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FLIGHT MEASUREMENTS BY VARIOUS METHODS OF THE DRAG CHARACTERISTICS OF THE XP-51 AIRPLANE

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MEMORANDUM REPORT

for the

Air Materiel Command, Army Air Forces

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SUMMARY

The variation of the over-all drag coefficient of the XP-51 airplane was measured in dives up to a Mach number of 0.8. During the tests the airplane was instrumented so that the over-all drag variation was obtained by three methods, each of which employed different combinations of instrumentation. The methods used are termed the accelerometer, the energy, and the dive-angle methods.

A discussion of the relative accuracy of the results obtained with each of the methods is given both from the standpoint of instrument accuracy and of the accuracy with which the data may be reduced. It is concluded that with present instruments the accelerometer method yields the most accurate and consistent results.

A comparison of the present drag results with those obtained in the wind tunnel indicates that at supercritical Mach numbers the flight values do not rise as rapidly as those from the wind tunnel. A comparison between various sets of flight data indicates that sufficient spread of the data is obtained with present instrumentation that a number of measurements may be required in order to establish a drag variation of reasonable accuracy.

INTRODUCTION

In view of the need for obtaining flight data at high speeds an XP-51 airplane was made available by the Air Materiel Command, Army Air Forces for high-speed dive tests. Although the primary objective of the tests was to obtain general load data that could be applied to existing airplanes, a secondary objective was to compare the flight results where possible with wind-tunnel and other flight measurements. The wind-tunnel measurements were obtained on a $\frac{1}{3}$-scale model of the XP-51 airplane at the Ames Aeronautical Laboratory and the flight results from tests made in England on a similar model of the XP-51.

During the tests at Langley Field, Va., the XP-51 airplane was instrumented so as to obtain data at high Mach numbers on such items as: the pressure distribution over the wing and tail surfaces, the airplane pitching-moment variation, the control characteristics, the operation of specially installed dive-recovery flaps, the profile, and over-all drag variations.

In some cases these quantities were to be measured to the practical terminal Mach number of the airplane. Since measurements could not be obtained on all of the quantities simultaneously, the program was divided into several phases. Previous reports on the XP-51 project (references 1 and 2) have covered the operation of the dive-recovery flaps and the profile drag, respectively.

The purpose of this report is to present the results of the over-all drag coefficient variation with Mach number up to 0.80 for the XP-51 airplane, and to discuss in some detail the accuracy of the various methods that are available for determining the drag coefficient in flight.

APPARATUS AND TESTS

Airplane.- A side view of the XP-51 airplane is shown in figure 1 and a line drawing is given in figure 2. During the tests the airplane was coated with camouflage paint; no attempt was made to prepare either the wing or the fuselage to an aerodynamically smooth condition. Several minor modifications were made to the airplane whose effect on the drag was unknown. These modifications included:

(1) The installation of a fixed pitot-static head on a boom mounted on the right wing near the wing tip. The static holes were approximately 1-chord length forward of the leading edge.

(2) The installation of a shield on the upper side of the fuselage aft of the pilot to house a periscope that was used in other tests.

(3) The covering of the six machine-gun openings in the wing.

(4) The installation of a series of six small automobile-type light bulbs (about 3/8 inches high) across the span of the horizontal tail for use in other tests.

(5) The installation of a rake for measuring profile drag on the left wing at 51.3 percent of the semispan and three total-head tubes which projected 4 inches above the top surface of the left wing.

(6) The installation of dive-recovery flaps. These flaps formed a bump 1/4 inch high and 30 inches long on the lower surface of the wing. (See reference 1.)

Some of these modifications may be seen in figures 1 and 2.

Characteristics of the airplane, engine, propeller, and exhaust stacks are given in table I.

Instruments.- Among others, the following instruments were installed; those listed are pertinent to the results of this report.

Airspeed recorder

Pressure altitude recorder

Accelerometer for recording acceleration normal to thrust axis

Accelerometer for recording acceleration parallel to thrust axis

(The above instruments were of the continuously recording type.)

Directional gyro mounted on pilot's instrument panel and turned 90° for measuring attitude angle

Timer for synchronizing results from above instruments

Indicating thermometer

Mach number indicator

Indicating accelerometer

16-millimeter camera for photographing pilot's instrument panel at 16 frames per second

Tests.- The flight tests consisted of a number of increasingly fast dives starting from steady level flight at a pilot's indicated speed of 160 miles per hour and at a specified pressure altitude. The level flight portion, prior to the dive, was held for about 4 minutes following which an abrupt push-over was made to either a specified dive angle or to a dive angle which was comfortable to the pilot. In the latter case the pilot proceeded until a specified Mach number was reached, after which a 4g to 6g recovery was made.

For the most part, the dives were made with the engine throttled; in the throttled dives the manifold pressure was below lowest reading on the gage (10 inches of mercury) throughout the dive. In all dives, however, the propeller was set to govern at 2600 rpm and the small radiator spoiler flaps were open. In some of the later dives, in an attempt to reach high Mach numbers at the highest possible altitude, various amounts of power were used in the earlier parts of the dive. Records and motion pictures were taken during the period from just prior to the push-over until the pull-out had been completed.

On the way to the starting position the pilot observed the outside air temperature at 1000-foot intervals. The observations were always taken at an indicated speed of

160 miles per hour after conditions were stabilized. In order to establish the temperature-pressure altitude variation to be used with the subsequent dive the pilot's temperature observations were corrected for the small adiabatic temperature rise at 160 miles per hour.

METHOD OF REDUCING DATA

The variation of the over-all drag coefficient with Mach number was evaluated for a number of the dives by each of three different methods. Each of the methods utilized measurements obtained from different combinations of instruments and are termed the "accelerometer method," the "energy method," and the "dive-angle method."

Accelerometer method.- The readings obtained from the accelerometers and the airspeed recorder were the primary measurements used in evaluating the over-all drag by the accelerometer method, although the geometry of the airplane, recorded pressure altitude, and angle of attack were also used. These quantities were inserted in the following easily derived equation that expresses the over-all drag coefficient:

$$C_{D_1} = \frac{w}{q} (n_h \cos \alpha + n_v \sin \alpha) \qquad (1)$$

In equation (1)

C_{D_1}	is the over-all airplane drag coefficient including effects of propeller and exhaust jet thrust and induced drag
n_h	reading of accelerometer measuring accelerations parallel to thrust axis, g units (When the weight or inertia forces on the accelerometer vane act rearward a negative value is recorded.)
n_v	reading of accelerometer measuring accelerations normal to the thrust axis, g units
w	wing loading, W/S, pounds per square foot
q	dynamic pressure, $\frac{1}{2}\rho V^2$, pounds per square foot

α angle of attack of thrust axis and of the instrument base relative to flight path, degrees (The instrument board on which the accelerometer was mounted was parallel, within $\pm 0.1^\circ$, to the thrust axis.)

The dynamic pressure q used in equation (1) was derived from measurements of the impact pressure q_c and of the pressure altitude both of which were corrected for the installation error existing at the static openings of the pitot-static head. No lag corrections were made to either the airspeed or altitude measurements as studies now in progress indicate that for the lengths and sizes of tubing used in the present tests lag effects would be well within other errors.

The angle of attack α used in equation (1) was not measured directly but was determined from the equation:

$$\alpha = \alpha_{l_o} + \frac{n_v W}{q\, C_{L_\alpha}} \qquad (2)$$

where the additional terms are:

α_{l_o} airplane angle of zero lift measured from thrust line, taken as -1.3°

C_{L_α} slope of airplane lift curve per degree, taken as 0.098

The choice of the above numerical values was based on an examination of preliminary wind-tunnel data taken at Ames Laboratory on the $\frac{1}{3}$-scale model at a Mach number of about 0.70.

Although wind-tunnel lift-curve slopes and zero lift angles were available for the Mach number range of the flight tests they were not used because anyone confronted with the task of evaluating the drag from flight tests would not ordinarily have access to such data. In such cases it would be necessary either to start from a computed datum and apply a variation for Mach number or to assume some constant average value as was done in the present case.

Although the use of α in equation (1) is in the nature of a correction, it is necessary to include it in the evaluation of the data since in none of the dives was zero lift (that is $n_V = 0$) maintained for any length of time. The inclusion of the α term enables a time history of the drag variation to be calculated throughout the dive even though the lift coefficient is continually varying. In the more or less steady portion of the dive and at small values of load factor the corrections due to α were generally small; during the push-over and in the pull-out the corrections were larger and the evaluated results are influenced by the choice of the values of C_{L_α} and α_{l_o}.

Energy method.- The readings obtained from the airspeed and pressure-altitude recorder were the primary measurements used in evaluating the over-all drag coefficient by the energy method. The method is based on the assumption that the rate of change of the sum of the potential and kinetic energy of the airplane during the dive is equal to the power consumed in drag. The pertinent equations are:

$$\frac{d}{dt}\,(\text{Energy}) = W\frac{d}{dt}\left(h_a + \frac{V^2}{2g}\right) = \text{Drag}\,\frac{ds}{dt} = DV \qquad (3)$$

Since

$$D = C_{D_1}qS$$

$$C_{D_1} = \frac{W}{qV}\frac{d}{dt}\left(h_a + \frac{V^2}{2g}\right) = \frac{W}{qV}\left(\frac{dh_a}{dt} + \frac{V}{g}\frac{dV}{dt}\right) \qquad (4)$$

where the new terms not previously defined are:

V the true airspeed, feet per second

g acceleration of gravity, 32.2 feet per second^2

h_a the absolute altitude, feet

t time, seconds

The true airspeed V was obtained from the corrected measurements of the pressure altitude h_p and the impact pressure q_c together with the temperature observations taken at the various pressure altitudes during the climb.

The absolute altitude used in equation (4) was determined by usual methods for correcting pressure altitude to absolute altitude. It was found, however, that in these tests while the absolute altitude varied from the pressure altitude the quantities $\frac{dh_p}{dt}$ and $\frac{dh_a}{dt}$ varied only slightly.

Dive-angle method.- The readings obtained from the airspeed recorder and the movies of the gyro were the primary measurements used for evaluating the drag coefficient by the dive-angle method although the accelerometer readings were used to obtain the necessary secondary corrections for angle of attack changes. The following equation was used in the reduction of the data:

$$C_{D_1} = \left(\frac{W}{q} \sin \gamma - \frac{1}{g} \frac{dV}{dt}\right) \qquad (5)$$

where γ, the flight-path angle relative to the horizontal, was obtained from the movies taken of the instrument panel. In the tests the gyro was uncaged at 160 miles per hour just before the push-over. The initial gyro reading served as a datum and subsequent readings were corrected for the differences in computed angle of attack existing at the datum condition and the angle of attack computed for any other time. The pertinent equation for deriving the dive angle γ from the gyro readings was:

$$\gamma = \left(\gamma_{read} - \gamma_o\right) - \frac{W}{C_{L_\alpha}}\left(\frac{n_{v_o}}{q_o} - \frac{n_v}{q}\right) \qquad (6)$$

where the subscript o designates the readings in the datum position.

Corrections for thrust and induced drag.- Corrections were made to the over-all drag coefficients C_{D_1} computed by the various methods (equations (1), (4), and (5)) for thrust and induced drag in order to obtain the drag coefficient C_{D_o} for the airplane alone. Thus:

$$C_{D_o} = C_{D_1} + \frac{T_j}{qS} + \frac{T_p}{qS} - \frac{C_L^2}{\pi A} \qquad (7)$$

where T is the thrust in pounds and the subscripts j and p refer to jet and propeller thrust, respectively. No tests were made to determine the span loading efficiency factor, thus the induced drag portion was computed from the elementary equation $C_L^2/\pi A$. The use of this equation is justified in the present case, since the usual 5 percent correction will hardly affect the results within the plotting accuracy.

The jet thrust was determined from the equation:

$$T_j = NM_e\left(\overline{V}_j - V\right) \tag{8}$$

where

M_e average flow of exhaust gas, slugs per second per cylinder

N number of cylinders (12)

$\overline{V}_j$ mean exhaust gas jet velocity, feet per second

V flight speed, feet per second

In computing M_e it was assumed that there was 0.0021 pound of exhaust gas per second per brake horsepower. The value of the brake horsepower was obtained from performance charts for the Allison V 1710-81 engine. The velocity $\overline{V}_j$ was obtained from results given in reference 3.

The propeller thrust T_p (less compressibility effects) was determined from the charts given in reference 4. In this determination, the power coefficient C_p and the V/nD were first computed from the engine manifold pressure, measured airspeed, and engine rpm. The computed power coefficient C_p was then converted to the proper activity factor in order to enter the charts. The thrust coefficient C_T obtained from the charts was then reconverted to the proper activity factor following which the propeller thrust was computed from the equation:

$$T_p = C_T\,\rho n^2 D^4 \tag{9}$$

The above value of propeller thrust was corrected for compressibility effects by multiplying equation (9) by a tip speed correction factor F_t and a hub correction factor F_h. The values of these factors were obtained from references 5 and 6 and are similar to those given in reference 7.

In the throttled dives when the manifold pressure was 10 inches of mercury or below, the thrust and power were computed as though the pressure were 10 inches of mercury. It will be seen later that this assumption will not affect the results to any great extent.

RESULTS AND ACCURACY

In this section results are first presented for a selected dive in which the drag coefficient is determined by the various methods, following which the accuracy of the results obtainable with the various methods is briefly discussed, and finally the average flight drag variation is given for all of the dives.

Results for a selected dive.- Figure 3 shows a time history of some of the measured and computed quantities for a dive in which a Mach number of 0.786 was reached. This particular flight was chosen for illustration because it was the highest Mach number dive for which a complete set of instrument records was available for evaluating the drag by all three methods. The dive was started from a push-over at 31,200 feet and proceeded for approximately 20 seconds at which time a 4.0g pull-out was initiated. The throttle was set prior to the dive so as to govern at 19,000 feet and 160 miles per hour with a manifold pressure of 37 inches of mercury.

Table II lists some of the computations made in evaluating C_{D_o} and C_{D_1} by each of these methods. In order that an appraisal may be made of the contributions of the various drag components, table II also gives some of the computations for obtaining the jet and propeller thrust.

Figure 4(a) shows the variation of the drag coefficient C_{D_1} with Mach number while figure 4(b) shows the variation of C_{D_0} with Mach number. The values given in figure 4(a) were obtained from figure 3 and table II. The values for figure 4(b), however, are taken from lift coefficients falling within the range from ±0.2 in order that the effect of any span efficiency factor would be a minimum.

Accuracy.- The wide variation and irregularity of the drag curves shown in figure 4 for the various methods indicates the desirability of some discussion of the accuracy of measurements and operations.

The major quantities used in the equations for reducing the data are believed to be known to the following accuracy.

Quantity	Accuracy	Remarks
w	±0.005 or 1/2 percent	Corresponds roughly to a weight of 7 gallons gasoline
q	±1 inch H_2O or 1 percent whichever is greater	
V	Corresponding to accuracy of q above or 1/2 percent	
M	±0.01	
T_j	±20 pounds	
T_p	±100 pounds	Corresponds roughly to 100 thrust horsepower at 20,000 feet
n_h	±0.01g	Corresponds to 79 pounds error in force acting along flight path.

Quantity	Accuracy	Remarks
n_V	±0.05g	Error of this amount in combination with an error in angle of 3° would result in an error of 20 lb acting along the flight path per load factor
α	±1°	Due mainly to combined errors in a_{l_0} and C_{l_α}
γ	±2°	Due to combined errors in quantities in equation 6
$\frac{dV}{dt}$, $\frac{dh_a}{dt}$		Difficult to assess

Errors in the quantities $\frac{dV}{dt}$ and $\frac{dh_a}{dt}$ are difficult to determine since part of the error may be attributed to the measurements of V and h_a and part to the graphical differentiation that is required. Regardless of method, the absolute error in the evaluated drag coefficients, depends upon the accuracy with which the force acting along the flight path is known. Figure 5(a) shows the variation in the width of the error envelope with Mach number and altitude due to an error of 100 pounds force. Figure 5(b) shows a similar variation for an error of 100 thrust horsepower.

If it is assumed that the errors in the major quantities used in the equation for reducing the data are additive the maximum possible error in force along the flight path from the estimates given would be about 236 pounds. At 20,000 feet the maximum width of the error envelope for a load factor of 1.0 would then be as shown in figure 5(c). The discussion of errors in the preceeding paragraphs has implied that the errors are of accidental nature. The possibility of a certain consistent error will be touched upon later in the discussion of results.

Although it is not readily seen from figure 4, since the results given in this figure are from only one dive, it may be stated that the energy and dive angle methods yielded results with a considerably greater envelope band than that shown in figure 5(c). In contrast, the accelerometer method gave better results consistently with an envelope band somewhat greater than that shown in figure 5(c). In general, the band was smaller for the fully throttled dives than for the dives in which power was used.

Average flight variation.- In view of the preceding considerations the results from the accelerometer method were deemed to be the most accurate and therefore only the results obtained by this method are given in this report. Figure 6(a) shows the results obtained by the accelerometer method for eight dives of various degrees of severity where the range of airplane lift coefficient was ± 0.2. Corrections for propeller thrust, jet thrust, and induced drag were made for each dive as outlined in table II.

From the curves given in figure 6(a) an average curve was derived. Since the number of curves to be averaged differed in various ranges the final averaged curve of figure 6(b) has been broken into a number of segments, each segment being based on the number of curves noted. The dotted lines represent the mean deviations from the mean and serve as an indication of the reliability of the average curve.

In order to give some idea of the correlation between the rapid rise in the over-all drag curve and the critical Mach numbers, the critical speeds as determined from flight pressure distributions taken over three wing ribs located at 52, 114, and 185 inches from the airplane center line are noted on figure 6(b).

DISCUSSION

In connection with the mean drag-coefficient curve of figure 6(b), it may be noted that the largest value measured was about twice the low-speed value, and that the rapid rise in drag coefficient where $d(C_D/M) = 0.1$ is associated with a Mach number which is about 0.05 greater than the critical Mach number for the wing section at 52 inches. Aside from this general comment, it is of interest to present results from other drag measurements pertaining to the P-51 series of airplane and to discuss the requirements necessary to insure reasonable accuracy in flight measurements of drag coefficient.

Comparison of the present measurements with other available results for the P-51 series are shown in figure 7. Curve 1 shows the drag variation obtained at zero lift for a $\frac{1}{3}$-scale model of the XP-51 airplane tested in the Ames 16-foot wind tunnel. The tunnel tests were made on a smooth propellerless model which had some but not all of the protuberances that were present on the actual airplane. A comparison of the flight drag results with those obtained in the wind tunnel indicates that at the supercritical Mach numbers, even taking into consideration the mean deviations, the flight values do not rise as rapidly as those from the wind tunnel.

Curves numbers 2 and 3 were obtained from flight tests made in Great Britain on an early version of the Mustang which was similar in configuration to the XP-51. In the British tests, the drag variation was determined by the energy method. Curve 2 applies with the small radiator spoiler flap up, while curve 3 applies with the radiator spoiler flap down. The curves shown represent averages of points which were widely scattered.

Curve 4 shows the variation with Mach number of the apparent profile drag coefficient obtained from a rake survey behind a station 114 inches out from the wing center line on the XP-51. This curve was taken from reference 2 and represents only section data.

It may be noted that whereas both curves 1 and 4 show either no increase or slight increase in drag coefficient with Mach number for M less than 0.66 the mean flight curve shows an opposite trend which may be of significance. All the curves in figure 6(a) from which the mean curve was derived show this same tendency indicating the possibility that some consistent error was introduced into the computations. A consistent trend of the type shown could be introduced by employing either propeller characteristic or engine-power curves which were not directly applicable to the engine propeller combination used in the tests. It may be seen from figure 3 and table II that in the low-speed range (that is at the beginning of the dive) small but consistent errors in either the prediction of the engine power or the propeller thrust from the charts used would materially affect the results whereas in the high-speed range this effect would be much less important.

In connection with the British results (curves 2 and 3) a more recent British analysis of the data indicated that the instrumentation used was not adequate and recommended the use of the accelerometer method for future evaluations of flight drag. The same recommendation is made in reference 9 which shows that small errors in airspeed and altitude measurements give rise to large errors in the drag coefficient as determined by the energy method.

Although the comparisons of figure 7(a) are of principal interest since they pertain to the XP-51, other comparisons are contained in figure 7(b) for other versions of the P-51 airplane. Figure 7(b) shows the comparison of the XP-51 results with wind-tunnel and flight measurements for the P-51B airplane. Curve 5 shows the drag-coefficient-variation obtained at zero lift in the wind tunnel of a $\frac{1}{3}$-scale model of the P-51B airplane, without a propeller. (See reference 8.) Curves 6 and 7 are the drag variation measured in flight near zero lift by the accelerometer method on a P-51B without a propeller. (See reference 8.) Curve 6 represents the variation obtained in one flight in which it was stated that the least amount of dust was on the airplane while curve 7 represents the case of a dive with the most dust on the airplane.

It is believed that most of the variation obtained in the form of the drag curves given in figures 7(a) and 7(b) may be attributed to differences in the accuracy of the measurements and methods used in evaluating the data. On the basis of the present experience it may be stated that results obtained with the energy method are not as accurate as those obtained with the accelerometer method. In support of this statement it may be noted that the wind-tunnel tests of the $\frac{1}{3}$-scale model of the XP-51 indicated that the small radiator spoiler flap had barely a noticeable effect on the airplane drag below an M of 0.75 and a slight effect up to 0.80, whereas the flight tests for the Mustang (curves 2 and 3) showed that the radiator spoiler flap had a relatively large effect. It may also be noted from figures 4 and 6 that drag variations as large as those indicated by either curves 2 and 3 or curves 6 and 7 could be obtained between successive flights even though the airplane configuration had not been changed. This leads to the conclusion that unless improvements are made in technique several flights may be required in order to establish the drag variation for a given configuration.

CONCLUDING REMARKS

The detailed computations given for the selected dive (figs. 3 and 4 and table II), as well as results of computations not included in this report, indicate that further gain in accuracy may be had by improving both the instruments and the flight technique. Lacking direct measurements of propeller thrust, an improvement in accuracy would be obtained by using less power because the thrust could be more closely computed. An improvement may also be obtained by further increasing the accuracy of the accelerometers and taking special precautions in their location with respect to the airplane center of gravity and their orientation with respect to the angle of zero lift. It is felt, unless such improvements are accomplished, that (a) computations for converting pressure altitude to true altitude, (b) determinations of span efficiency factor, and (c) corrections for compressibility effects on propeller tips and hub lose much of their significance.

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TABLE I

CHARACTERISTICS OF XP-51 AIRPLANE

Airplane:	
Over-all length	32 ft $2\frac{5}{8}$ in.
Weight for tests, lb	7897
Wing span	37 ft 5/16 in.
Wing area, sq ft	235.75
Horizontal tail	
Stabilizer area, sq ft	27.70
Elevator area (including 1.24 sq ft balance), sq ft	13.76
Vertical tail	
Fin area, sq ft	9.44
Rudder area (including 0.63 sq ft balance), sq ft	11.16
Engine:	Allison V1710-81-99
Normal rating	1000 bhp at 2600 rpm at sea level 955 bhp at 2600 rpm at 15,700 feet
Gear ratio	2.00:1
Propeller:	Curtiss constant-speed
Drawing number	614CC1.5 - 18
Serial number	AF 40-12646
Diameter	10 ft 6 in.
Angle high at 42 in. station	58°
Angle low at 42 in. station	23°
Activity factor (total)	265.5
Exhaust stacks:	
Area of each stack, sq in.	4.95
Inclination to thrust axis	24° 40'
Inclination to plane of symmetry	12° 50'

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TABLE II

COMPUTATIONS FOR EVALUATION OF DRAG COEFFICIENT OF XP-51

FLIGHT 43

Time (sec)	Airspeed V (ft/sec)	Dynamic pressure q (lb/sq ft)	Mach number M	Temperature °F	Normal load factor n_v (g units)	Longitudinal load factor n_h (g units)	Pressure altitude h_p (ft)	Absolute altitude h_a (ft)	Dive angle γ_1 (deg)	Corrected dive angle γ (deg)	Angle of attack α (deg)	Advance ratio V/nD	Manifold pressure (in. Hg)	Brake horsepower
0	392.7	62.7	0.389	-35.4	0.86	-0.085	31,200	32,400	2.0	-4.6	3.38	1.73	20.0	500
1.0	395.8	63.9	.392	-35.4	.53	-.070	31,200	32,400	5.0	-1.9	1.53	1.74	20.0	500
1.7	400.8	65.8	.397	-35.4	.49	-.063	31,200	32,400	----	----	1.24	1.76	20.1	505
2.2	402.8	66.3	.399	-35.4	.06	-.055	31,190	32,400	----	----	-.99	1.77	20.2	510
2.6	404.9	67.0	.401	-35.4	-.18	-.040	31,190	32,390	----	----	-2.22	1.78	20.3	515
3.1	409.9	68.2	.406	-35.4	.06	-.051	31,190	32,350	----	----	-1.01	1.80	20.5	520
4.0	419.0	71.6	.415	-35.4	-.59	-.065	31,190	32,250	19.5	10.5	-4.12	1.84	20.8	530
4.4	424.3	73.6	.420	-34.9	-.41	-.073	31,040	32,200	----	----	-3.20	1.87	20.9	535
5.0	429.4	75.6	.425	-34.5	-.80	-.085	30,950	32,150	27.0	18.8	-4.91	1.89	21.0	540
6.0	446.0	82.4	.441	-33.8	-.67	-.075	30,760	32,000	36.0	28.0	-4.08	1.96	21.2	545
6.6	457.5	86.8	..453	-33.6	-.59	-.070	30,700	31,800	----	----	-3.63	2.01	21.5	550
7.0	464.0	89.0	.457	-----	-.67	-----	------	------	41.0	31.0	-----	2.04	21.8	560
8.0	483.0	96.8	.475	-----	-.67	-----	------	------	47.5	37.7	-----	2.13	22.0	570
8.7	497.0	103.8	.490	-31.8	-.61	-.035	30,220	31,320	----	----	-3.31	2.19	22.2	580
9.0	503.0	107.2	.496	-----	-.10	-----	------	------	52.5	44.7	-----	2.21	22.5	585
10.0	523.0	119.7	.514	-----	-.37	-----	------	------	56.0	47.5	-----	2.30	23.0	595
11.0	543.5	132.5	.543	-----	.49	-----	------	------	60.0	53.8	-----	2.39	23.7	610
11.4	552.5	134.1	.545	-28.1	.59	0	29,360	30,350	----	----	.21	2.43	23.9	615
12.0	565.2	141.2	.555	-----	.15	-----	------	------	59.5	52.4	-----	2.49	24.1	625
13.0	585.6	153.4	.574	-----	.72	-----	------	------	60.5	54.6	-----	2.58	25.0	640
14.0	606.8	168.1	.594	-----	1.10	-----	------	------	59.0	53.8	-----	2.67	26.0	670
14.4	616.5	175.6	.604	-24.8	.60	.030	27,930	28,990	----	----	-.13	2.71	26.4	680
15.0	630.5	186.6	.620	-----	.63	-----	------	------	59.0	52.7	-----	2.77	27.0	695
15.7	647.0	197.0	.633	-23.1	.19	.045	27,440	28,310	----	----	.07	2.85	27.7	710
16.0	651.1	200.5	.635	-----	.67	-----	------	------	58.5	52.2	-----	2.86	28.0	720
16.6	667.5	212.6	.650	-20.6	.15	.060	26,970	27,870	----	----	-1.06	2.94	28.7	740
17.0	676.4	219.5	.658	-----	.10	-----	------	------	59.5	52.2	-----	2.98	29.0	750
17.8	696.5	237.3	.678	-17.9	.49	.080	26,440	27,270	----	----	-.60	3.06	30.0	780
18.0	701.5	239.9	.681	-----	.35	-----	------	------	60.5	53.6	-----	3.09	30.2	790
19.0	723.0	259.4	.699	-15.4	.06	.105	25,750	26,600	61.0	53.6	-1.22	3.18	31.4	815
19.7	738.0	275.0	.713	-15.0	1.14	.110	25,310	26,210	----	----	.12	3.25	32.2	835
20.0	745.0	281.5	.722	-----	.44	-----	------	------	62.5	55.6	-----	3.28	32.7	850
20.6	757.0	297.4	.734	-13.4	.53	.160	24,810	25,700	----	----	-.69	3.33	33.3	870
21.0	767.7	307.1	.740	-----	.49	.200	------	------	62.0	55.1	-.75	3.38	34.0	890
21.4	773.0	313.3	.746	-11.0	1.58	.190	24,370	25,200	----	----	.42	3.40	34.4	900
22.0	784.0	323.9	.748	-----	1.21	-----	------	------	60.5	54.3	-----	3.45	35.0	915
22.5	792.5	332.4	.756	-7.3	1.29	.280	23,660	24,500	----	----	.03	3.49	35.7	930
23.0	800.0	345.3	.766	-----	1.31	.290	------	------	60.0	53.9	0	3.52	36.1	950
23.5	807.0	358.0	.770	-----	1.50	-----	------	------	59.0	53.0	-----	3.55	36.8	965
23.8	810.1	359.9	.774	-3.6	1.80	.325	22,850	23,700	----	----	.40	3.56	37.1	975
24.0	812.5	364.3	.775	-----	1.48	-----	------	------	57.5	51.4	-----	3.58	37.2	980
24.4	816.5	370.2	.778	-2.1	1.99	.360	22,450	23,300	----	----	.55	3.59	37.7	990
24.5	817.5	371.6	.779	-----	2.12	-----	------	------	55.5	50.0	-----	3.60	37.9	995
24.7	819.0	374.4	.780	-1.6	1.99	.385	22,310	23,100	----	----	.53	3.60	38.0	1000
25.0	821.5	377.8	.780	-----	2.46	-----	------	------	55.0	49.8	-----	3.61	38.3	1005
25.1	822.0	378.0	.780	-.7	2.70	.370	22,060	22,830	----	----	1.15	3.62	38.5	1010
25.5	824.0	384.6	.782	-----	1.24	-----	------	------	53.0	46.7	-----	3.63	39.0	1020
25.65	824.5	386.6	.783	.5	.86	.425	21,740	22,470	----	----	-.53	3.63	39.0	1020
26.0	826.0	390.0	.784	-----	1.97	-----	------	------	51.0	45.3	-----	3.63	39.3	1025
26.1	826.5	391.2	.784	.7	2.07	.415	21,500	22,160	----	----	.52	3.64	39.5	1030
26.5	827.5	395.5	.783	-----	2.19	-----	------	------	50.0	44.5	-----	3.64	39.9	1035
26.9	827.8	400.1	.785	3.2	2.13	.435	21,070	21,660	----	----	.53	3.64	40.0	1040
27.0	828.0	400.4	.785	-----	2.27	-----	------	------	48.0	42.5	-----	3.64	40.2	1045
27.2	829.4	402.7	.786	3.8	2.47	.440	20,940	21,500	----	----	.79	3.65	40.2	1045
27.5	828.0	404.8	.784	-----	2.20	-----	------	------	46.5	40.9	-----	3.64	40.5	1050
28.0	828.0	408.6	.784	-----	2.59	-----	------	------	45.0	39.7	-----	3.64	41.0	1065
28.5	827.0	412.9	.786	6.2	2.78	.450	20,330	20,870	43.5	38.4	1.00	3.64	41.1	1070
29.0	825.0	414.1	.780	7.8	3.33	.425	19,960	20,660	42.0	37.3	1.46	3.63	41.5	1080
29.5	823.0	409.6	.774	-----	3.57	-----	------	------	38.0	33.5	-----	3.62	41.8	1090
29.7	822.1	411.9	.775	8.7	3.40	.405	19,730	20,400	----	----	1.51	3.62	41.8	1090
30.0	820.0	411.1	.772	-----	3.79	-----	------	------	34.0	29.7	-----	3.61	41.9	1095
30.2	818.5	410.6	.769	9.8	4.02	.375	19,470	20,240	----	----	2.07	3.60	42.0	1100
30.5	817.0	410.6	.768	-----	3.72	-----	------	------	31.5	27.1	-----	3.59	42.0	1100
30.9	813.5	409.8	.766	10.5	3.98	.350	19,300	20,020	----	----	2.06	3.58	42.0	1100
31.0	812.5	408.8	.765	-----	3.91	-----	------	------	30.0	25.8	-----	3.58	42.0	1100
31.7	807.1	405.0	.759	11.1	4.02	.300	19,170	19,830	----	----	2.11	3.55	42.0	1100
32.0	803.0	402.8	.755	-----	3.47	-----	------	------	22.5	18.0	-----	3.53	42.0	1100
32.2	801.1	400.9	.753	11.5	3.40	.325	19,040	19,730	----	----	1.62	3.52	42.0	1100
33.0	794.2	394.6	.746	-----	3.47	-----	------	------	17.5	13.1	-----	3.49	42.0	1100
33.9	783.5	384.8	.736	12.2	3.67	.260	18,900	19,500	----	----	1.96	3.45	42.0	1100
34.0	783.0	384.8	.735	-----	3.60	-----	------	------	13.0	8.8	-----	3.45	42.0	1100
35.0	772.5	374.4	.727	-----	3.38	-----	------	------	6.0	1.6	-----	3.40	42.0	1100
36.0	762.4	364.4	.716	12.3	2.10	.200	18,880	19,470	1.5	-4.0	.67	3.35	41.9	1095
37.0	750.5	353.9	.706	-----	1.50	-----	------	------	0	-6.0	-----	3.30	41.8	1090
38.0	741.9	344.1	.697	11.8	1.19	.170	18,990	19,600	-1.5	-7.8	-.13	3.26	41.6	1085

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TABLE II - Concluded

COMPUTATIONS FOR EVALUATION OF DRAG COEFFICIENT ON XP-51

FLIGHT 43 - Concluded

Time (sec)	Propeller thrust (lb)	Jet thrust (lb)	ΔC_D propeller	ΔC_D jet thrust	Airplane C_L	Induced drag $C_L{}^2/\pi A$	Over-all drag C_{D_1} accelerometer	Over-all drag C_{D_1} energy	Over-all drag C_{D_1} dive angle	Parasite drag C_{D_o} accelerometer	Parasite drag C_{D_o} energy	Parasite drag C_{D_o} dive angle
0	581.6	44.9	0.0393	0.0030	0.457	0.0113	-0.0183	------	------	0.0127	------	------
1.0	577.7	44.9	.0386	.0030	.277	.0041	-.0292	------	------	.0083	------	------
1.7	590.9	45.7	.0375	.0029	.251	.0034	-.0267	------	------	.0103	------	------
2.2	567.0	46.1	.0369	.0030	.032	.0001	-.0283	------	------	.0115	------	------
2.6	585.3	46.7	.0376	.0030	-.090	.0004	-.0165	------	------	.0237	------	------
3.1	578.3	47.4	.0366	.0030	.032	.0001	-.0245	------	------	.0150	------	------
4.0	575.0	48.2	.0348	.0029	-.277	.0041	-.0105	------	------	.0229	------	------
4.4	575.5	48.7	.0331	.0028	-.187	.0019	-.0228	------	------	.0112	------	------
5.0	557.0	49.3	.0316	.0028	-.354	.0068	-.0072	------	------	.0204	------	------
6.0	546.7	49.0	.0279	.0025	-.270	.0039	-.0010	------	------	.0255	------	------
6.6	520.0	49.3	.0253	.0024	-.225	.0027	-.0126	-0.0147	------	.0124	0.0183	------
7.0	550.0	50.2	.0263	.0024	-.251	.0034	------	------	-0.0014	------	------	0.0239
8.0	537.0	50.7	.0233	.0022	-.218	.0026	------	------	.0180	------	------	.0409
8.7	521.3	51.4	.0213	.0021	-.200	.0022	.0001	-.0042	------	.0213	.0170	------
9.0	505.8	51.8	.0205	.0021	-.032	.0001	------	------	.0344	------	------	.0569
10.0	516.0	51.9	.0179	.0018	-.098	.0005	------	------	.0317	------	------	.0509
11.0	500.0	52.5	.0162	.0017	.122	.0008	------	------	.0392	------	------	.0555
11.4	488.8	52.9	.0157	.0017	.148	.0012	.0005	.0056	------	.0167	.0218	------
12.0	482.0	53.2	.0145	.0016	.039	.0001	------	------	.0274	------	------	.0434
13.0	463.4	53.9	.0129	.0015	.154	.0013	------	------	.0247	------	------	.0378
14.0	447.1	56.4	.0111	.0014	.219	.0026	------	------	.0172	------	------	.0271
14.4	430.8	56.9	.0106	.0014	.116	.0007	.0055	.0130	------	.0168	.0243	------
15.0	428.3	58.0	.0096	.0013	.103	.0006	------	------	.0102	------	------	.0205
15.7	379.2	58.7	.0084	.0013	.135	.0010	.0078	.0149	------	.0165	.0236	------
16.0	377.7	59.9	.0082	.0013	.109	.0006	------	------	.0069	------	------	.0158
16.6	361.6	61.1	.0071	.0012	.026	.0001	.0090	.0167	------	.0172	.0251	------
17.0	354.7	61.7	.0069	.0012	.013	.0000	------	------	.0063	------	------	.0144
17.8	330.8	63.8	.0057	.0011	.071	.0003	.0106	.0175	------	.0171	.0240	------
18.0	304.3	65.2	.0056	.0012	.043	.0001	------	------	.0100	------	------	.0167
19.0	283.9	66.4	.0047	.0011	.006	.0000	.0134	.0195	.0133	.0192	.0253	.0191
19.7	268.9	67.2	.0040	.0010	.142	.0011	.0137	.0210	------	.0176	.0249	------
20.0	240.1	68.6	.0035	.0010	.046	.0001	------	------	.0202	------	------	.0246
20.6	210.2	70.1	.0030	.0010	.058	.0002	.0173	.0218	------	.0211	.0256	------
21.0	213.9	71.3	.0030	.0010	.051	.0001	.0211	------	.0247	.0250	------	.0294
21.4	187.4	72.1	.0026	.0010	.167	.0015	.0216	.0235	------	.0237	.0256	------
22.0	166.6	72.4	.0023	.0010	.109	.0006	------	------	.0305	------	------	.0332
22.5	171.0	73.3	.0021	.0009	.129	.0009	.0263	.0276	------	.0284	.0297	------
23.0	141.9	75.1	.0017	.0009	.129	.0009	.0281	------	.0374	.0298	------	.0391
23.5	126.4	75.8	.0015	.0009	.122	.0008	------	------	.0400	------	------	.0416
23.8	120.5	76.4	.0014	.0009	.168	.0015	.0314	.0359	------	.0322	.0367	------
24.0	112.2	76.6	.0013	.0009	.117	.0007	------	------	.0425	------	------	.0440
24.4	102.9	77.2	.0012	.0009	.180	.0018	.0345	.0443	------	.0348	.0446	------
24.5	103.3	77.5	.0012	.0009	.165	.0015	------	------	.0449	------	------	.0455
24.7	103.7	77.8	.0012	.0009	.178	.0017	.0361	.0487	------	.0365	.0491	------
25.0	95.5	78.1	.0011	.0009	.188	.0019	------	------	.0486	------	------	.0487
25.1	95.9	78.3	.0011	.0009	.239	.0031	.0378	.0525	------	.0367	.0514	------
25.5	96.7	79.1	.0011	.0009	.121	.0008	------	------	.0487	------	------	.0499
25.65	96.6	79.0	.0011	.0009	.075	.0003	.0363	.0647	------	.0380	.0564	------
26.0	87.6	78.9	.0010	.0009	.146	.0012	------	------	.0507	------	------	.0514
26.1	88.5	79.7	.0010	.0009	.177	.0017	.0373	.0507	------	.0375	.0509	------
26.5	88.1	79.3	.0010	.0009	.160	.0014	------	------	.0529	------	------	.0534
26.9	99.7	79.7	.0010	.0008	.178	.0017	.0382	.0518	------	.0383	.0519	------
27.0	99.7	79.8	.0010	.0008	.163	.0014	------	------	.0538	------	------	.0542
27.2	88.8	79.9	.0010	.0009	.205	.0023	.0393	.0521	------	.0379	.0517	------
27.5	89.5	80.5	.0010	.0009	.182	.0018	------	------	.0551	------	------	.0552
28.0	90.6	81.6	.0010	.0009	.212	.0024	------	------	.0565	------	------	.0560
28.5	102.5	82.1	.0010	.0008	.225	.0027	.0404	.0525	.0576	.0395	.0516	.0567
29.0	91.6	82.5	.0010	.0009	.269	.0039	.0413	.0522	.0592	.0393	.0502	.0572
29.5	111.2	83.4	.0012	.0009	.292	.0046	------	------	.0583	------	------	.0558
29.7	110.8	83.1	.0012	.0009	.277	.0041	.0401	.0514	------	.0381	.0494	------
30.0	111.6	83.7	.0012	.0009	.267	.0039	------	------	.0555	------	------	.0537
30.2	121.7	84.2	.0013	.0009	.328	.0058	.0426	.0505	------	.0390	.0469	------
30.5	121.8	84.3	.0013	.0009	.263	.0037	------	------	.0552	------	------	.0537
30.9	140.3	84.2	.0015	.0009	.325	.0057	.0401	.0485	------	.0368	.0452	------
31.0	140.5	84.3	.0015	.0009	.278	.0041	------	------	.0556	------	------	.0539
31.7	150.6	84.7	.0016	.0009	.333	.0060	.0372	.0453	------	.0337	.0418	------
32.0	169.3	84.6	.0018	.0009	.251	.0034	------	------	.0489	------	------	.0482
32.2	169.6	84.8	.0018	.0009	.284	.0044	.0354	.0427	------	.0337	.0410	------
33.0	207.5	84.9	.0022	.0009	.295	.0047	------	------	.0454	------	------	.0438
33.9	236.7	85.2	.0025	.0009	.319	.0055	.0335	.0359	------	.0314	.0338	------
34.0	246.1	85.3	.0026	.0009	.274	.0041	------	------	.0416	------	------	.0410
35.0	260.2	86.8	.0030	.0010	.263	.0037	------	------	.0324	------	------	.0327
36.0	293.6	86.4	.0034	.0010	.193	.0020	.0207	.0261	.0245	.0231	.0285	.0269
37.0	336.9	86.4	.0039	.0010	.126	.0009	------	------	.0207	------	------	.0247
38.0	346.9	86.7	.0044	.0011	.116	.0007	.0162	.0178	.0140	.0210	.0226	.0188

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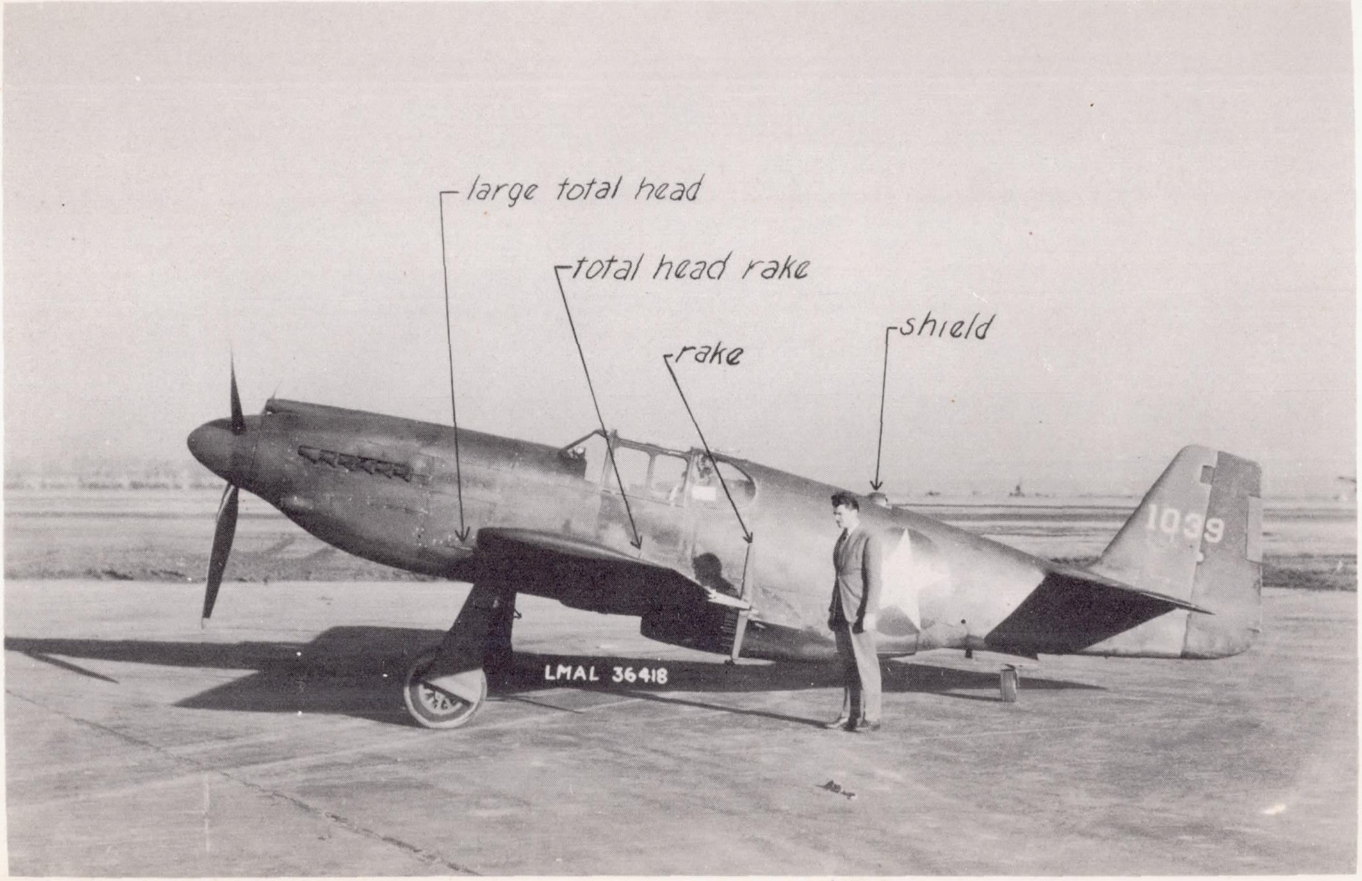
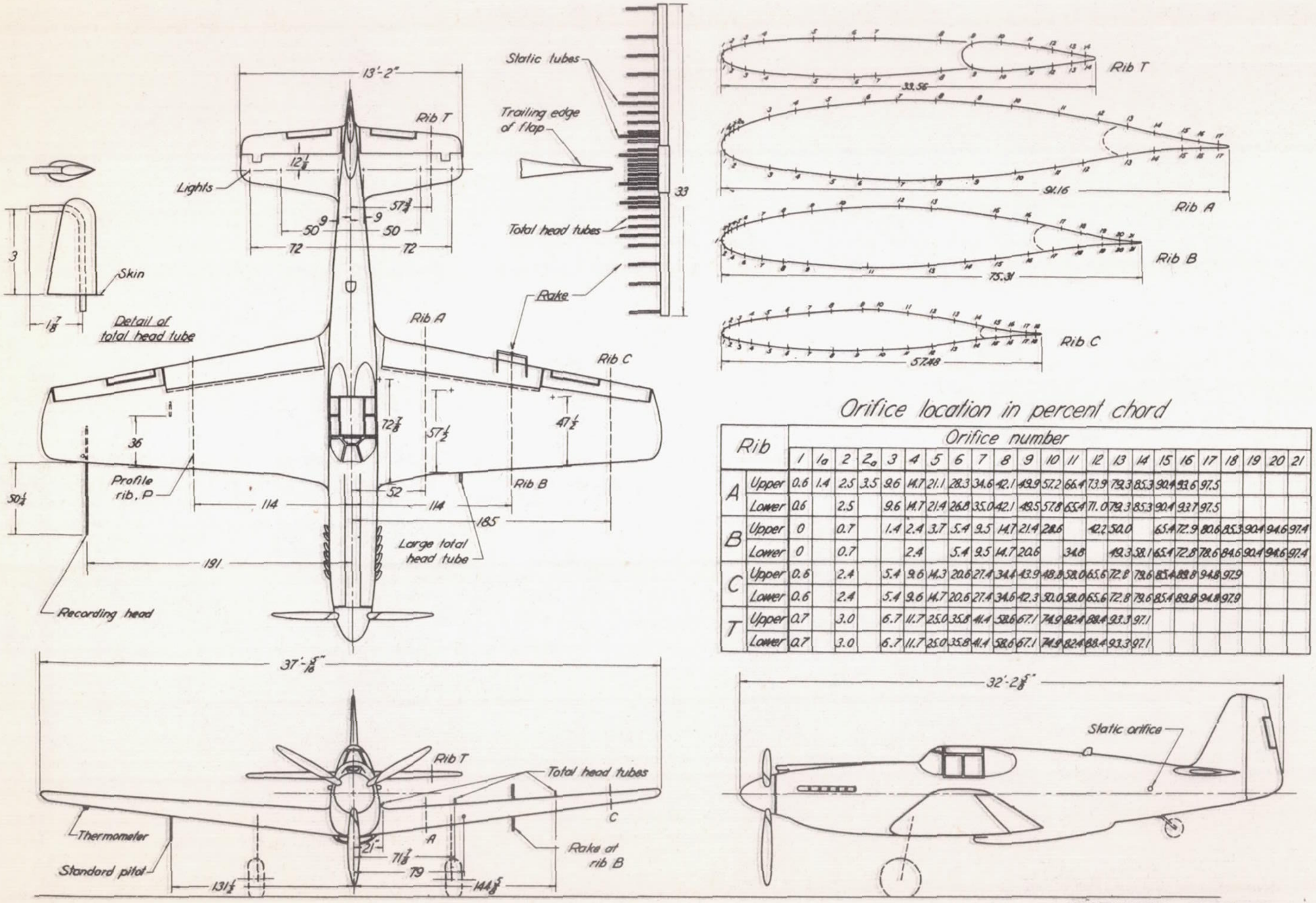


Figure 1.- The North American XP-51 airplane.



Orifice location in percent chord

Rib		Orifice number																						
		1	1a	2	2a	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
A	Upper	0.6	1.4	2.5	3.5	9.6	14.7	21.1	28.3	34.6	42.1	49.9	57.2	66.4	73.9	79.3	85.3	90.4	93.6	97.5				
	Lower	0.6		2.5		9.6	14.7	21.4	26.8	35.0	42.1	49.5	57.8	65.4	71.0	79.3	85.3	90.4	93.7	97.5				
B	Upper	0		0.7		1.4	2.4	3.7	5.4	9.5	14.7	21.4	28.6		42.2	50.0		65.4	72.9	80.6	85.3	90.4	94.6	97.4
	Lower	0		0.7			2.4		5.4	9.5	14.7	20.6		34.8		49.3	58.1	65.4	72.8	78.6	84.6	90.4	94.6	97.4
C	Upper	0.6		2.4		5.4	9.6	14.3	20.6	27.4	34.4	43.9	48.8	58.0	65.6	72.8	79.6	85.4	89.8	94.8	97.9			
	Lower	0.6		2.4		5.4	9.6	14.7	20.6	27.4	34.6	42.3	50.0	58.0	65.6	72.8	79.6	85.4	89.8	94.8	97.9			
T	Upper	0.7		3.0		6.7	11.7	25.0	35.8	41.4	58.6	67.1	74.9	82.4	88.4	93.3	97.1							
	Lower	0.7		3.0		6.7	11.7	25.0	35.8	41.4	58.6	67.1	74.9	82.4	88.4	93.3	97.1							

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Figure 2.- Line drawing of XP-51 airplane showing location of various items.

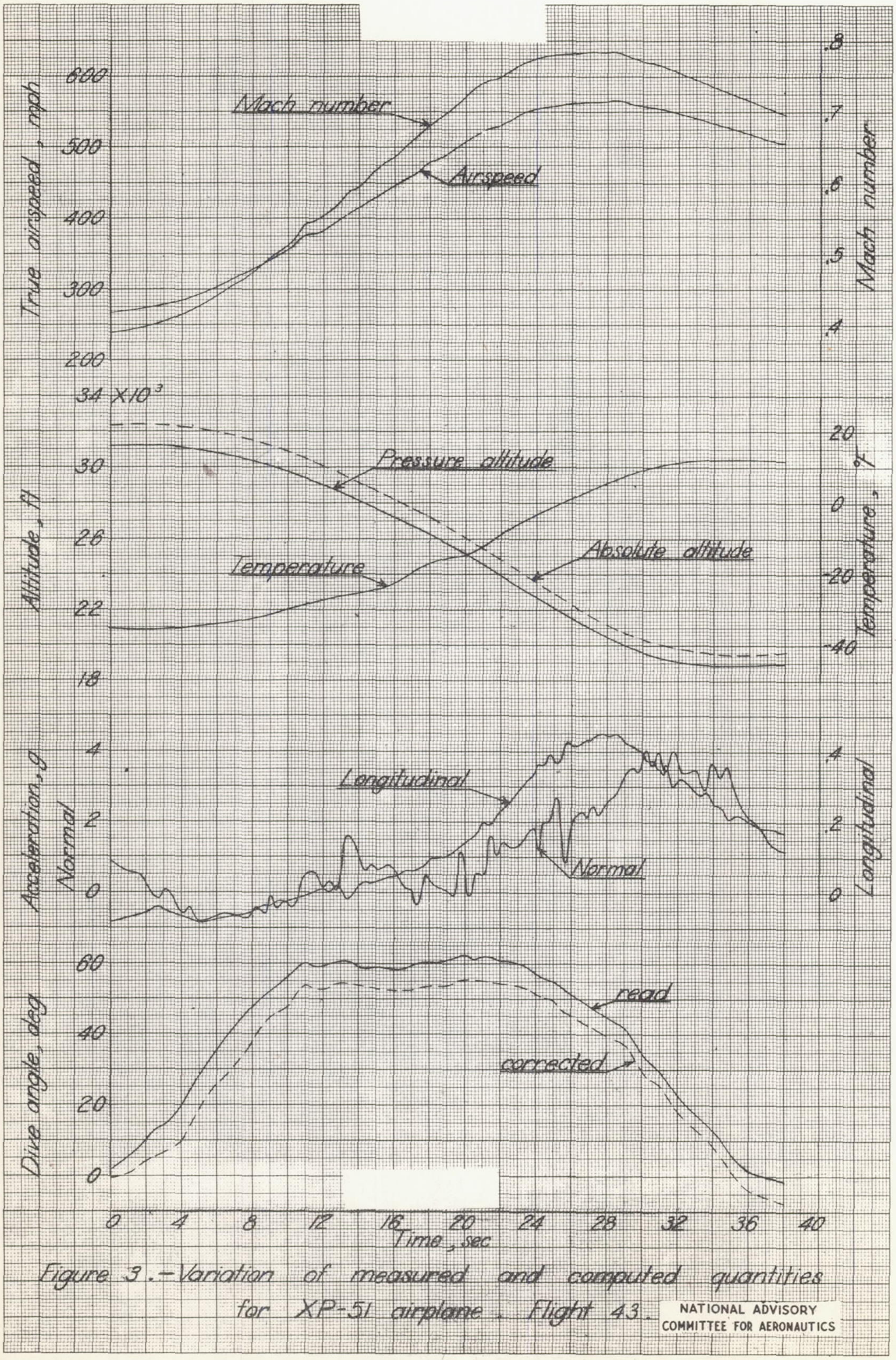

Figure 3.—Variation of measured and computed quantities for XP-51 airplane. Flight 43.

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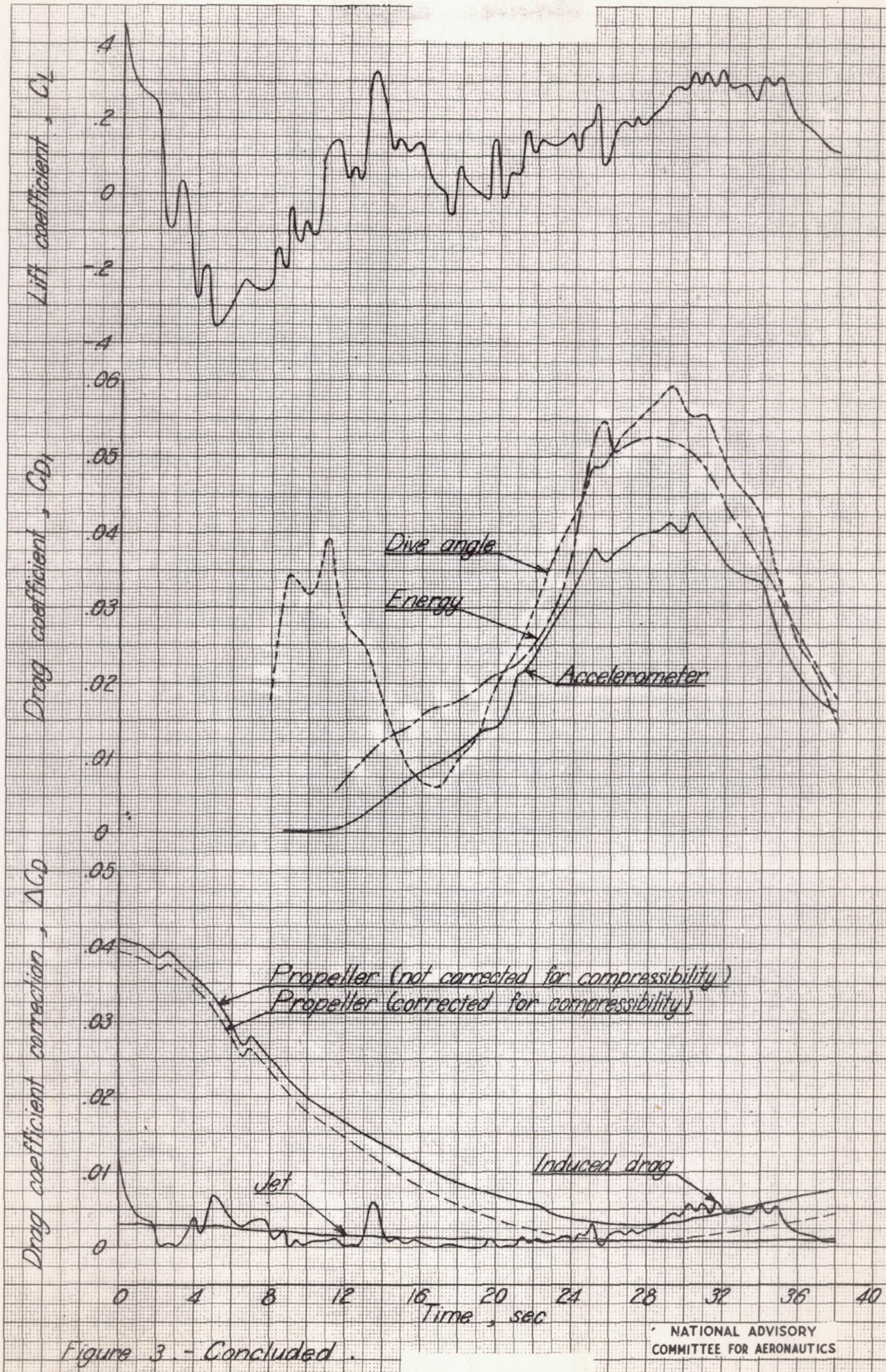
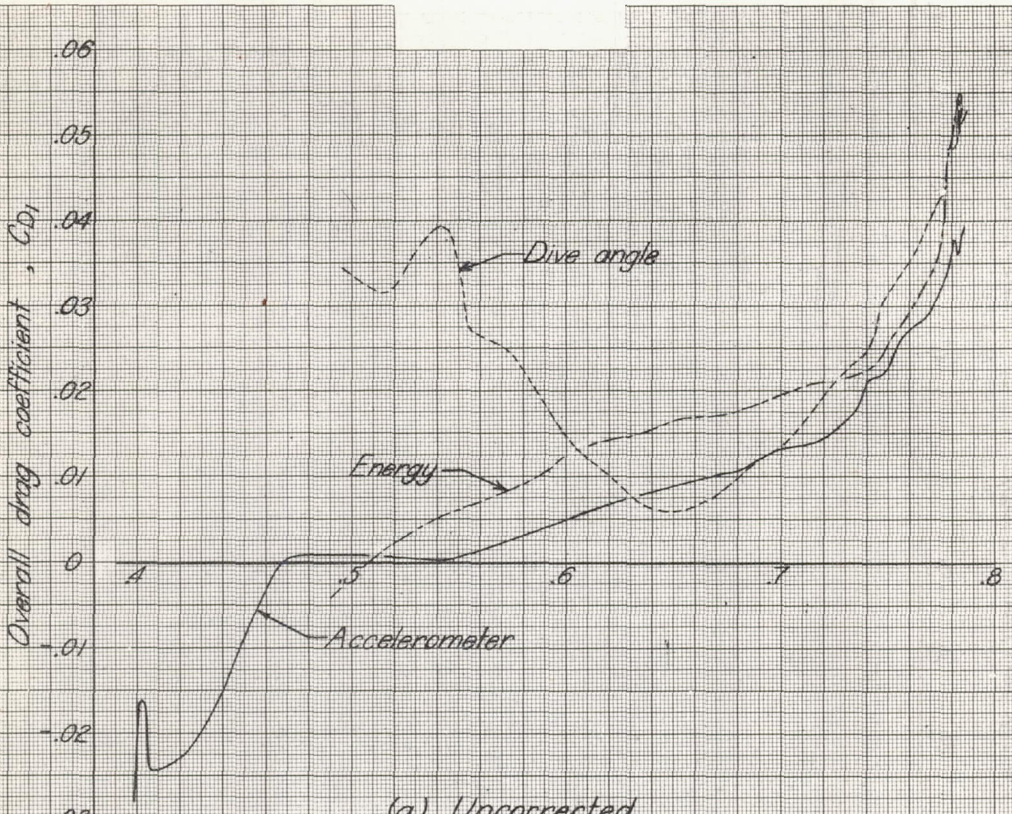
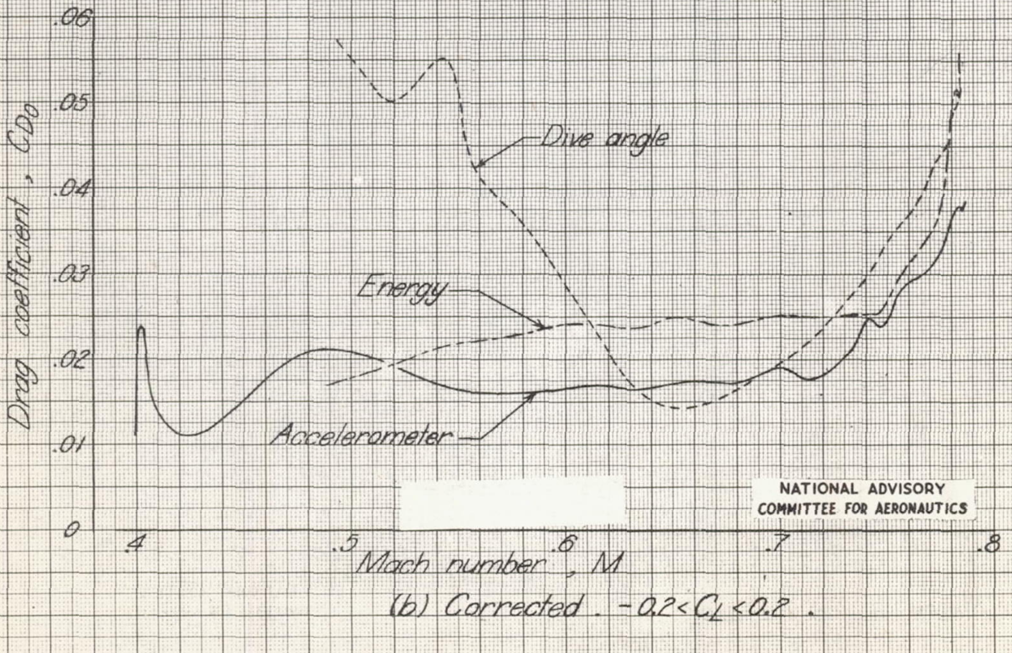


Figure 3.- Concluded.



(a) Uncorrected .



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(b) Corrected . $-0.2 < C_L < 0.2$.

Figure 4.- Variation of drag coefficient with Mach number for XP-51 airplane . Flight 43 .

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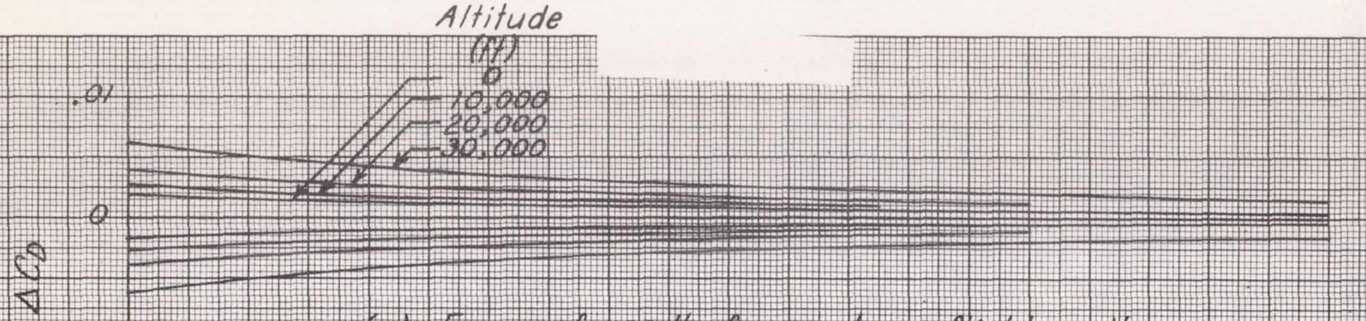
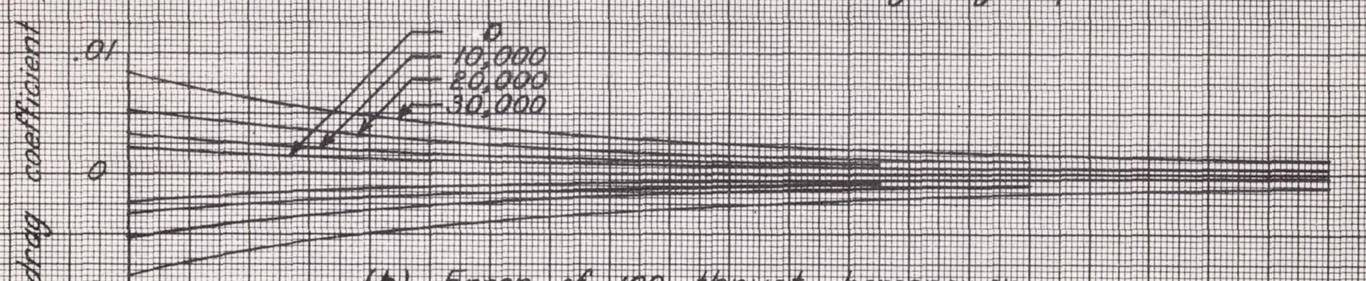
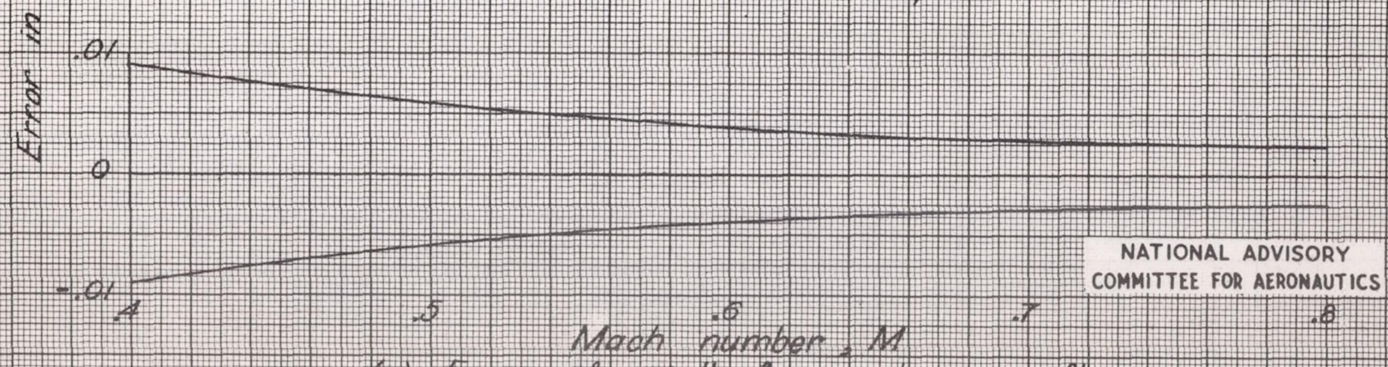


(a) Error of 100 lb force along flight path.



(b) Error of 100 thrust horsepower.



(c) Error of 236 lb force at 20,000 ft.

Figure 5. - Variation in width of error envelope with Mach number under several conditions.

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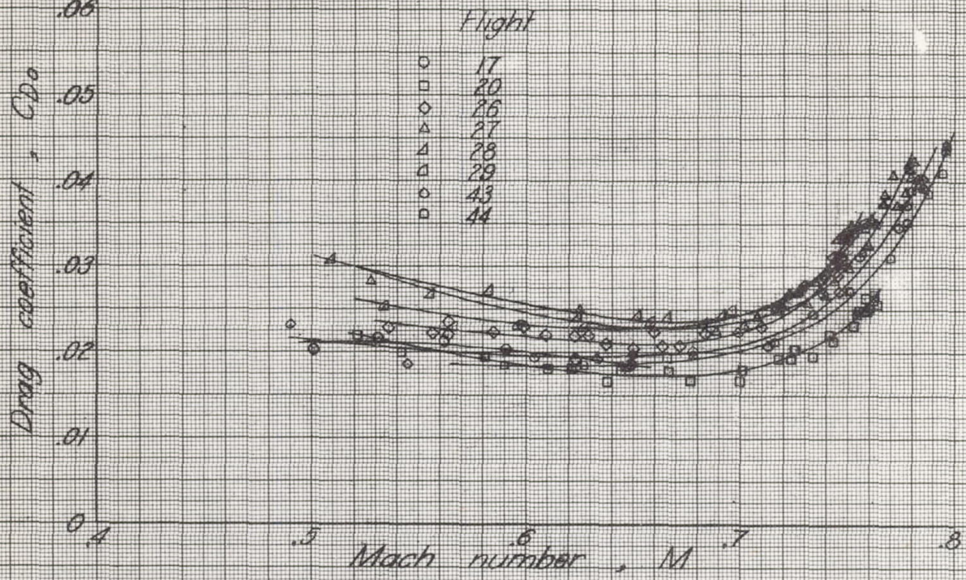
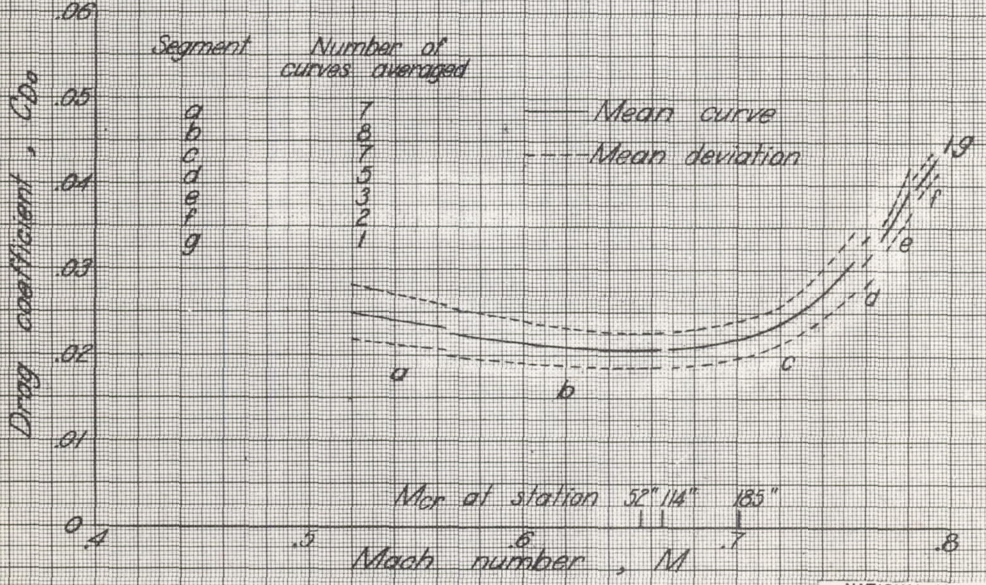


(a) From 8 dives.



(b) Mean and mean deviation.

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Figure 6.- Variation of drag coefficient with Mach number for XP-51 airplane. Accelerometer method. $-0.2 < C_L < 0.2$.

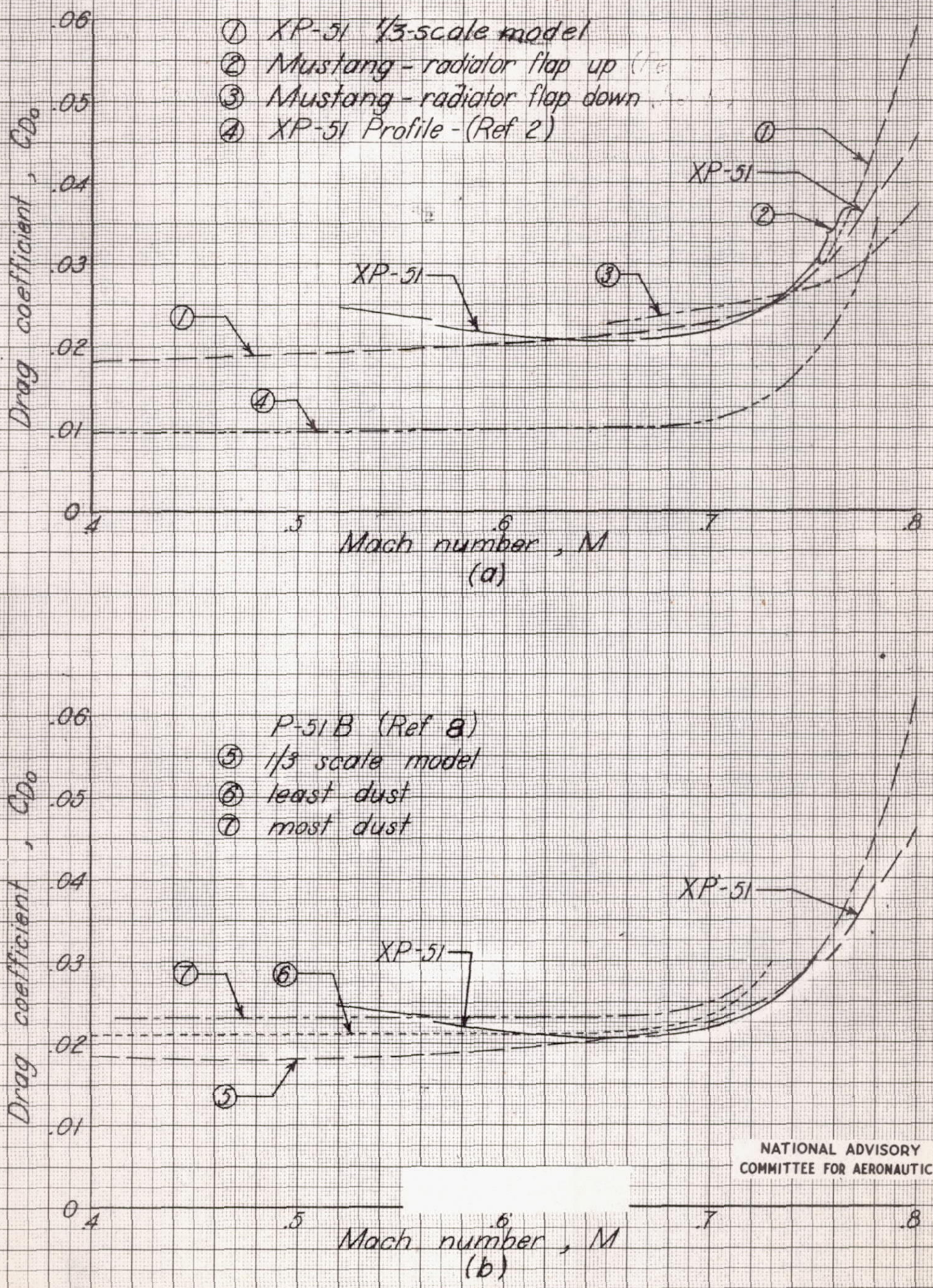

Figure 7.- Comparison of flight drag results for XP-51 with some wind tunnel and flight results at low lift coefficients. $-0.2<C_L<0.2$.