NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 318

SPEED AND DECELERATION TRIALS OF U. S. S. LOS ANGELES

By S. J. De FRANCE and C. P. BURGESS

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

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

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

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $=0.07651$ lb./ft.^{3}

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

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

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

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

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

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

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

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

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

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

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

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

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

α, Angle of attack.

ϵ, Angle of downwash.

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NAVY BUILDING, WASHINGTON, D. C.

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By S. J. De France and C. P. Burgess

SUMMARY

The trials reported herein were instigated by the Bureau of Aeronautics of the Navy Department for the purpose of determining accurately the speed and resistance of the U. S. S. "Los Angeles" with and without water recovery apparatus, and to clear up the apparent discrepancies between the speeds attained in service and in the original trials in Germany.

The trials proved very conclusively that the water recovery apparatus increases the resistance about 20 per cent, which is serious, and shows the importance of developing a type of recovery having less resistance.

Between the American and German speed trials without water recovery there remains an unexplained discrepancy of nearly 6 per cent in speed at a given rate of engine revolutions. Warping of the propeller blades and small cumulative errors of observation seem the most probable causes of the discrepancy.

It was found that the customary resistance coefficients C, are 0.0242 and 0.0293 without and with the water recovery apparatus, respectively. The corresponding values of the propulsive coefficient K, are 56.7 and 44.6. If there is any error in these figures, it is probably in a slight overestimate of C, and an underestimate of K. The maximum errors are almost certainly less than 5 per cent.

No scale effect was detected indicating variation of C with respect to velocity.

INTRODUCTION

Less careful deceleration trials in 1925 and 1926 showed the extreme delicacy of such tests, and the necessity for special precautions to attain trustworthy results. The Bureau of Aeronautics accordingly requested the National Advisory Committee for Aeronautics and the Goodyear-Zeppelin Corporation to lend their personnel and apparatus to assist in the proposed trials. Four different instruments for measuring air speed were provided, and were checked by running the airship over a measured triangular course, approximately 10 miles to a leg, in Lower New York Bay.

APPARATUS

The four instruments used for measuring the air speed were: (*a*) The ship's electric air-speed meter of the suspended windmill type, having a wooden windmill about 8 inches in diameter turning a commutator by which a condenser is alternately charged from the ship's electric system and discharged through a galvanometer graduated in knots.

(*b*) The ship's Venturi air-speed meter consisting of a double Venturi tube located about 2 feet from the hull of the ship, abreast of the control car. The manometer with indicating dial graduated in meters per second is mounted in the control car.

(*c*) A Pitot-static tube belonging to the National Advisory Committee for Aeronautics, suspended below the control car by 75 feet of ½-inch flexible metal hose housing two small rubber tubes for transmitting the static and dynamic pressures to the recording apparatus.

(*d*) An apparatus belonging to the Goodyear-Zeppelin Corporation having separate static and impact orifices. The static pressure was obtained by orifices on a light "fish" suspended by a single rubber tube about 40 feet below the control car. In the trials without the water recovery apparatus, the impact head was obtained by a hook tube extending only a few feet from the hull. In the later trials with the water recovery installed, a Pitot-static head was mounted on a V-shaped frame about 19 feet below the bottom of the control car.

Both the National Advisory Committee for Aeronautics and the Goodyear-Zeppelin Pitot-static apparatus were hooked up to the N. A. C. A. recording instrument. The principal elements of the recorder are pressure capsules, each containing a steel diaphragm of high natural period, in which the opposite sides are acted upon by the static and dynamic pressures. The movements of the diaphragm are recorded by a beam of light reflected upon a moving photographic film. This instrument is described in detail in N. A. C. A. Technical Note No. 64. (Reference 1.)

The engine speeds were observed and recorded by the mechanics in the power cars, using the centrifugal tachometers which are parts of the ship's equipment. These tachometers were calibrated during the trials by a portable stroboscope designed and furnished by the Goodyear-Zeppelin Corporation. This instrument is described by Doctor Klemperer of the Goodyear-Zeppelin Corporation as follows: "It consisted of a small electric motor taken from an automobile horn, equipped with a 2-slot shutter disc and centrifugal tachometer of fairly wide dial divisions in the range of the R. P. M. of the tests. Ten R. P. M. differences could be easily recognized by watching the apparent motion of the propeller through the prism and shutter of the stroboscope and adjusting a rheostat so as to prevent the propeller image from rotating in either direction. A 6-volt dry battery furnished the current."

SPEED TRIALS WITHOUT WATER RECOVERY APPARATUS

The speed trials without water recovery apparatus were held on September 2, 1927, over a triangular course between Sandy Hook, Staten Island, and Rockaway. The lengths and compass courses of the three legs of the triangle are as follows:

Leg	Direction, degrees	Length	
		Feet	Nautical miles
AC	343	59, 500	9. 79
CB	100	60, 800	10. 00
BA	222. 5	63, 200	10. 40

Two complete runs were made around this course, in opposite directions, passing directly over the marks at the beginning and end of each leg, with a wide outward turn between successive legs. The observed ground speeds are recorded in Table I. The wind velocity was calculated and compensated by the geometrical construction shown in Figure 4.

The ground speeds are determined from the distance and time on each leg of the course, and plotted as vectors from a single point as in Figure 1; a circle is drawn through the ends of the vectors representing the ground speeds on three successive runs. If the ship's air speed and the wind velocity are constant during these runs, the radius of the circle represents the air speed, and the line from the origin of the vectors to the center of the circle represents the direction and velocity of the wind to the same scale as the ground speed vectors. It is found that one circle can be passed very nearly through the ends of all six vectors, showing that the wind was nearly constant at 10.2 knots from the southwest, and the ship's air speed was 58.4 knots.

The speeds indicated by the four air-speed meters on the ship are summarized in Table II; the agreement between them is quite good. Most reliance is placed upon the N. A. C. A. Pitot-static instrument, which was calibrated in the wind tunnel and in flight just before these trials, and found to be correct to within ± 0.5 M. P. H. at speeds up to 70 M. P. H. It is, therefore, believed that the ship's true air speed was 59.7 ± 0.5 kts. The discrepancy between this figure and the 58.4 kts. calculated from the ground speed is no more than might be expected from irregularities in steering, and lengthening of the course through errors in allowing for drift.

The records of the engine revolutions show that 1,230 R. P. M. was maintained with great constancy during the trial. This was the highest engine speed which it was considered safe to maintain. The runs on the measured course were made at only one speed.

SPEED TRIALS WITH WATER RECOVERY

A series of speed trials with the water recovery apparatus installed in the ship were conducted while returning from Harrisburg to Lakehurst on the night of September 6–7, 1927. Each trial was of four minutes duration. The air speed was observed or recorded by the four instruments used in the previous trials. Since these instruments had already been checked against ground-speed, it was considered unnecessary to attempt to measure the ground speed and wind velocity in these trials.

Runs were made at four different rates of engine revolutions as recorded in Table III. In all speed and deceleration trials except one, the precaution was taken to close all hatches, windows

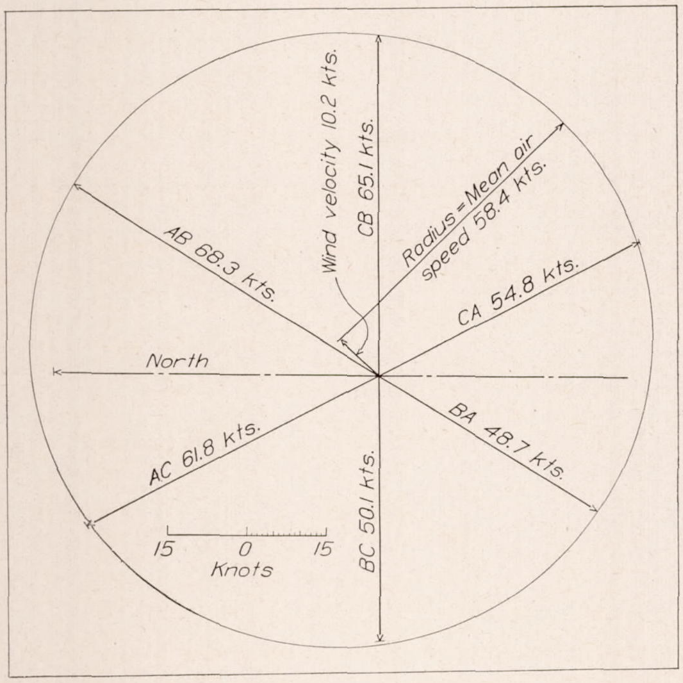

FIGURE 1

and other openings, and to house within the ship the various windmills used for driving the pumps and generators. In the fifth speed run on September 7, at 1,150 R. P. M., the hatches were opened. Table III shows that this reduced the speed by only about half a knot in comparison with the second run at the same R. P. M. In general service, it has several times been observed that the speed at 1,150 R. P. M. is only about 48 to 49 knots, and indeed, this observation was made on this very night of September 6–7, before commencing the speed trials. Since opening the hatches apparently accounts for only about half a knot speed, the remaining 2 knots discrepancy between service and speed trial conditions must be due to other causes. The ship was practically in equilibrium in the service conditions, so that the only explanation appears to be the difference between ordinary steering, and the specially careful steering in the smooth air of the speed trials. It was noted that the air was so ideally smooth in the trials on September 7 that the ship held her course during each of the 4-minute runs with practically no movements of either rudders or elevators.

DECELERATION TRIALS

Four deceleration runs were carried out on September 2, 1927, without the water recovery apparatus; and four on the night of September 6–7, with that apparatus installed. In each series of four runs, the propellers were blocked in the first two runs, and idling in the second two.

The theory of the deceleration test is that when an airship in static equilibrium is moving without power through air at rest or in uniform motion, the resistance is given by:

$$R=m\frac{dv}{dt}=\rho V_m\frac{dv}{dt} \tag{1}$$

where R = the resistance

V_m = the virtual volume

$\frac{dv}{dt}$ = the deceleration.

The virtual volume V_m is the actual air volume inclosed by the ship, plus the additional volume of air carried along externally by the motion of the ship. Lamb has calculated the additional volume coefficients for ellipsoids of various fineness ratios moving in the ideal, non-viscous, incompressible fluid of hydrodynamic theory. Munk has suggested that the additional volume be assumed equal to $\frac{\pi r^3}{3}$ where r is the radius of the largest cross section of the airship. By Lamb's coefficients or Munk's approximation, the virtual volume of conventional airships, such as the *Los Angeles*, is about 4 per cent more than the actual volume. The practice of the Goodyear-Zeppelin Corporation, based upon Karman's theory of frictional resistance is to allow 8 per cent instead of 4 per cent for the additional volume in order to include the air carried along by the frictional wake and the parasite parts. The larger allowance for additional volume seems reasonable, and is adopted in this report.

A customary expression for the resistance of bodies moving in air is

$$R=A\rho v^2/2 \tag{2}$$

where A is an area defined as the area of drag.

Combining expressions (1) and (2),

$$dt/dv=S/v^2 \tag{3}$$

where S is a length equal to 2 V_m/A.

By integration of (3),

$$t=-S/v+B.$$

In a deceleration test starting at $v=v_0$ when $t=0$ $B=S/v_0$, whence at time t and speed v,

$$S=\frac{t}{1/v-1/v_0}.$$

In other words, S is the reciprocal of the slope of $1/v$ plotted against t.

From the definition of S,

$$A=2\ V_m/S \tag{4}$$

The area of drag found in this way includes the drag of the propellers, for which a correction must be made. The propellers of the *Los Angeles* have a diameter of 11.83 feet, a mean blade width of 0.073 times the diameter, and a pitch/diameter ratio of 0.46. They closely resemble Durand's propeller No. 11, for which the experimentally determined drag coefficients are 0.028 when stopped, and 0.048 when spinning freely; whence the areas of drag for the propellers of the *Los Angeles* are:

$$A=2\times0.028\times\overline{11.83}^2=7.84 \text{ sq. ft. for each stopped propeller,}$$

and

$$A=2\times0.048\times\overline{11.83}^2=13.44 \text{ sq. ft. for each idling propeller.}$$

Five times these areas, according to whether the propellers were stopped or idling, are subtracted from the overall drag area to obtain the net drag area of the airship.

The shape coefficient is given by:

$$C=\frac{A}{V^{2/3}}$$

where C = shape coefficient

A = net area of drag

V = actual air volume.

It is assumed in the calculations in this report that $V=2,840,000$ cubic feet and $V_m=1.08\times V=3,070,000$ cubic feet.

The reciprocals of the speeds, and the characteristic lengths S, calculated from the readings or records of the air-speed meters are plotted in Figures 2 to 26. The corresponding values of S, A, and C are summarized in Tables IV to VII.

Inspection of the values of C in Tables IV and V shows that the two recording instruments agreed fairly well. Much less accurate results are to be expected from the readings of the indicating instruments during deceleration tests; and it is obvious from the large discrepancy between the readings of the Venturi meter and the other instruments that there was a lag in the action of the Venturi indicator.

Both recording instruments showed an exceptionally high mean rate of deceleration on the fourth run, and it is probable that there was some disturbance producing erroneous results. Neglecting the fourth run, the mean C without water recovery is 0.0244 according to the N. A. C. A. instrument, and 0.0240 according to the Goodyear-Zeppelin one, or 0.0242 average for both instruments together. The maximum departure of either instrument from this average figure is 2.5 per cent, and the mean departure is 0.9 per cent. This is considered very good for a test of this nature.

In the four runs with water recovery, both recording instruments showed a little more net resistance (after allowing for the propellers) with the propellers blocked than with them idling. This may have been due to some slight delay in blocking the propellers after cutting the ignition. The mean values of C are 0.0288 by the National Advisory Committee for Aeronautics, and 0.0298 by the Goodyear-Zeppelin instrument, or 0.0293 average of both. For some unknown reason, the agreement between the two air-speed meters is not quite so good as in the trials without water recovery. The maximum variation of C according to either instrument from the average of both is 3.75 per cent, and the mean departure is 2.30 per cent.

An interesting point in regard to the motion of the ship during deceleration tests was brought out by Doctor Klemperer after the trials. The elevator man was instructed to keep the ship in horizontal trim during each test, regardless of rise or fall. Stopping the engines appeared to cause a sudden drop of the ship's bow, felt by the personnel, and indicated by the inclinometer. This was thought to be due to removal of the nosing-up couple produced by the thrust of the propellers at a considerable distance below the center of resistance; and it was checked by applying up-elevator. Doctor Klemperer has suggested that the apparent drop of the bow was mainly an illusion due to the initial inertia force of about one-thirtieth of the weight of the ship acting forward, combining with gravity to produce a resultant indistinguishable from the true gravitational force, but actually inclined at about 2° forward of the vertical. According to this theory, the lifting of the elevator turns the ship upward, and probably an oscillating movement follows with some increase in the resistance. The altimeter and variometer readings taken at 1-minute intervals (see Tables VIII and IX) do not show any appreciable vertical movements; but it is possible that there was some such motion during the first 30 seconds, which is the most important part of the deceleration test. It is estimated that 2° pitch would not increase the resistance more than 3 per cent. The lesson for future deceleration trials is to instruct the elevator man to ignore his own sensations and the indications of the inclinometer, but to keep the ship level by observation of some distant object.

SCALE EFFECT

For practical design purposes, it is important to learn as much as possible about scale effect, or the variation of the resistance coefficient with Reynolds Number. It is the practice of some designers to assume that the resistance varies as $(vL)^{1.87}$ instead of as $(vL)^2$. This is equivalent to assuming that C is proportional to $(vL)^{-0.13}$ instead of constant. If this is true, then in a deceleration trial, S should vary inversely as $(1/v)^{0.13}$, or when $1/v$ has twice its initial value, S should be diminished in the ratio of 1 to $2^{0.13}$ or 1/1.094. This change in S can not be detected in the curves of $1/v$ against t; but on the other hand, it is true that at the higher values of $1/v$, the points are rather scattered, and there is so much uncertainty about the exact slope of the line that it is impossible to affirm definitely that there is no appreciable increase in the resistance.

The speed trials are also inconclusive in regard to scale effect. In an airship in steady conditions the propeller thrust is almost exactly proportional to the square of the R. P. M. Figure 26 shows the speed increasing slightly faster than the R. P. M. in the trials without water recovery apparatus, indicating that the resistance varied a little less rapidly than as the square of the speed; or in other words, there was some positive scale effect. On the other hand, in the trials with the water recovery apparatus installed, the speed was observed at several R. P. M. and found to vary slightly less rapidly than as the R. P. M., indicating some negative scale effect.

On the whole, it does not seem unduly conservative in the design of larger and faster ships than the *Los Angeles* to assume that there is no scale effect tending to reduce the value of the drag coefficient C.

COORDINATION OF SPEED AND DECELERATION TRIALS

The customary propulsive coefficient K is defined by:

$$K=\frac{\rho v^3 V^{2/3}}{550 \text{ HP.}}$$

$$=\frac{\rho V^{2/3}}{550}\left(\frac{v}{n}\right)^3 \frac{n^3}{\text{HP.}}$$

where n is the engine revolutions per second, and the other symbols have their usual significance. The horsepower is proportional to ρ and to n^3 when driving a propeller at air speeds proportional to n, as in an airship. It follows that $\rho\, n^3/\text{HP.}$ is constant. According to information furnished by Doctor Klemperer, tests of the engines of the *Los Angeles* in Germany showed that 1,970 HP. is developed at full throttle at 1,360 R. P. M. when $\rho=0.0022$ slugs/cubic feet, whence

$$\frac{\rho V^{2/3} n^3}{550 \text{ HP.}}=\frac{0.0022\times 20{,}000\times \overline{1{,}360}^3}{550\times 1{,}970\times \overline{60}^3}=0.473/\text{cu. ft.}$$

From the curves of speed vs. R. P. M. in Figure 26 of this report, at 1,230 R. P. M., $v/n=4.55$ feet and 4.93 feet, with and without water recovery, respectively. Whence without water recovery,

$$K=0.473\times \overline{4.93}^3=56.7$$

and with water recovery,

$$K=0.473\times \overline{4.55}^3=44.6$$

The propulsive efficiency is given by

$$E=\frac{Rv}{550 \text{ HP.}} \tag{5}$$

where E= the propulsive efficiency, and R= the resistance of the airship. Also

$$R=\frac{C\rho v^2 V^{2/3}}{2} \tag{6}$$

Combining (5) and (6)

$$E=\frac{C\rho v^3 V^{2/3}}{2\times 550 \text{ HP.}}=\frac{CK}{2} \tag{7}$$

Whence, without water recovery,

$$E=\frac{.0242\times 56.7}{2}=68.6 \text{ per cent}$$

and with water recovery,

$$E=\frac{.0293\times 44.6}{2}=65.3 \text{ per cent}$$

The propellers were designed to have an efficiency of 67.5 per cent without water recovery, which agrees well with the 68.6 per cent calculated from these trials in the same condition. The

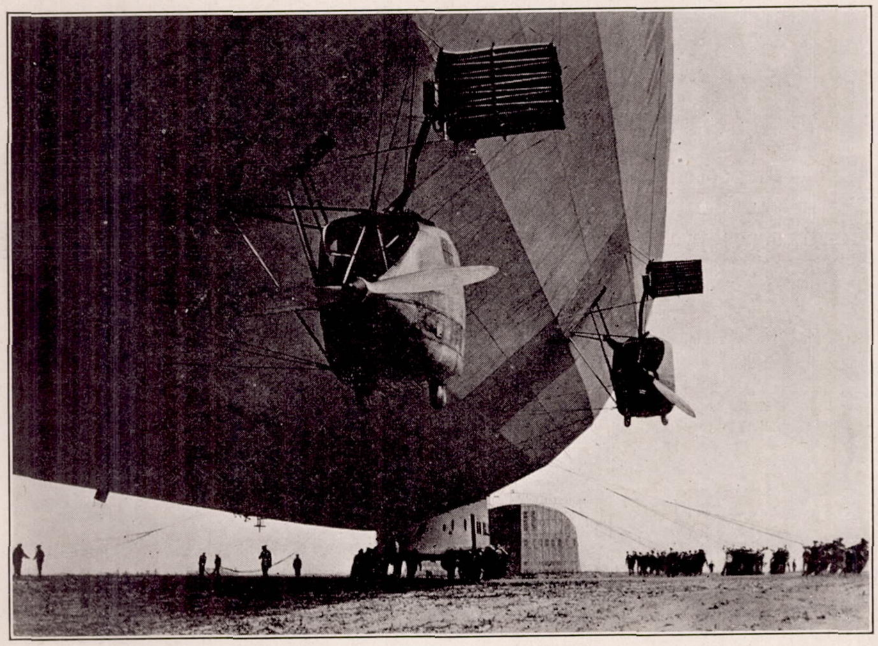

FIGURE 27.—Side power cars and water recovery apparatus of U. S. S. *Los Angeles*

water recovery apparatus increases the slip by reducing the speed, and interferes to some extent with the flow of air to the propellers. Both effects reduce the propulsive efficiency, so that the difference in the efficiencies with and without water recovery is not surprising.

RESISTANCE OF WATER RECOVERY APPARATUS

The deceleration trials showed that the water recovery increased the area of drag 20 per cent, from 488 square feet to 586 square feet. Two of the five units are shown in Figure 27. The actual projected frontal area of the 1-inch diameter tubes constituting the principal cooling elements of the apparatus is only 16 square feet. The headers, water separators, piping, special struts and fittings add approximately 37 square feet to the projected frontal area. A large frictional drag is to be expected from the long headers with their axes parallel to the air flow, and the 45 rows of tubes so placed that they present the frontal area of only one row. Furthermore, the angular arrangement of the tubes in elevation, and their spacing in plan view produces much turbulence, so that the large excess of drag area over frontal area is not surprising.

The increase of drag coupled with the diminished propulsive efficiency with the water recovery involves a loss of 21 per cent in the endurance, or almost as much as the change from hydrogen to helium. Looking at the problem from another point of view, the size would have to be increased about 50 per cent to obtain a ship with the present type of water recovery apparatus capable of the same endurance at a given speed as the *Los Angeles* without that apparatus. This shows the enormous importance of developing a condenser that will use the skin of the ship for cooling area, instead of a system of external tubes as at present.

COMPARISON OF GERMAN AND AMERICAN SPEED AND DECELERATION TRIALS

Speed and deceleration trials of the *Los Angeles* were carried out in Germany when the ship was new and in the hands of her builders, the Luftschiffbau-Zeppelin. At that time there was no water-recovery equipment on the ship. An air speed of 32.5 m/sec. (106.7 ft./sec.) was observed at 1,250 R. P. M. on 4 engines and 1,150 R. P. M. on 1 engine, or a mean of 1,230 R. P. M. for all engines, whence $v/n = 5.20$ feet.

From the German deceleration trials the net area of drag was calculated to be 377 square feet at high speeds and 441 square feet at low speeds. The change from the smaller to the larger area of drag appeared to occur at a critical speed of about 22 m/s, which agrees with the results found by Munk in an analysis of the speed trials of earlier Zeppelin airships. (See N. A. C. A. Technical Report No. 117—Reference 2.) The speeds were measured by Venturi and Pitot tubes suspended 30 feet below the hull. The rates of deceleration indicated by the instruments were much the same as by the Venturi air-speed meter in the American trials without water recovery; and it is suspected that there were errors due to lag of the instruments such as were proved to occur in the Venturi meter in the American trials. If the German figures on speed and deceleration are accepted,

$$C = \frac{A}{V^{2/3}} = \frac{377}{20{,}000} = .01885$$

$$K = .473 \times \overline{5.20^3} = 66.5$$

$$E = \frac{CK}{2} = 62.7 \text{ per cent}$$

This is an improbably low value of E, and confirms the suspicion that C is too small.

Since lag of the instruments affords a very probable explanation of the low rate of deceleration observed in the German trials, the real discrepancy to be cleared up between the German and American trials is the relation of ship's speed to engine revolutions, without water recovery, i. e., it should be explained why $v/n = 5.20$ feet in Germany and $v/n = 4.93$ feet in America.

The difference is less than 6 per cent, but it leads to 17 per cent discrepancy in the apparent value of K, and also of C calculated from K and a known value of E. Some change of v/n might result from slackening of the outer cover, although there appeared to be very little slackness during the American trials. A more probable explanation is warping of the propeller blades, and some difference in a propeller of American manufacture supposed to be copied from the German propeller for which it was substituted, but actually having slightly greater pitch.

Finally, it must be remembered that the discrepancy of 6 per cent in question would result if in the German trials the observations of ship's speed and engine revolution were in error by only 1.5 per cent on the plus and minus sides, respectively, and the opposite errors were made in the American trials. The fact that such small errors involve 18 per cent discrepancy in the apparent value of K shows the great difficulty in determining this coefficient accurately.

Of the three quantities C, K, and E the last is the most definite and certain. For the *Los Angeles* without water recovery, E is undoubtedly close to 67.5 per cent. The calculation of E by the expression $E = CK/2$, using the values of C and K determined by the American trials, gave $E = 68.6$ per cent. Although this is a good agreement, it is not proof of the accuracy of the trial results because it is possible that C and K are in error in equal percentages in opposite directions. If the use of the elevators in the deceleration trials produced an increase in C over the actual value, the true value of K is probably slightly greater than calculated from the observations of speed and engine revolutions in the speed trials.

CONCLUSIONS

The water-recovery apparatus increases the resistance of the *Los Angeles* about 20 per cent, and reduces the propulsive efficiency about 7 per cent. Most of this added resistance could be eliminated by adopting a type of water-recovery apparatus using the surface of the hull for cooling area. Such an apparatus would probably weigh considerably more than the present type, and would have the further disadvantages of less simple and rugged construction and less facility of temperature control.

During deceleration trials, the ship should be kept in level trim by observing a distant object instead of by watching the inclinometer which gives erroneous indications because of the superposition of the longitudinal deceleration upon the acceleration of gravity. Too much use of the elevators in the deceleration trials may have increased the resistance of the ship by about 3 per cent.

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2. Munk, Max M.: The Drag of Zeppelin Airships. N. A. C. A. Technical Report No. 117, 1921.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
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TABLE I.—GROUND SPEEDS OF U. S. S. "LOS ANGELES" ON SPEED TRIALS SEPTEMBER 2, 1927

Leg	Course	Length	Time	Speed	Speed
	Degrees	*Feet*	*Seconds*	*Ft./sec.*	*Knots*
AC	332	59, 500	570	104. 3	61. 8
CB	89	60, 800	552	110. 0	65. 1
BA	211. 5	63, 200	769	82. 3	48. 7
AB	31. 5	63, 200	548	115. 3	68. 3
BC	269	60, 800	718	84. 7	50. 1
CA	152	59, 500	642	92. 6	54. 8

TABLE II.—AIR SPEEDS SHOWN BY FOUR AIR-SPEED METERS IN THE SPEED TRIALS OF SEPTEMBER 2, 1927, WITHOUT WATER-RECOVERY APPARATUS

Run	Leg	Air speed, knots			
		N. A. C. A. instrument	Goodyear-Zeppelin	Electric meter	Venturi meter
1	1	59. 5	60. 5	59. 0	59. 5
1	2	60. 0	61. 0	59. 0	60. 0
1	3	59. 5	60. 7	58. 8	59. 5
2	3	59. 5	60. 5	58. 0	59. 5
2	2	60. 0	61. 2	60. 0	60. 0
2	1	59. 5	60. 3	59. 5	59. 0
Mean	-------	59. 7	60. 7	59. 1	59. 6

The mean ground speeds were 59.0 knots for run 1, and 57.7 knots for run 2.

TABLE III.—AIR SPEEDS SHOWN BY FOUR AIR-SPEED METERS IN THE SPEED TRIALS OF U. S. S. "LOS ANGELES," SEPTEMBER 6–7, 1927, WITH WATER RECOVERY APPARATUS INSTALLED

Run No.	Time run began		R. P. M.	Air speed, knots			
				N. A. C. A. meter	Goodyear-Zeppelin	Electric meter	Venturi meter
	Hours	*Minutes*					
1	23	21	1, 250	56. 0	56. 5	57. 5	55. 5
2	23	30	1, 150	51. 3	51. 5	52. 5	50. 5
3	23	38	1, 050	46. 5	47. 0	49. 0	47. 0
4	23	47	950	41. 0	42. 0	43. 0	42. 0
5	23	59	1, 150	------------	------------	52. 5	50. 0

TABLE IV.—SUMMARY OF DECELERATION TRIALS OF U. S. S. "LOS ANGELES," SEPTEMBER 2 AND 7, 1927, BASED ON N. A. C. A. AIR-SPEED METER RECORDS

Run No.	Condition	Propellers	S	A (total)	A (net)	C
			Feet	*Square feet*	*Square feet*	
1	Without water recovery.	Blocked----	11, 600	529	490	0. 0245
2		---do------	11, 760	522	483	. 0242
3		Idling------	11, 050	556	489	. 0244
4		---do------	10, 520	584	517	. 0259
5	With water recovery.	Blocked----	9, 820	625	586	. 0293
6		---do------	9, 840	624	585	. 0292
7		Idling------	9, 730	631	564	. 0282
8		---do------	9, 650	636	569	. 0285

TABLE V.—SUMMARY OF DECELERATION TRIALS OF U. S. S. "LOS ANGELES," SEPTEMBER 2 AND 7, 1927, BASED ON GOODYEAR-ZEPPELIN AIR-SPEED METER RECORDS

Run No.	Condition	Propellers	S	A (total)	A (net)	C
			Feet	*Feet*	*Feet*	
1	Without water recovery	Blocked----	11, 700	525	486	0. 0243
2		---do------	11, 810	520	481	. 0240
3		Idling------	11, 390	539	472	. 0236
4		---do------	10, 520	584	517	. 0258
5	With water recovery.	Blocked----	9, 500	646	607	. 0303
6		---do------	9, 500	646	607	. 0303
7		Idling------	9, 220	666	599	. 0299
8		---do------	9, 650	636	569	. 0285

TABLE VI.—SUMMARY OF DECELERATION TRIALS OF U. S. S. "LOS ANGELES," SEPTEMBER 2 AND 7, 1927, BASED ON ELECTRIC AIR-SPEED METER READINGS

Run No.	Condition	Propellers	S	A (total)	A (net)	C
			Feet	*Square feet*	*Square feet*	
1	Without water recovery.	Blocked----	11, 600	529	490	0. 0245
2		---do------	10, 900	563	524	. 0262
3		Idling------	9, 530	644	577	. 0288
4		---do------	10, 400	590	523	. 0262
5	With water recovery.	Blocked----	8, 400	731	692	. 0346
6		---do------	8, 850	694	655	. 0327
7		Idling------	9, 150	671	604	. 0302
8		---do------	8, 820	696	629	. 0315

TABLE VII.—SUMMARY OF DECELERATION TRIALS OF U. S. S. "LOS ANGELES," SEPTEMBER 2 AND 7, 1927, BASED ON VENTURI AIR-SPEED METER READINGS

Run No.	Condition	Propellers	*S*	*A* (total)	*A* (net)	*C*
			Feet	*Square feet*	*Square feet*	
1	Without water recovery.	Blocked	12, 800	480	441	0. 0220
2		do	13, 300	462	423	. 0212
3		Idling	13, 400	458	391	. 0195
4		do	13, 700	448	381	. 0191
5	With water recovery.	Blocked	13, 400	458	419	. 0209
6		do	12, 220	502	463	. 0232
7		Idling	12, 500	491	424	. 0212
8		do	13, 600	451	384	. 0192

TABLE VIII.—GENERAL DATA

[Taken on deceleration trials, September 2, 1927, without water recovery]

Time	Temperature	Humidity	Altitude	Elevator angle	Pitch angle	Variometer fifth of meter/second
FIRST RUN						
Minutes	° *F.*	*Per cent*	*Feet*	*Degrees*	*Degrees*	
0	68	88	1, 675	0	0	R1
1	68	88	1, 725	U3	D½	R1
2	68	88	1, 740	U5	U½	R1
3	68	88	1, 840	U5	0	R2
SECOND RUN						
0	69	90	1, 710	U4	D½	0
1	69	90	1, 790	U4	0	R1
2	69	90	1, 825	U3	0	R2
3	69	90	1, 900	U6	0	R2
THIRD RUN						
0	70	90	1, 750	0	0	R1
1	70	90	1, 850	U5	0	R3
2	70	90	1, 900	U7	0	R1½
FOURTH RUN						
0	71	89	1, 700	0	D½	R1
1	71	89	1, 775	U5	0	R2
2	71	89	1, 875	U8	0	R3

TABLE IX.—GENERAL DATA

[Taken on deceleration trials, September 7, 1927, with water recovery]

Time		Temperature	Altitude	Elevator angle	Pitch angle	Variometer fifth of meter/second
Min.	*Sec.*	*° F.*	*Feet*	*Degrees*	*Degrees*	
FIFTH RUN						
0		64	3, 100	2½D	0	R1
1		64	3, 150	5U	0	R1
2		64	3, 150	2U	0	0
3		64	3, 150	0	0	0
SIXTH RUN						
0	0	64	3, 000	4D	0	F1
	20	64	3, 010	4U	0	R2
	40	64	3, 050	0	0	R1
1	00	64	3, 050	3U	0	0
1	20	64	3, 050	5U	0	0
1	40	64	3, 050	4U	0	0
2	00	64	3, 050	0	0	0
SEVENTH RUN						
0	0	64	3, 040	5D	2D	F1
	20	64	3, 025	0	0	0
	40	64	3, 025	5U	0	0
1	00	64	3, 025	5U	0	0
1	20	64	3, 040	5U	0	0
1	40	64	3, 040	0	0	0
2	00	64	3, 040	4U	0	0
EIGHTH RUN						
0	0	64	3, 040	1D	0	0
	20	64	3, 040	0	0	R1
	40	64	3, 040	1D	0	R1
1	00	64	3, 075	5U	0	0
1	20	64	3, 070	0	0	R1
1	40	64	3, 070	7U	0	0
2	00	64	3, 070	4U	0	0
2	20	64	3, 100	10U	1D	0

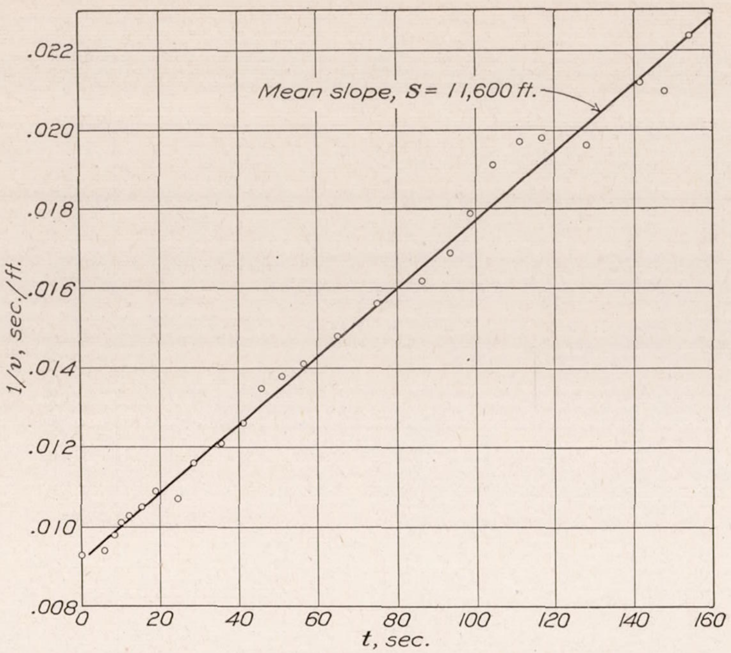

FIGURE 2.—Run No. 1. Deceleration without water recovery. Propellers stopped. Speeds by electric meter

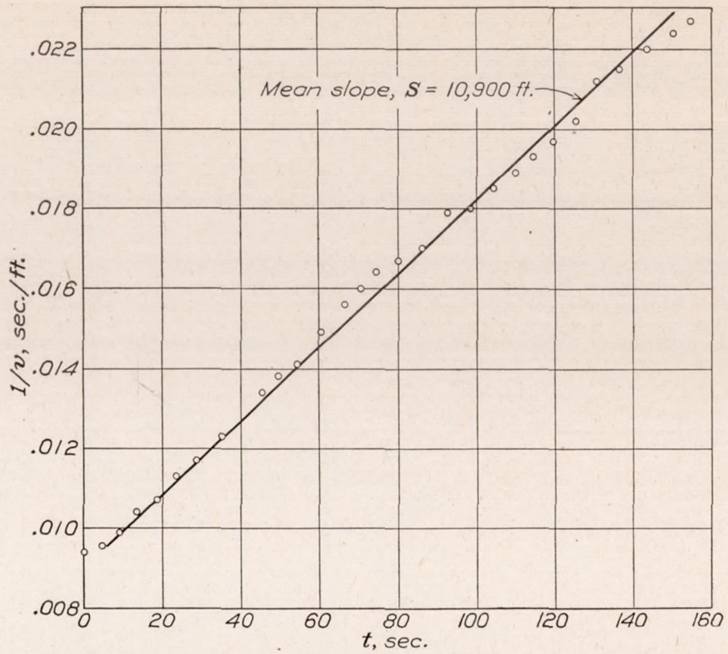

FIGURE 3.—Run No. 2. Deceleration without water recovery. Propellers stopped. Speeds by electric meter

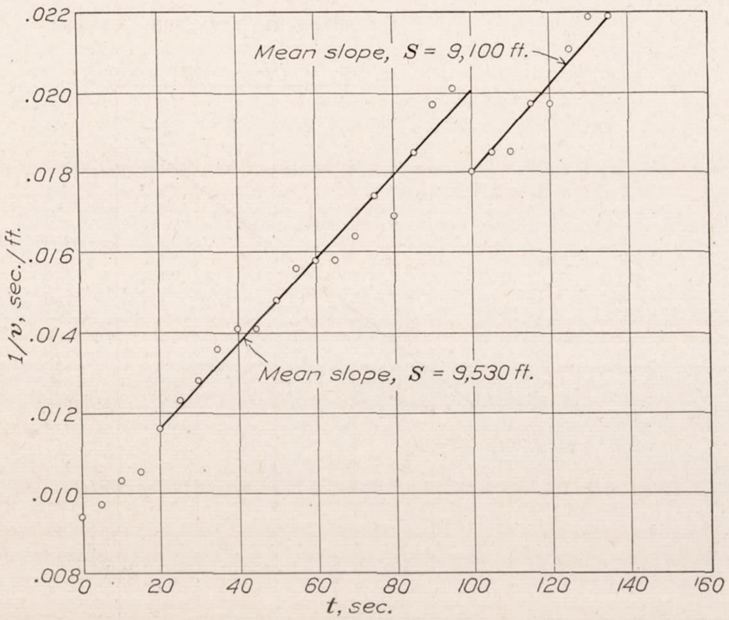

FIGURE 4.—Run No. 3. Deceleration without water recovery. Propellers idling. Speeds by electric meter

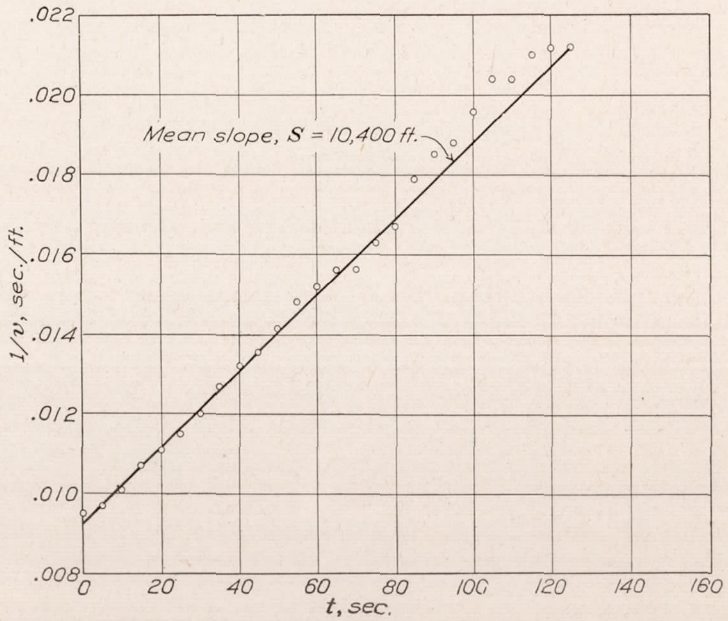

FIGURE 5.—Run No. 4. Deceleration without water recovery. Propellers idling. Speeds by electric meter

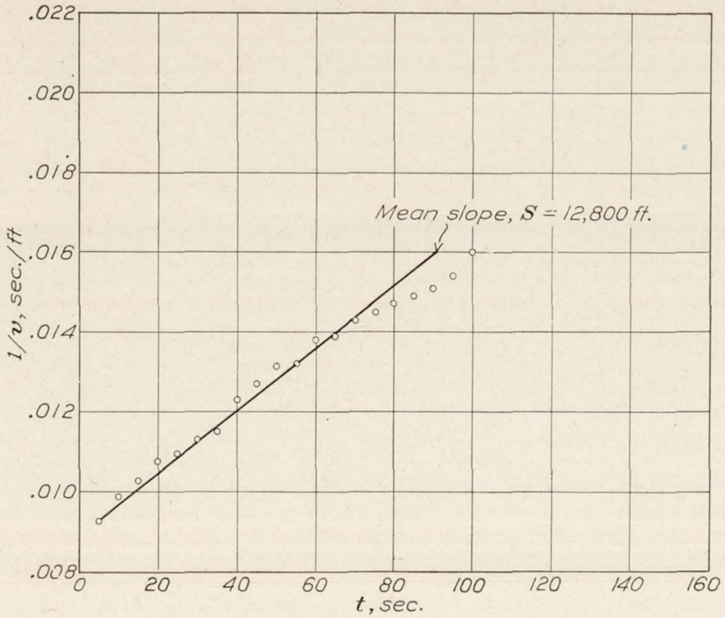

FIGURE 6.—Run No. 1. Deceleration without water recovery. Propellers stopped. Speeds by Venturi meter

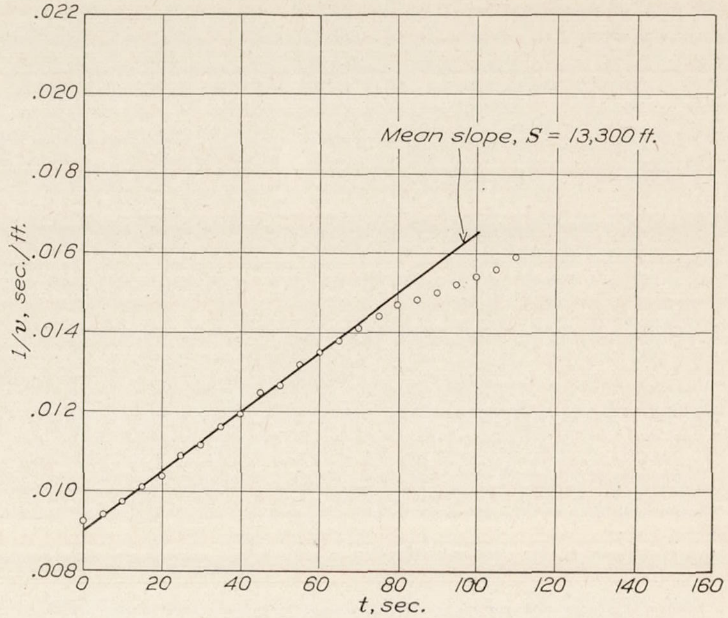

FIGURE 7.—Run No. 2. Deceleration without water recovery. Propellers stopped. Speeds by Venturi meter

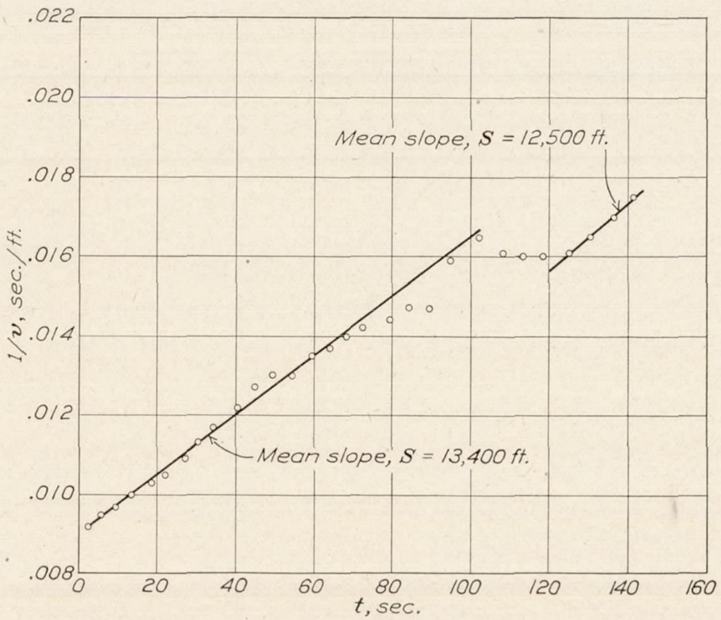

FIGURE 8.—Run No. 3. Deceleration without water recovery. Propellers idling. Speeds by Venturi meter

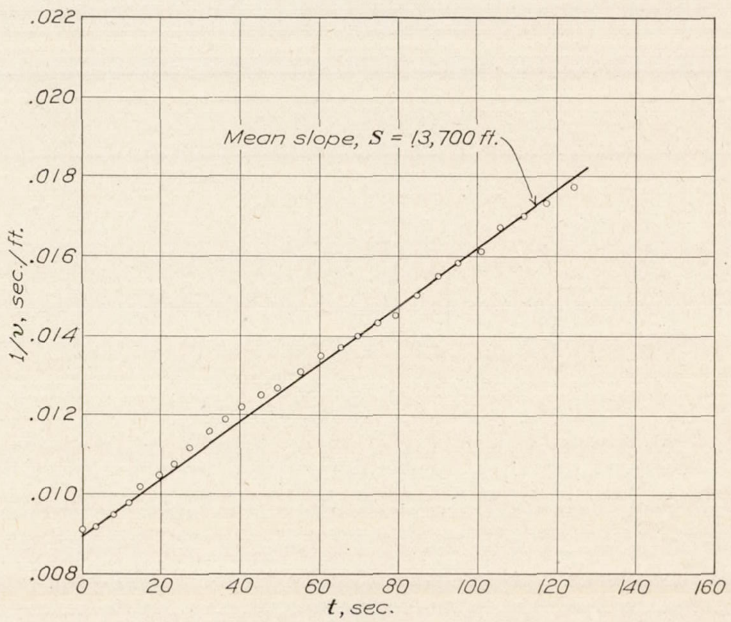

FIGURE 9.—Run No. 4. Deceleration without water recovery. Propellers idling. Speeds by Venturi meter

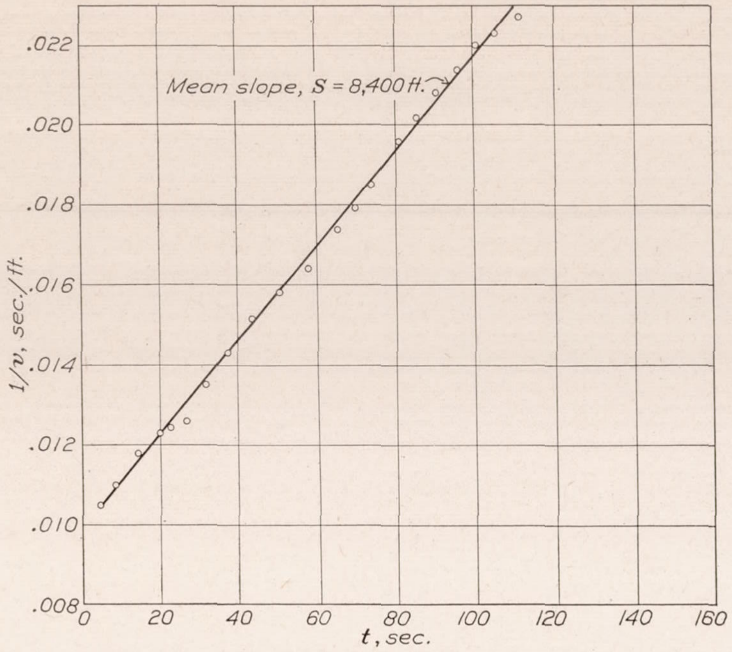

FIGURE 10.—Run No. 5. Deceleration with water recovery. Propellers stopped. Speeds by electric meter

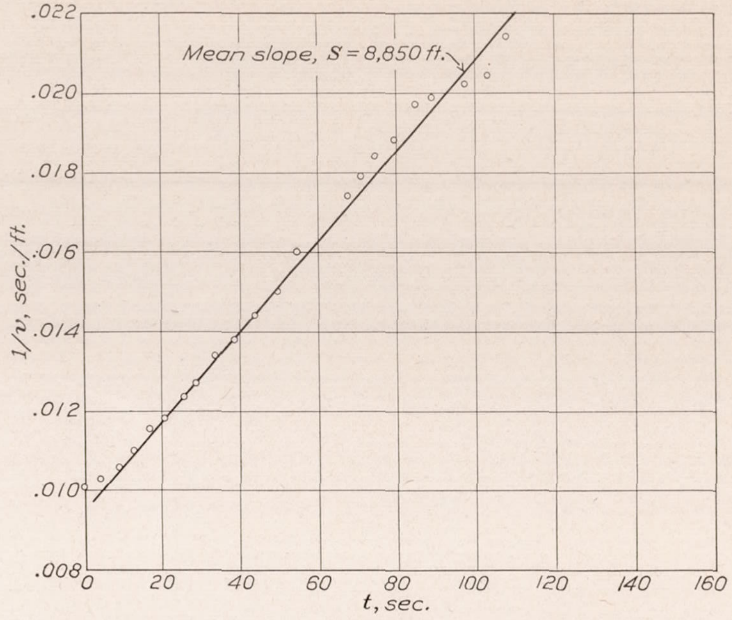

FIGURE 11.—Run No. 6. Deceleration with water recovery. Propellers stopped. Speeds by electric meter

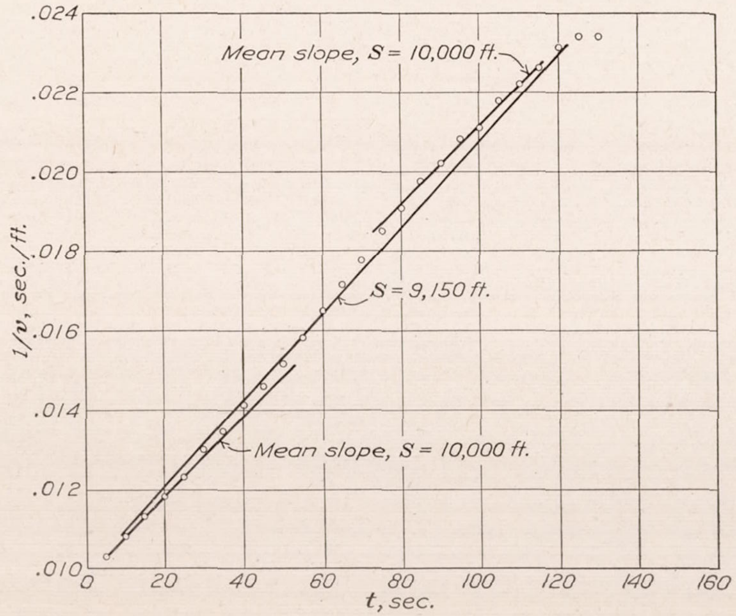

FIGURE 12.—Run No. 7. Deceleration with water recovery. Propellers idling. Speeds by electric meter

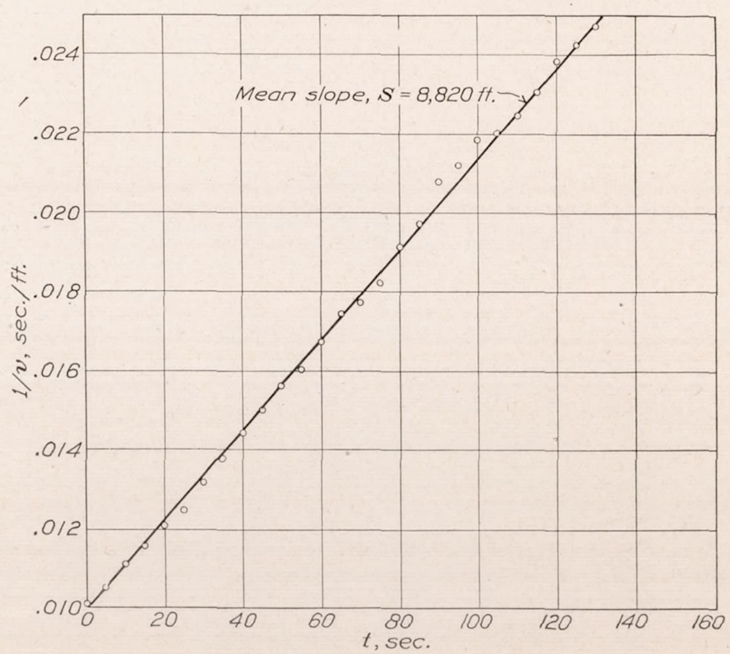

FIGURE 13.—Run No. 8. Deceleration with water recovery. Propellers idling. Speeds by electric meter

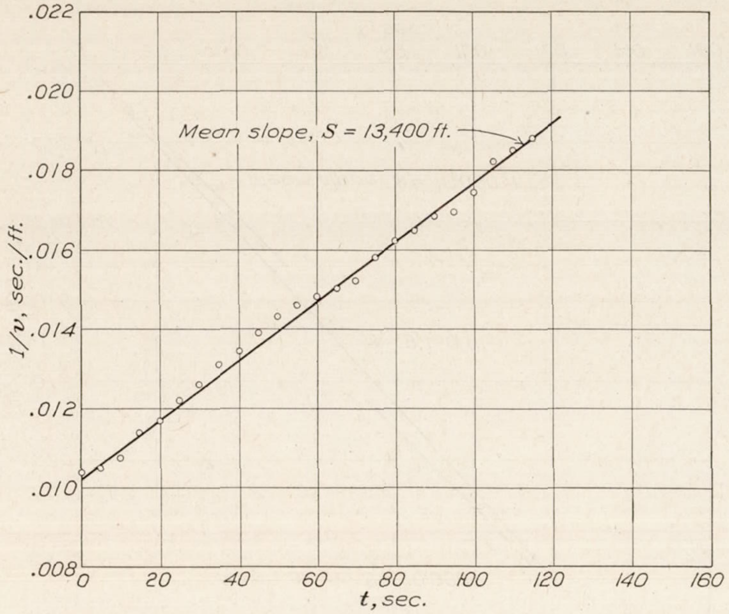

FIGURE 14.—Run No. 5. Deceleration with water recovery. Propellers stopped. Speeds by Venturi meter

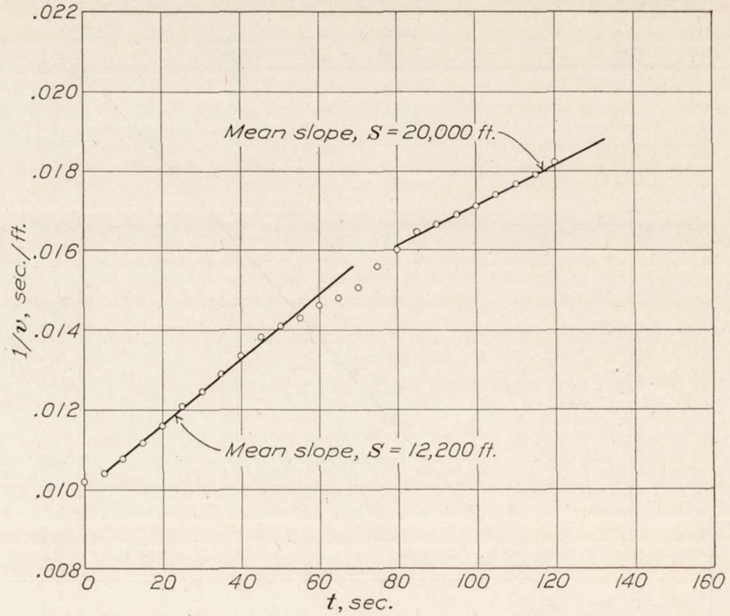

FIGURE 15.—Run No. 6. Deceleration with water recovery. Propellers stopped. Speeds by Venturi meter

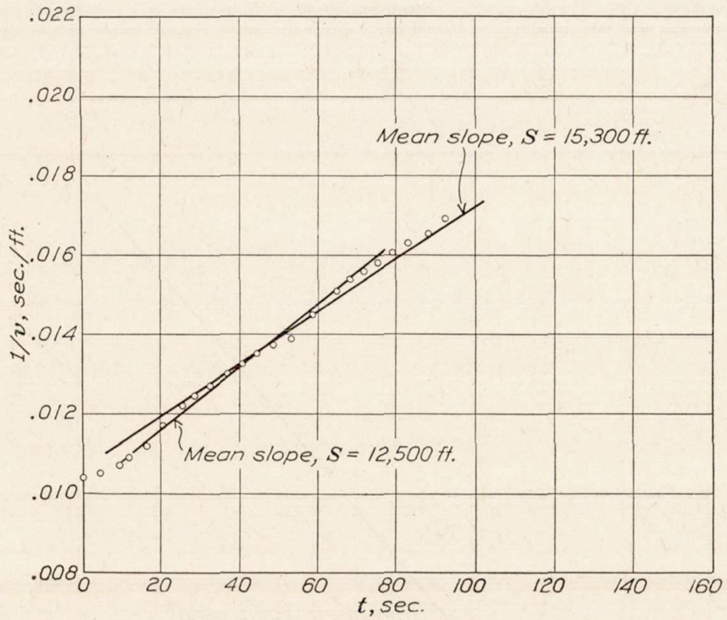

FIGURE 16.—Run No. 7. Deceleration with water recovery. Propellers idling. Speeds by Venturi meter

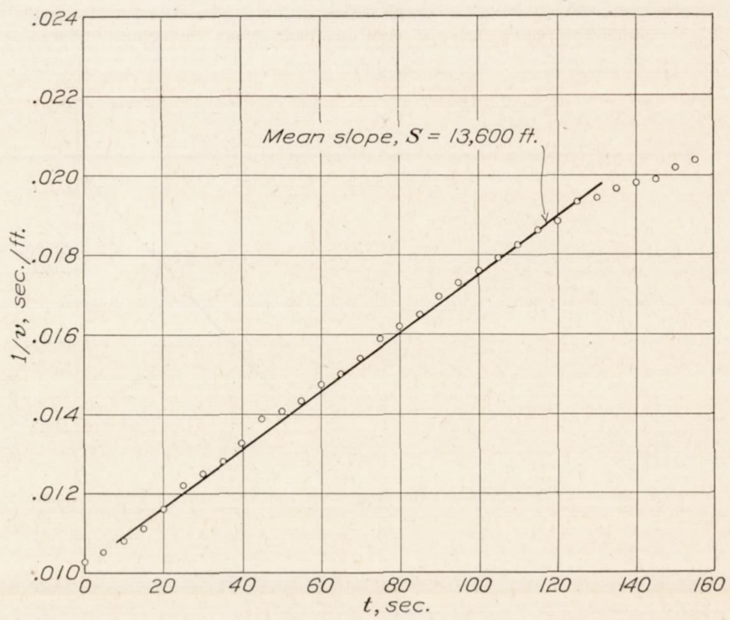

FIGURE 17.—Run No. 8. Deceleration with water recovery. Propellers idling. Speeds by Venturi meter

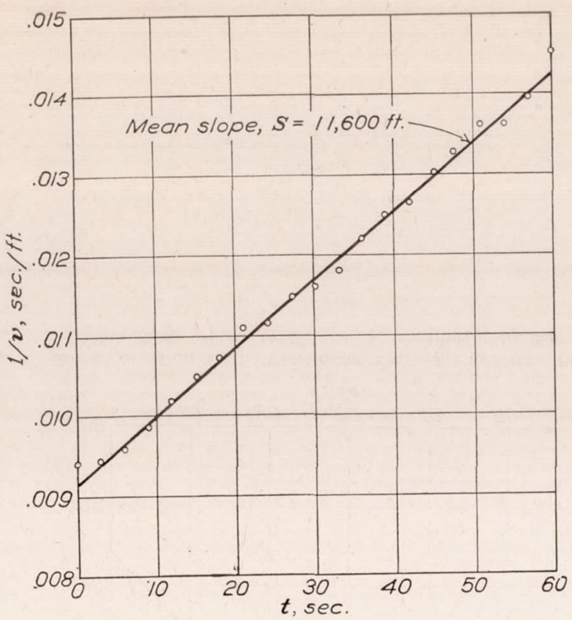

FIGURE 18.—Run No. 1. Deceleration without water recovery. Propellers stopped. Speeds by N. A. C. A. recording instrument

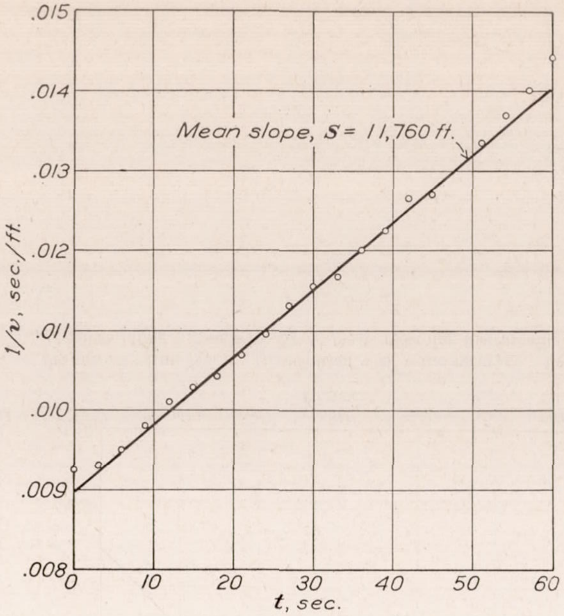

FIGURE 19.—Run No. 2. Deceleration without water recovery. Propellers stopped. Speeds by N. A. C. A. recording instrument

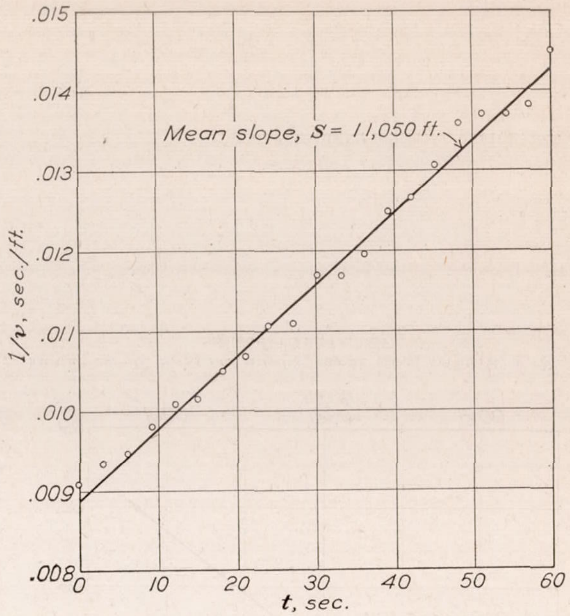

FIGURE 20.—Run No. 3. Deceleration without water recovery. Propellers idling. Speeds by N. A. C. A. recording instrument

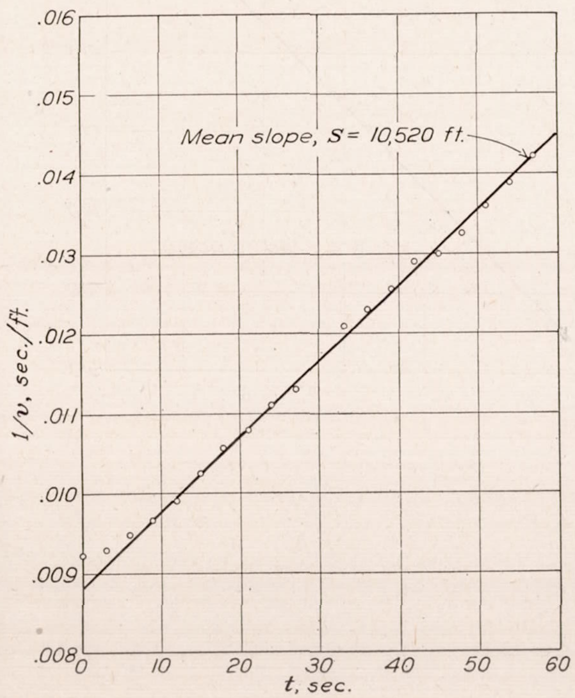

FIGURE 21.—Run No. 4. Deceleration without water recovery. Propellers idling. Speeds by N. A. C. A. recording instrument

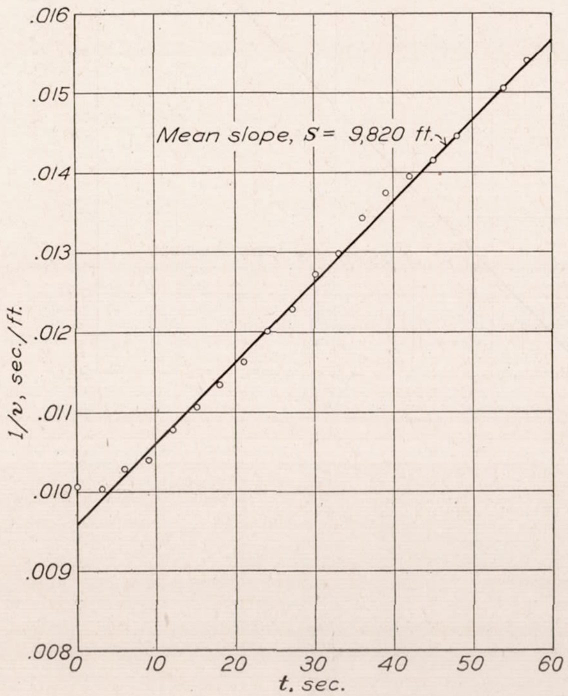

FIGURE 22.—Run No. 5. Deceleration with water recovery. Propellers stopped. Speeds by N. A. C. A. recording instrument

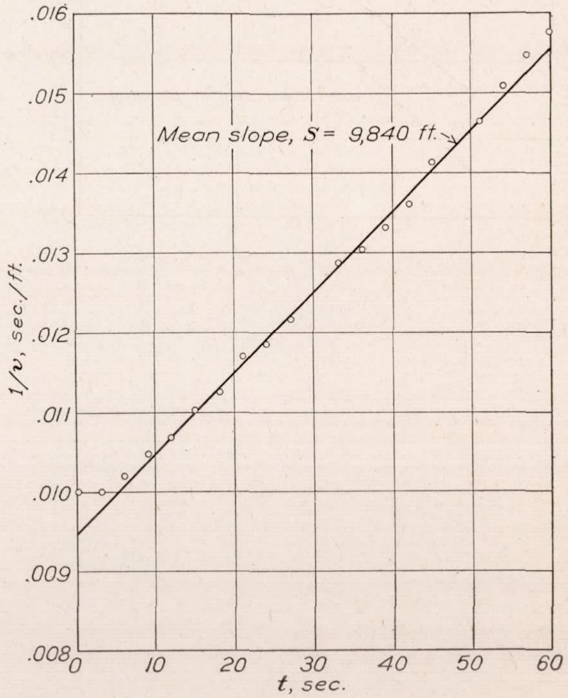

FIGURE 23.—Run No. 6. Deceleration with water recovery. Propellers stopped. Speeds by N. A. C. A. recording instrument

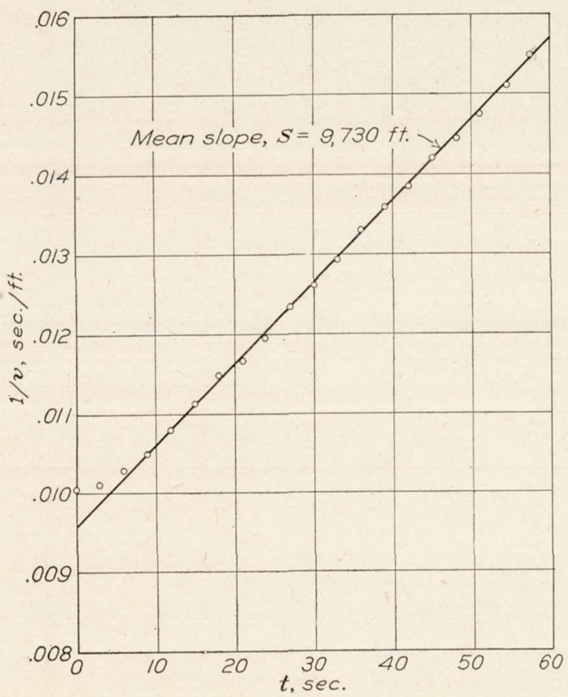

FIGURE 24.—Run No. 7. Deceleration with water recovery. Propellers idling. Speeds by N. A. C. A. recording instrument

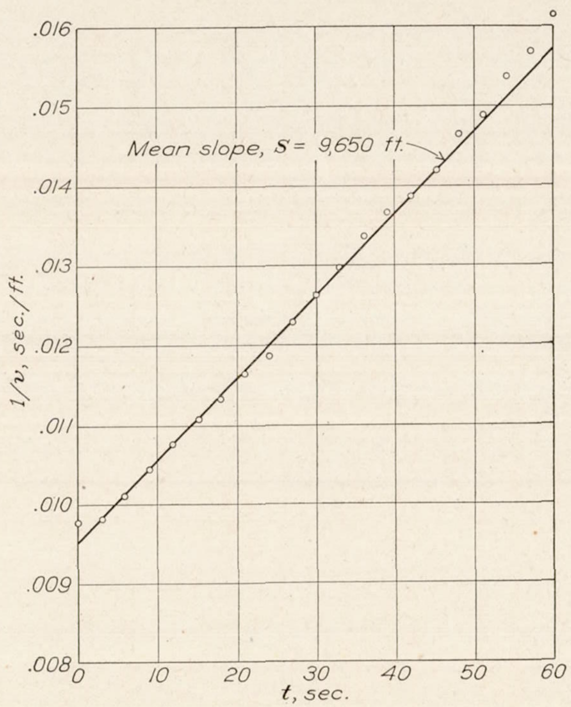

FIGURE 25.—Run No. 8. Deceleration with water recovery. Propellers idling. Speeds by N. A. C. A. recording instrument

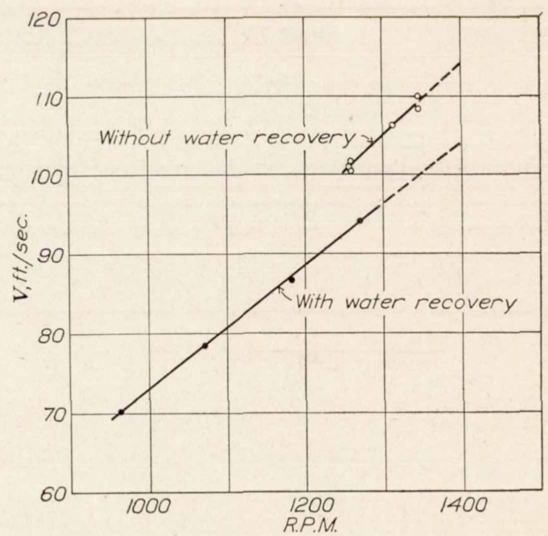

FIGURE 26.—U. S. S. *Los Angeles* true air speed versus R. P. M. September 2 and 6, 1927

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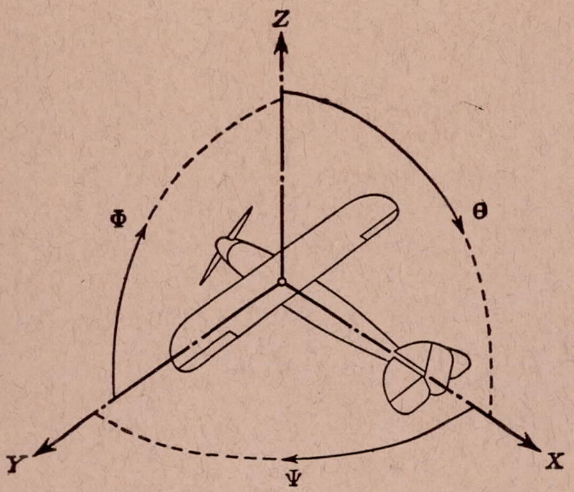

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

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

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.