 9

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

\[
E = \frac{\rho A V^2}{2 \times 550 \times \text{hp}}
\]

\[
K = \frac{V \sqrt{\frac{V^2}{2E}}}{550 \times \text{hp} \times \rho}
\]

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 questionable 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 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 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 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.

**REFERENCES**


### TABLE I

<table>
<thead>
<tr>
<th>Airship</th>
<th>Number of</th>
<th>Propeller diameters</th>
<th>Nominal pitch</th>
<th>( \eta/D )</th>
<th>Maximum blade angle, ( b ) (feet)</th>
<th>( \eta/D )</th>
<th>Total drag area, (square feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>5</td>
<td>11.38</td>
<td>5.44</td>
<td>0.039</td>
<td>0.798</td>
<td>0.726</td>
<td>10.63</td>
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<tr>
<td>TC-10</td>
<td>2</td>
<td>8.29</td>
<td>3.53</td>
<td>0.204</td>
<td>0.054</td>
<td>0.060</td>
<td>1.45</td>
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<td>Furtian</td>
<td>7</td>
<td>9.25</td>
<td>5.28</td>
<td>0.196</td>
<td>0.074</td>
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<td>EMC-2</td>
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<td>8.50</td>
<td>3.64</td>
<td>0.226</td>
<td>0.106</td>
<td>0.070</td>
<td>1.18</td>
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<td>7.56</td>
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<td>0.267</td>
<td>0.118</td>
<td>0.097</td>
<td>1.40</td>
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### TABLE II

<table>
<thead>
<tr>
<th>Airship</th>
<th>Hull volume, cubic feet</th>
<th>Total air volume, cubic feet</th>
<th>Length, feet</th>
<th>Diameter, feet</th>
<th>Length diameter ratio</th>
<th>Virtual volume, cubic feet</th>
<th>Drag area, square feet</th>
<th>Drag coefficient, ( C_d )</th>
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<tr>
<td>Los Angeles</td>
<td>2,782,000</td>
<td>2,840,000</td>
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<td>126</td>
<td>1.00</td>
<td>1,800</td>
<td>300</td>
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<tr>
<td>TC-10</td>
<td>300,000</td>
<td>307,700</td>
<td>132.8</td>
<td>44.4</td>
<td>2.92</td>
<td>225,300</td>
<td>141</td>
<td>0.06</td>
</tr>
<tr>
<td>Furtian, first test</td>
<td>36.500</td>
<td>36.300</td>
<td>118.4</td>
<td>126</td>
<td>3.05</td>
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<td>97</td>
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<td>307,700</td>
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<td>44.4</td>
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