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PRELIMINARY EXPERIMENTS TO DETERMINE SCALE AND SLIP STREAM EFFECTS ON A 1/24TH SIZE MODEL OF A JN4H BIPLANE

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PRELIMINARY EXPERIMENTS TO DETERMINE SCALE AND SLIP STREAM EFFECTS ON A 1/24TH SIZE MODEL OF A JN4H BIPLANE

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PRELIMINARY EXPERIMENTS TO DETERMINE SCALE AND SLIP STREAM EFFECTS ON A 1/24TH SIZE MODEL OF A JN4H BIPLANE.

By D. L. Bacon

SUMMARY.

The following report gives lift, drag, and longitudinal moment values obtained in tests of a particularly accurate model over a wide range of speeds. A measure of the slip stream corrections on lift and drag forces was obtained by the use of a power-driven model propeller.

The results are plotted, together with corresponding free flight data from Report No. 70, against the parameter *VL*.

Measurements were also made of forces and longitudinal moments for all angles from 0° to 360°.

INTRODUCTION.

This work was undertaken at the Langley Field Aerodynamic Laboratory of the National Advisory Committee for Aeronautics to obtain results on a small model of a complete airplane which might be used for comparison with corresponding tests made in full flight. Somewhat similar tests have been previously made at various other laboratories;[1] but, as certain discrepancies exist between corresponding tests in different tunnels, it has been deemed advisable to obtain a direct comparison for this particular installation.

The present work covers tests on a 1/24th scale model at speeds varying from 6.7 m./sec. (15 m. p. h.) to 40.2 m./sec. (90 m. p. h.). A slip stream correction has been obtained by the use of a small belt-driven propeller mounted in front of the model, and force coefficients thus obtained are compared with the measurements of the same forces made in full flight on a geometrically similar airplane.

EXPERIMENTAL METHODS.

These researches were carried out on an N. P. L. type balance[2] in the 5-foot wind tunnel at Langley Field. The model was built to the mean of actual measurements taken from the two full-size airplanes with which its characteristics are compared. The aluminum wings are everywhere within .002″ of the specified ordinates, the body and wheels within .010″, the engine compartment and engine are accurately represented and the radiator, made of a perforated brass plate, is so proportioned that its resistance per unit area is equal to that of a full-sized radiator. This fact was properly verified by a special test of the radiator alone. The air passing through the radiator circulates about the sump of the model engine and leaves the compartment in the same manner as with the full-sized airplane. The tail surfaces are cambered and the struts are to scale.

The truss and control wires have been omitted from the model, as have also the control horns, because the resistances of these parts can more readily be measured in full-sized tests of the individual members. This numerical addition of a separately determined drag has been fully justified by other experiments which show the interference effects to be negligible. The resistance of these omitted parts, amounting to .036 kg./m./sec. at full scale, or about 20 per cent of the total drag at low angles, has therefore been calculated by means of the usual coefficients,[3] and added to the values of drag as measured.

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[1] Notably at the R. A. E. See A. C. A. R. & M. 656.

[2] For description see N. A. C. A. Report No. 72.

[3] U. S. Navy Aircraft Design Data.

As serious difficulty was encountered in previous experiments with deflection of the model and balance spindle, while testing at high speeds, a system of wire bracing was adopted which held the model with great rigidity in the desired position. Although this bracing proved highly satisfactory, the internal stresses in the model became so high at 90 m. p. h. (40.2 m./sec.) that it was thought incompatible with the safety of the model to increase the speed beyond this point.

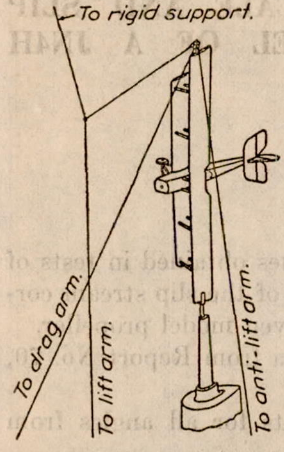

FIG 2.—Model set up for lift and drag runs.

The bracing used while measuring pitching moments is shown in Fig. 1. A mast is inserted in the upper extremity of the wing opposite to the holding spindle and in line with it. This mast is held in a bearing wired to the walls of the tunnel, thus permitting free rotation and ensuring that the Y axis of the airplane remains parallel to the axis of the balance.

While determining lift and drag forces a second method of wire bracing illustrated in Fig. 2 was employed. The mast was retained on the upper wing tip, and from it one wire was lead directly to the drag arm of the balance and another to the antilift arm. An equally simple method could not be used, however, on the lift arm because of interference with the lower wing. In place of this, wires leading from the model and from the lift arm were spliced to a ring which in turn was supported by a wire from the wall of the chamber. It is obvious that if the line of action of this latter wire passes through the pivot of the balance and if it lies in the plane of the lift arm the tension in the wire adds somewhat to the stability of the balance but does not otherwise affect its readings. In aligning these wires no painstaking measurements need be made of their various angles, the position of the external fastening need only be adjusted by trial until a change in the tension in the wire attached to it is found to have no effect on the equilibrium of the balance.

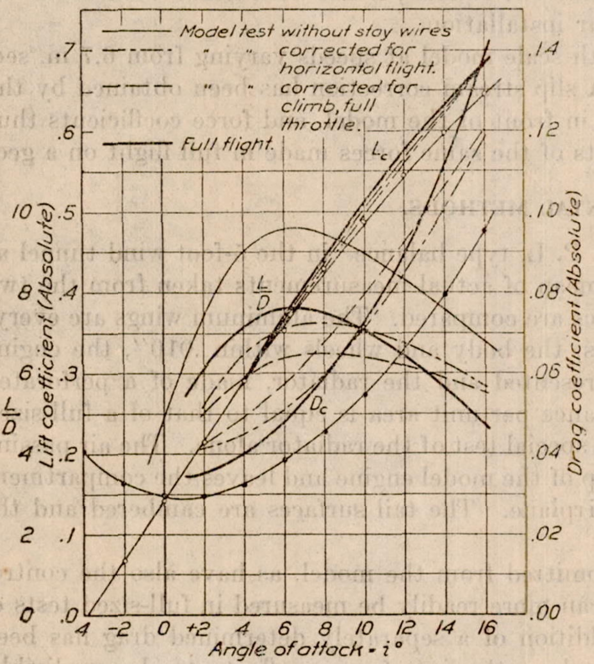

FIG. 4.—Results of model tests at VL=22.5 $\frac{m^2}{sec.}$ VL=16.5 M. P. H. × ft.

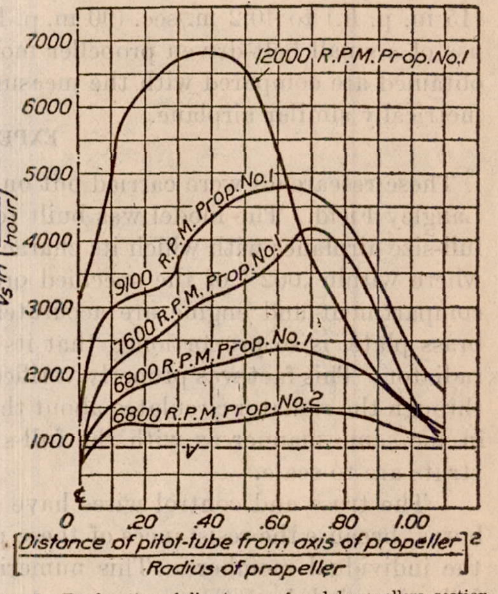

FIG. 5.—Exploration of slip stream of model propellers, section one diameter behind propeller.

The crude but satisfactory device used to reproduce slip stream effect upon the model consisted of a belt-driven ball-bearing spindle carrying a 4¼″ wooden propeller in its proper position relative to the model, as shown in Fig. 3. Because of the relatively low speeds at which the propeller was driven it was necessary to use a comparatively steep pitch and wide blade in

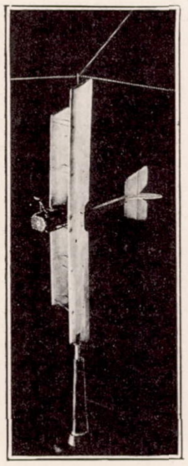

FIG. 1.—MODEL SET UP FOR MOMENT RUNS.

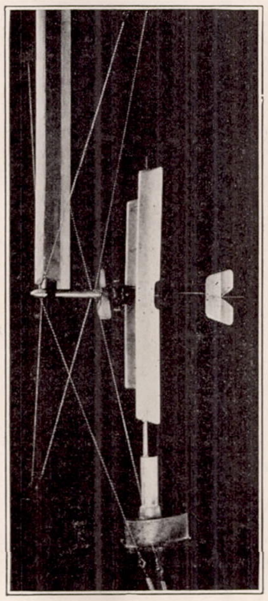

FIG. 3.—MODEL SET UP FOR SLIP STREAM CORRECTION.

order to obtain the desired slip stream velocities. A propeller geometrically similar to that used in full flight would require a rotational speed varying from 15,000 to 40,000 r. p. m., which was above the range available when these tests were made. The high pitch of the propeller used undoubtedly increased the rotation of the slip stream but this is of relatively small importance. Apparatus is now being developed for turning a model propeller at strictly proportionate speeds.

Two different propellers were used having different pitches. In order to determine the actual slip stream velocities (V_s) a complete traverse of the slip stream area was made, one diameter behind the blade, and the square root of the mean value of V_s^2 when plotted against the square of the distance from the propeller axis in terms of the radius, taken as the nominal slip stream velocity (see Fig. 5).

In order to determine the appropriate values of $\frac{V_s}{V}$ for all angles of flight, a similar exploration was made of the slip stream in actual flight, taking simultaneous readings of V, V_s, and r. p. m. of the propeller. This was done under two conditions of flight, namely, horizontal flight in which the throttle is wide open at maximum speed, gradually closed until the speed of minimum power is reached near $i = 6°$, and then opened wide at minimum speed. The second series was made at wide throttle, beginning with high speed horizontal flight, then pulling the airplane up through its entire range of climbing angles and ending with minimum speed in horizontal flight. The two curves thus intersect at maximum and minimum flying speeds. The values of $\frac{V_s}{V}$ thus determined are plotted against both angle of attack and flying speed in Fig. 6. A few points computed on the basis of the momemtum theory are plotted for comparison.

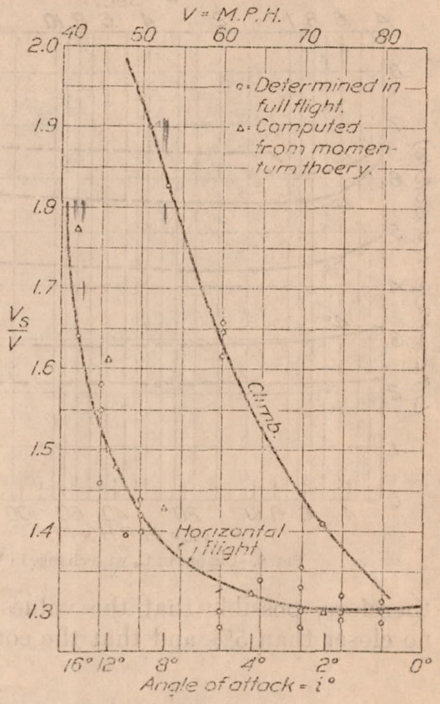

FIG. 6.—Slip stream velocity from free flight tests.

In measuring the lift and drag increments caused by the slip stream, a constant tunnel speed of 13.4 m./sec. (30 m. p. h.) was maintained and a number of different slip stream speeds produced by changing the rate of revolution or the pitch of the propeller. Data were thus obtained for a large range of $\frac{V_s}{V}$ ratios at each angle of attack. For the present report, however, only those force measurements for values of $\frac{V_s}{V}$ corresponding to horizontal flight and to climb with wide open throttle have been used. These are shown in Fig. 7, where the force increment due to the slip stream in per cent of the force on the model without slip stream is plotted against the angle of attack.

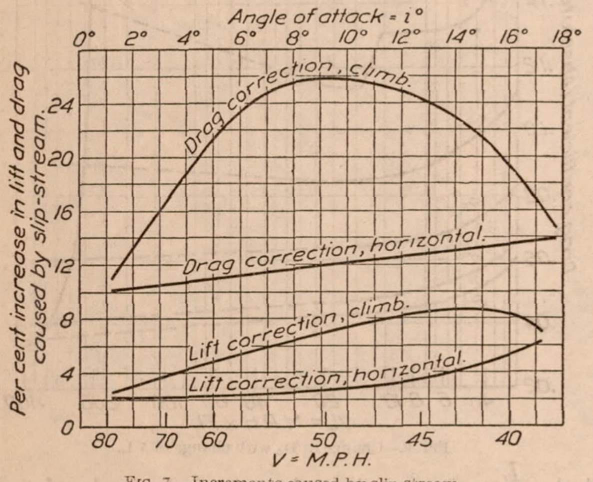

FIG. 7.—Increments caused by slip stream.

ACCURACY OF DATA.

Lift and drag measurements have a precision of approximately 1% except for drag values near the angle of maximum $\frac{L}{D}$, where the error in drag may be as great as 3%, due to inherent difficulties of measurement.

Air speed measurements during these tests were made by means of a side plate orifice previously calibrated against the N. P. L. standard pitot tube belonging to the Massachusetts Institute of Technology, assuming a constant of 1.00. The steadiness of flow was of the order of ±1% at all speeds.

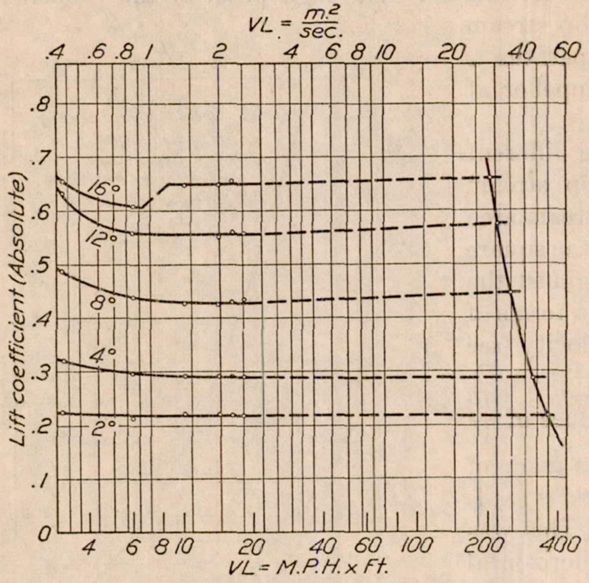

FIG. 8.—Change in L_c with change in VL.

Spindle drag and interference corrections were obtained by the method outlined in N. A. C. A. Technical Note No. 37. The additional drag of the bracing wires was determined by removing the model and supporting these wires from an extension spindle. No interference effects due to the wires could be detected.

In order to get an idea of the change in angle of attack through warping of the model at high air speeds, the upper end of the top wing was observed through a telescope. The warp was estimated at one-fourth of one degree.

The difficulty of accurately measuring either drag force or angle of attack during full flight tests, especially in the neighborhood of maximum and minimum flying speeds, is such that serious errors may be introduced. It is, therefore, possible that the values given in report No. 70 of lift on the full size airplane are no closer than 5% and that the corresponding drag values may be 20% in error.[4]

DISCUSSION OF RESULTS.

A representative set of curves for a single speed is shown in Fig. 4. The heavy lines shown on this chart are those of standard wind tunnel tests and do not include either slip stream or stay wire corrections. The corresponding dotted lines indicate the effect of adding calculated drag for parts not included on the model and the increase in both lift and drag forces due to the slip stream. Emphasis should be laid on the very considerable increase in drag when climbing, caused by the slip stream. The customary method of calculating the rate of climb by the formula:

$$\text{Rate of climb in ft./min.} = \frac{33{,}000 \times (\text{Reserve horsepower})}{\text{Total weight of airplane}}$$

where reserve horsepower is taken as the difference between the horsepower required for horizontal flight and the thrust horsepower available, usually gives a rate of climb considerably higher than that realized in actual flying tests. This is evidently due to the failure to consider the higher slip stream velocity obtained under climbing conditions.

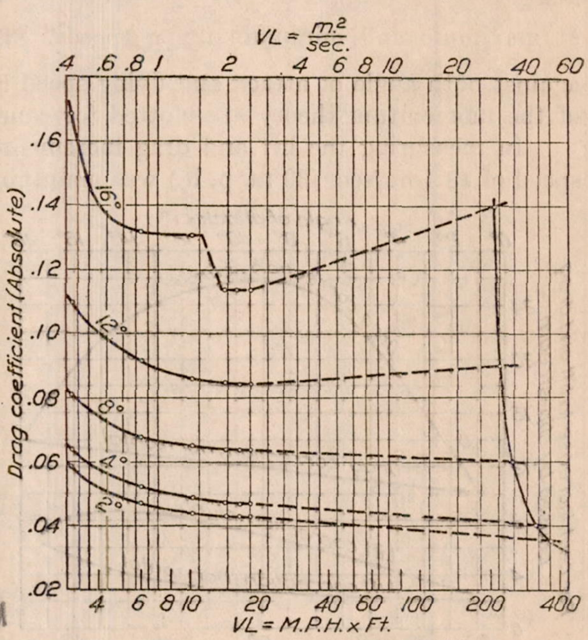

FIG. 9.—Change in D_c with change in VL.

The absolute lift and drag coefficients and the $\frac{L}{D}$ ratio are plotted against the scale of test in Figs. 8, 9, and 10, respectively. The scale *VL* is expressed in both metric and English units, *V* being the relative speed in meters per second or miles per hour and *L* the length of the wing

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[4] Since these tests were made, much more accurate instruments have been devised which will soon provide comparatively accurate full scale data.

chord in meters or feet. The series of points on the right-hand side of the chart represent full flight conditions as obtained by averaging the measurements given for airplanes 1 and 2 of Report No. 70.

A critical region of flow will immediately be noticed at 16° for $VL = 1.4$ m.²/sec. At lower scale values for this angle of attack turbulent flow occurs with consequently reduced lift and increased drag. That either type of flow may exist at $VL = 1.4$ m.²/sec. is indicated by the fact that while measuring drag the break came at a somewhat higher speed and while measuring lift it occurred slightly below.

It appears from these curves that both force coefficients decrease with increase of VL at low scale values, while at values of VL greater than 1.0 m.²/sec. the lift coefficient remains constant within the limits of experimental error. If the full scale drag measurements can be trusted the drag coefficients for small angles continue to decrease slowly with increase of scale.[5] All of the force measurements were made with the elevators set neutral. This procedure is justified by the curves given in Fig. 12, which show that in steady flight the elevators are never far enough from neutral to appreciably affect the total force on the machine except at the very highest angles of attack. In the neighborhood of 16° the elevator must be pulled up to its highest position, thus greatly adding to the resistance of the airplane. Unfortunately, no direct measurements of this increased drag were made under slip stream conditions, but those made without slip stream indicate this elevator drag increment to be in the neighborhood of 25% of the total drag at 16° angle of attack.

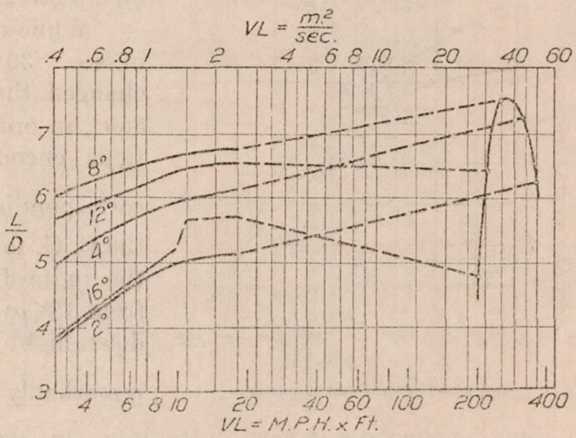

FIG. 10.—Change in L/D with change in VL.

In order to determine whether a simple exponential equation could be derived for the drag coefficient in terms of VL the drag curves were replotted on full logarithmic coordinates. The resulting lines, however, were not straight and no further mathematical analysis was attempted. The lift being constant with respect to VL, $\frac{L}{D}$ becomes inversely proportional to the drag coefficient and for normal flying angles continues to improve at the highest speeds of the model tests. The effect of elevator drag corrections would be to make the 12-degree and 16-degree model tests at high VL agree closely with the full scale.

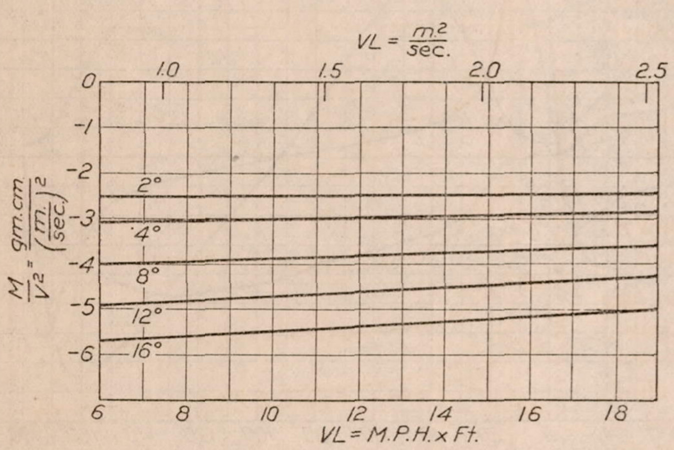

FIG. 11.—Pitching moment about holding spindle. (Stalling moment is positive.)

In Fig. 11, $\frac{M}{V^2}$ is plotted against VL for the range of model tests only, as no strictly comparable full flight data are at present available. The readings at $VL = 1.40$m.²/sec. do not lie on the curves and indicate either that the model was incorrectly aligned during this run or that some irregularity of air flow occurs at this speed, either as a peculiarity of the model or as an inherent characteristic of some part of the wind tunnel installation. With this exception the moment coefficients about the balance spindle decrease with great regularity as the speed of test increases.

The elevator angle required at 13.4 m./sec. (30 m. p. h.) to produce zero moment about the C. G. or to trim the model is plotted in Fig. 12 against the same angle determined during full

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[5] W. Margoulis, Critical Review of Aeronautical Works. 6510 NAC/1.

flight. There may be some doubt regarding these latter values, as they were interpolated from a series of trimming angles at different engine speeds in order to get conditions of zero thrust which would simulate wind tunnel tests without slip-stream. The curves given show that it may be necessary to lower the elevator somewhat more than the model test would indicate while gliding at high speed.

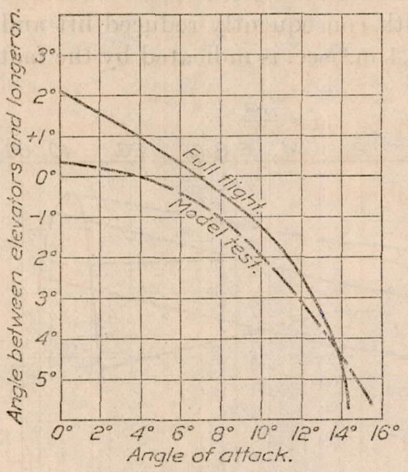

FIG. 12.—Tests without slip stream.

No attempts have yet been made to determine the effect of slip stream while measuring moments on models.

While doing the above work one run was made at 13.4 m./sec. (30 m. p. h.) in which the angle of attack was changed throughout a complete revolution from zero to 360°, in order to get some idea of the nature of the conditions encountered during stunting. Fig. 13 shows the corresponding changes in lift, drag, $\frac{L}{D}$, and moment about the C. G. for this test. Normal flight is confined between the limits of 0° and 18°, stalling and pancaking occurs roughly from 18° to 90°, tail sliding near 160° and sustained upside down flight near 320°. It will be noticed that the lift has a remarkably high peak at 170° and a corresponding $\frac{L}{D}$ of about 6, but the airplane is very unstable in this position, which anyone will acknowledge who has snapped out of a long tail slide.

The minimum gliding angle during a tail slide would be cot^{-1} 6.0 or 9½°, and that during an inverted glide cot^{-1} 2.7 or 20°. In this position the stability is almost neutral and it is evident that prolonged glides in this position are by no means difficult; in fact, they might be made unpleasantly easy by slightly increasing the angle of the tail plane.

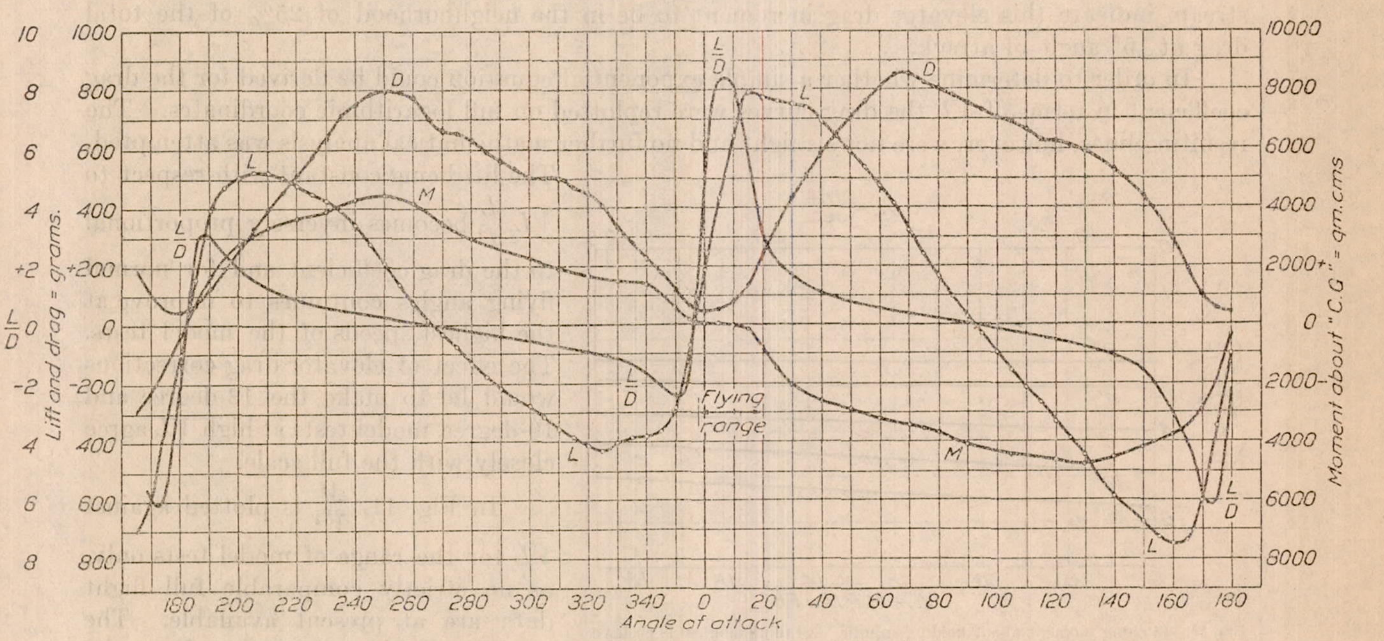

FIG. 13.—Forces and moments on complete JN4H model around 360°.

CONCLUSION.

It appears from the data here presented that by choosing model test conditions so that VL is greater than 1.200 m.^{2}/sec. (8.8 m. p. h. x ft.) the lift of a full-size airplane of a type analogous to the JN 4H may be predicted within the usual accuracy of full-scale measurements.

The accuracy of the drag prediction can not be fully determined from these tests, as sufficiently precise free-flight data are lacking. It seems probable that minimum drag may be estimated within 10 per cent, but that drag at high angles may be considerably in error unless proper corrections are made for elevator drag.

The additional labor of reproducing slip stream effects upon the model is undoubtedly justified when accurate results are required, as it eliminates the necessity of making several doubtful assumptions preparatory to the usual slip stream correction computations.

Preparations are now being made to increase the accuracy of full-flight drag determinations to a degree which will make them comparable with laboratory tests. Not until then will it be possible to say whether extreme exactitude in model making may be rewarded by proportionately accurate absolute values applicable to full scale airplanes, or even whether the relative order of merit of a series of small models will be maintained in actual practice.

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