NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMPARATIVE DRAG MEASUREMENTS AT TRANSONIC SPEEDS OF RECTANGULAR AND SWEPTBACK NACA 65-009 AIRFOILS MOUNTED ON A FREELY FALLING BODY

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SUMMARY

Directly comparable drag measurements of an airfoil with a conventional rectangular plan form and an airfoil with a sweptback plan form mounted on a freely falling body have been made. Both airfoils had NACA 65-009 sections and were identical in span, frontal area, and chord perpendicular to the leading edge. The sweptback plan form incorporated a sweepback angle of 45°. The data obtained have been used to establish the relation between the airfoil drag coefficients and the free-stream Mach number over a range of Mach numbers from 0.90 to 1.27.

The results of these measurements indicate that the drag of the sweptback plan form is less than 0.3 that of the rectangular plan form at a Mach number of 1.00, and less than 0.4 that at a Mach number of 1.20.

INTRODUCTION

Recent interest in aerodynamic shapes and configurations which will afford minimum drag at transonic velocities has led to the present series of tests in which the variation of drag coefficient with Mach number is determined during the free fall of a test body from high altitude. The first series of tests on freely falling bodies was reported in reference 1. The present paper reports results of two free-fall tests conducted in June 1945 as an initial experimental check on the low-drag characteristics of swept wings at transonic speeds as suggested by Jones in reference 2. The data obtained from these tests provide a direct comparison of the drag of an airfoil having a rectangular plan form with that of a similar airfoil having a sweepback angle of 45°.

The results of this investigation are presented as curves showing the variation of drag coefficient with Mach number.

APPARATUS AND METHOD

Test airfoils and bodies.– The general arrangements of the two test bodies are shown in the photographs (fig. 1) and the details and dimensions are shown on the line drawing (fig. 2). Both the airfoil with the conventional rectangular plan form and the airfoil with the sweptback plan form had equal frontal areas and spans and incorporated NACA 65–009 sections of equal chord perpendicular to the leading edge. This airfoil section was selected as representative of those now being considered for use on high-speed aircraft.

The bodies on which the test airfoils were mounted were made cylindrical, both for ease of fabrication and for reducing interference effects of the body on the airfoil drag. They were fitted with a pointed nose, similar to that of the bodies of reference 1, and with a small fairing at the tail in order to reduce the body drag at high speeds. The bodies were ballasted by addition of lead in the nose to a total weight of approximately 1300 pounds in order to attain the desired velocity and to insure a stable configuration.

The test airfoils, which were mounted near the rear of the cylindrical part of the body, entered the body through rectangular slots $9\frac{1}{2}$ inches long and 1 inch wide. They were staggered so that each pair of airfoils could be mounted on separate balances which measured the reaction between each pair of airfoils and the body. This system has the additional advantage of reducing interference effects of the rear airfoil on the front airfoil.

Measurements.– The force exerted by each pair of airfoils on the body, as measured by a spring balance, and the total retardation of body and airfoils, as measured by a sensitive accelerometer alined with the longitudinal axis of the body, were recorded at two separate ground stations during the fall of the test body by means of the NACA radio-telemetering system. A time history of the position of the body in space was recorded during the fall by use of radar and phototheodolite equipment. The drag force D acting on each pair of airfoils was obtained from the relation

$$D = R + W_T a_e$$

where

R	measured reaction between airfoils and body, pounds
W_T	weight of airfoils, pounds
a_e	reading of accelerometer, g

A survey of the atmospheric conditions applying to each test was obtained from synchronized observations of static pressure, temperature, and actual altitude during the descent of the airplane after each test.

Reduction of data.- The velocity of the body during free fall was obtained both by differentiation of the flight path as recorded by the radar and phototheodolite equipment and by integration of the vector sum of the gravitational acceleration and the directed retardation measured by the accelerometer. The directly measured values of airfoil drag D, the static pressure p, the temperature T, and the airfoil frontal area F were combined with the velocity V to obtain Mach number M and the nondimensional parameter D/Fp. In the transonic speed range, where the drag is determined primarily by Mach number rather than airspeed, curves showing the variation of D/Fp with Mach number provide the most convenient way of specifying the drag as a function of size, altitude, and Mach number. Values of conventional drag coefficient based on the frontal area of the airfoil were then obtained from simultaneous values of these parameters by use of the relation

$$C_{D_F} = \frac{D/Fp}{\frac{\gamma}{2} M^2}$$

where the ratio of specific heats γ was taken as 1.4. The conventional-airfoil drag coefficient C_D based on plan area was obtained by multiplying the values of C_{D_F} by the ratio of the frontal area to plan area. The areas used did not include area within the body.

RESULTS AND DISCUSSION

Time histories of the important quantities obtained throughout each drop are given in figures 3 and 4.

A check on the over-all accuracy of the velocity and total drag-force measurements is provided by a comparison of the velocity determined by differentiation of the flight-path data with the velocity obtained from step-by-step integration of the resultant accelerations obtained from the accelerometer. It will be noted that the two velocity curves on each time history agree within 5 to 10 miles per hour. A discrepancy of this magnitude corresponds to a mean error of 0.005g to 0.01g in the measured acceleration. This mean error is within the expected limits of accuracy of the accelerometer. The velocity curve representing the differentiation of the flight-path data was used in computing the Mach number. The accelerometer data were used as a guide in fairing this curve over the final 3 seconds of the drop. For these 3 seconds, the radar and phototheodolite data became less accurate because ground haze obscured the test body on the phototheodolite correction photographs and ground signals interfered with the radar-range signal.

The results of the airfoil-drag tests for both the conventional rectangular plan form and the sweptback plan form are summarized in figure 5 by curves showing the variation with Mach number of D/F_p ratios and drag coefficients based on both frontal and plan areas. Separate curves are presented for the front and rear airfoils of each type.

The small differences between the drag values for the front and rear airfoils may be caused by interference effects between the airfoils or between the body and airfoils. Because of these effects the data for the front airfoil should be the more reliable.

The maximum possible inaccuracies in the drag parameters decrease with increasing Mach number because of the increase in static pressure and airspeed throughout the fall. The maximum possible inaccuracy in D/F_p decreases from ±0.020 at a Mach number of 0.9 to ±0.009 at a Mach number of 1.2. Corresponding uncertainties for C_D are ±0.0033 at a Mach number of 0.9 and ±0.0015 at a Mach number of 1.2. The error in Mach number is less than ±0.01.

From the $\frac{D}{F_p}$-curves of figure 5, it may be seen that for the conventional rectangular plan form the drag per square foot of frontal area increased abruptly from 0.05 of atmospheric pressure at a Mach number of 0.90 to 0.35 at a Mach number of 0.98 and then increased at a much slower rate to approximately 0.63 of atmospheric pressure at a Mach number of 1.20. Similarly, figure 5 shows that the drag per unit frontal area for the sweptback plan form increased almost linearly from 0.04 of atmospheric pressure at a Mach number of 0.9 to 0.29 at a Mach number of 1.27. The drag per square foot of cross-sectional area for the sweptback plan form is less than 0.3 that for the conventional rectangular plan form at a Mach number of 1.0 and less than 0.4 that at a Mach number of 1.2. A theoretical explanation of the low-drag characteristics of the sweptback plan form appears in reference 2.

An independent verification of the lower drag of the sweptback plan form is provided by the difference in the total drag of the two test bodies. At a Mach number of 1.2 the directly measured airfoil drags indicate a difference in D/Fp between the rectangular and sweptback airfoils of about 0.40. (See fig. 4.) This difference in D/Fp, when independently computed from the total drag measurements, was indicated to be about 0.54. Inasmuch as the discrepancy between these values is about twice as large as the sum of the uncertainties of the individual drag measurements, at least a part of the discrepancy must result from differences in the interference effect of the two airfoil plan forms on the body drag. The body drag for the model with the rectangular plan form was evidently greater than that with the sweptback plan form. The reason for the sudden drag rise evident in the curves of figure 5 for the front airfoil of the conventional rectangular plan form at a Mach number of 1.07 is not apparent. Future tests are expected to clarify this phenomenon.

It may be noted from figure 3 that the total drag of the body equipped with the rectangular airfoil showed a short-period oscillation of small amplitude. The first evidence of this oscillation appeared at a Mach number of 0.98 with a negligible amplitude and a frequency of 2 cycles per second. The oscillation became appreciable and regular at $M = 1.05$ and increased slowly to an amplitude of ±20 pounds and a frequency of 3 cycles per second at the impact Mach number of 1.20. It appears likely that this small oscillation of the total drag resulted from a slight yawing and a rotation of the body during the descent. The body was observed to rotate but did not appear to yaw visibly during the fall. The body with the sweptback airfoil neither yawed nor rotated during the fall, according to reports of observers.

CONCLUDING REMARKS

Directly comparable drag measurements have been made of an airfoil with a conventional rectangular plan form and an airfoil with a sweptback plan form mounted on a freely falling body. These measurements indicate that the drag of the sweptback plan form is less than 0.3 that of the rectangular plan form at a Mach number of 1.00 and less than 0.4 that at a Mach number of 1.20.

For the conventional rectangular plan form, the drag per square foot of frontal area increased abruptly from 0.05 of atmospheric pressure at a Mach number of 0.90 to 0.35 at a Mach number of 0.98 and then increased at a much slower rate to approximately 0.63 at a Mach number of 1.20.

The drag per square foot of frontal area for the airfoils with sweptback plan form increased almost linearly from 0.04 of atmospheric pressure at a Mach number of 0.90 to 0.29 at a Mach number of 1.27.

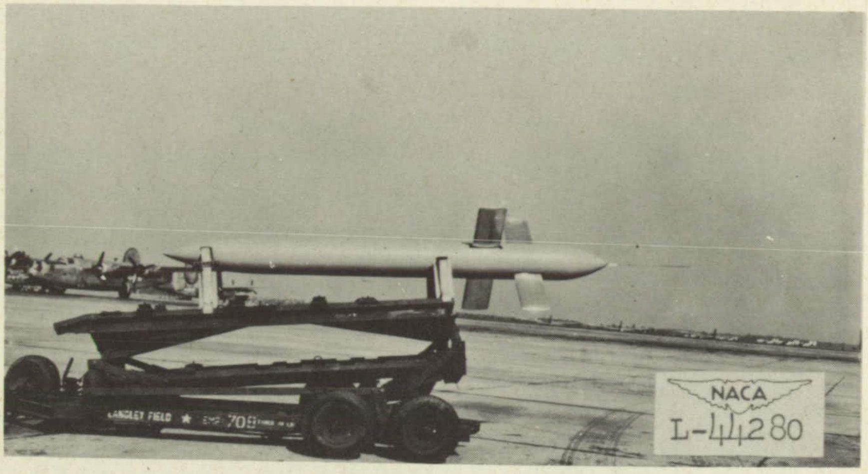
The appreciable magnitude of the drag reduction effected by the sweptback plan form indicates that continued research is desirable to improve further the aerodynamic characteristics of such configurations.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., August 9, 1945

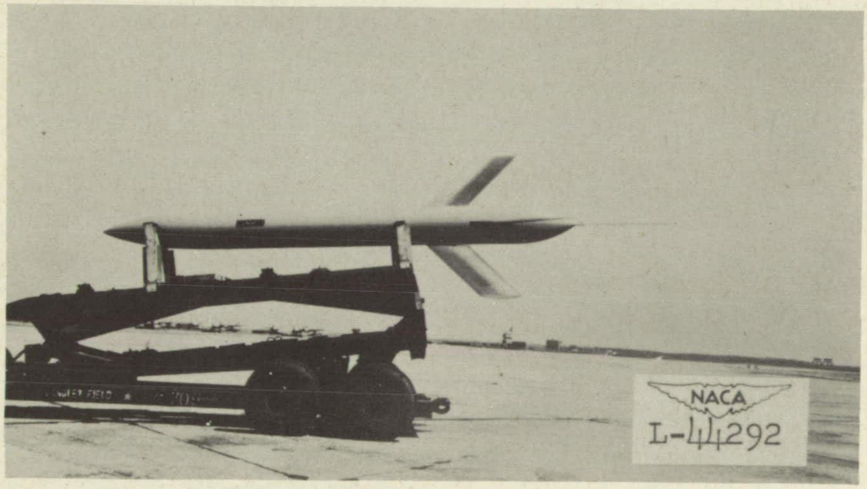
REFERENCES

1. Bailey, F. J., Jr., Mathews, Charles W., and Thompson, Jim Rogers: Drag Measurements at Transonic Speeds on a Freely Falling Body. NACA ACR L5E03, 1945.

2. Jones, Robert T.: Wing Plan Forms for High-Speed Flight. NACA Rep. 863, 1947.

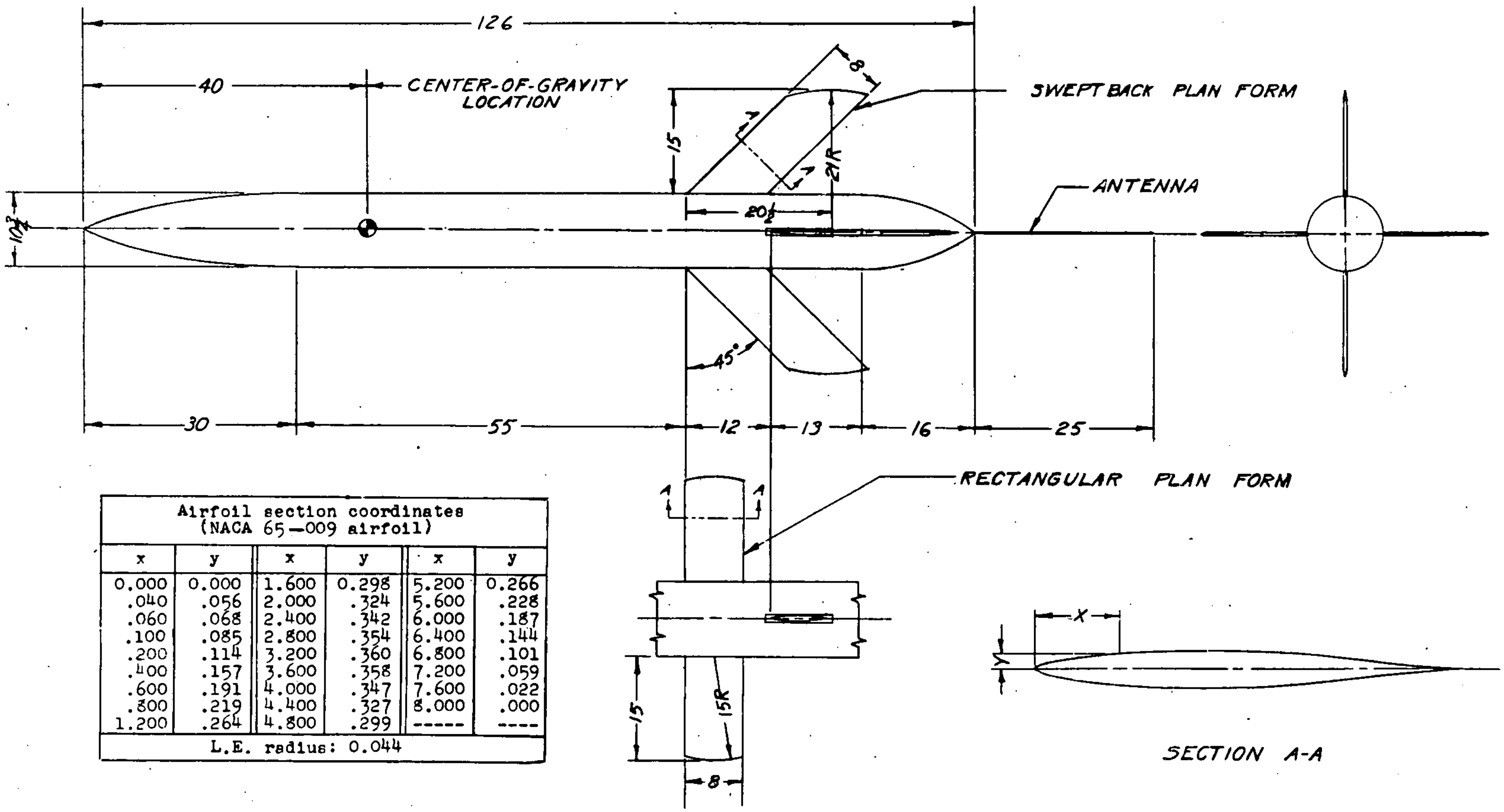


(a) Rectangular plan form.



(b) Sweptback plan form.

Figure 1.- General views of airfoil test bodies.



Airfoil section coordinates
(NACA 65—009 airfoil)

x	y	x	y	x	y
0.000	0.000	1.600	0.298	5.200	0.266
.040	.056	2.000	.324	5.600	.228
.060	.068	2.400	.342	6.000	.187
.100	.085	2.800	.354	6.400	.144
.200	.114	3.200	.360	6.800	.101
.400	.157	3.600	.358	7.200	.059
.600	.191	4.000	.347	7.600	.022
.800	.219	4.400	.327	8.000	.000
1.200	.264	4.800	.299	-----	----

L.E. radius: 0.044

Figure 2.– General arrangements and dimensions of airfoil test bodies. (All dimensions are in inches.)

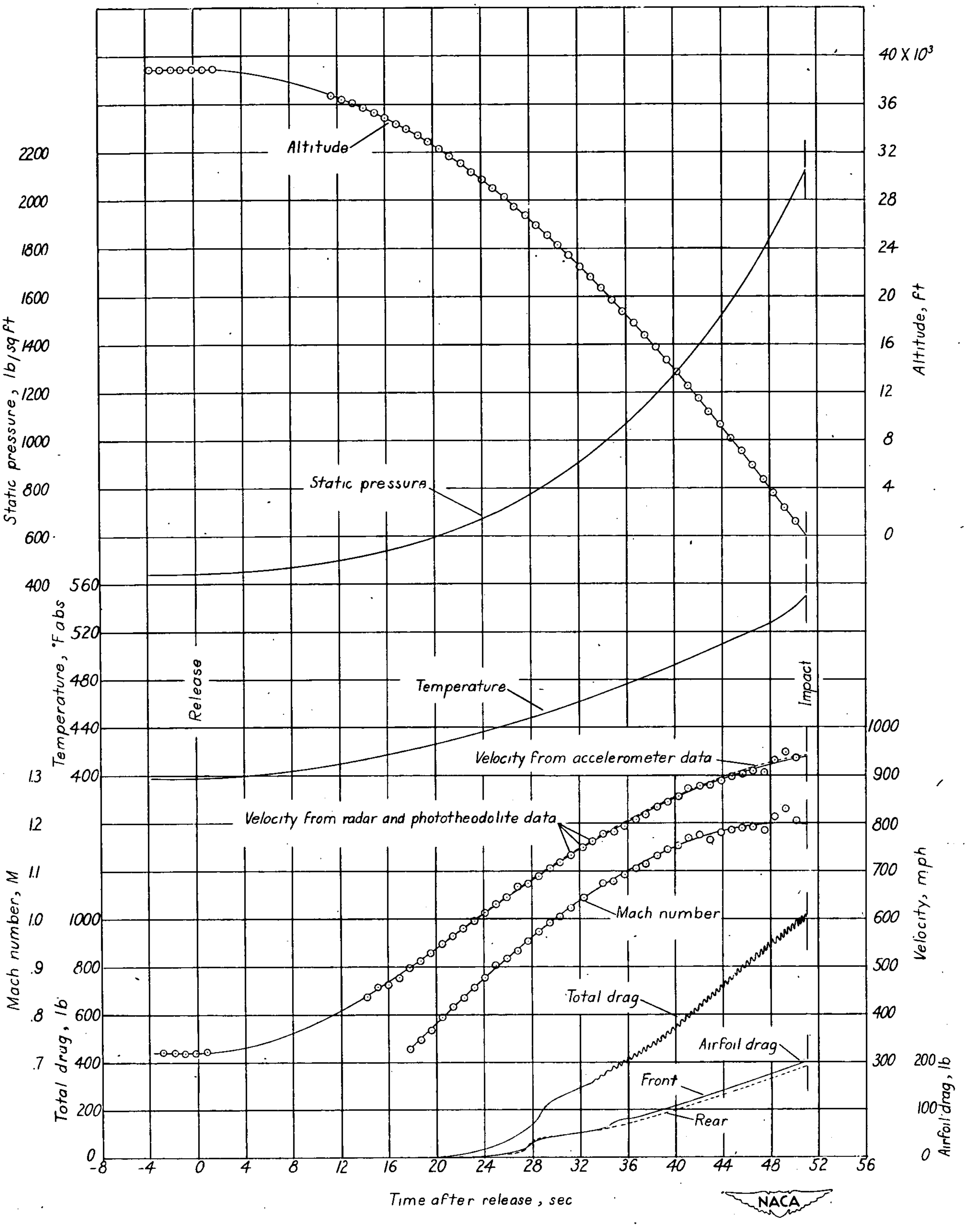


Figure 3.- Time history of free fall of 1295-pound test body equipped with airfoils of conventional rectangular plan form. (NACA 65-009 section.)

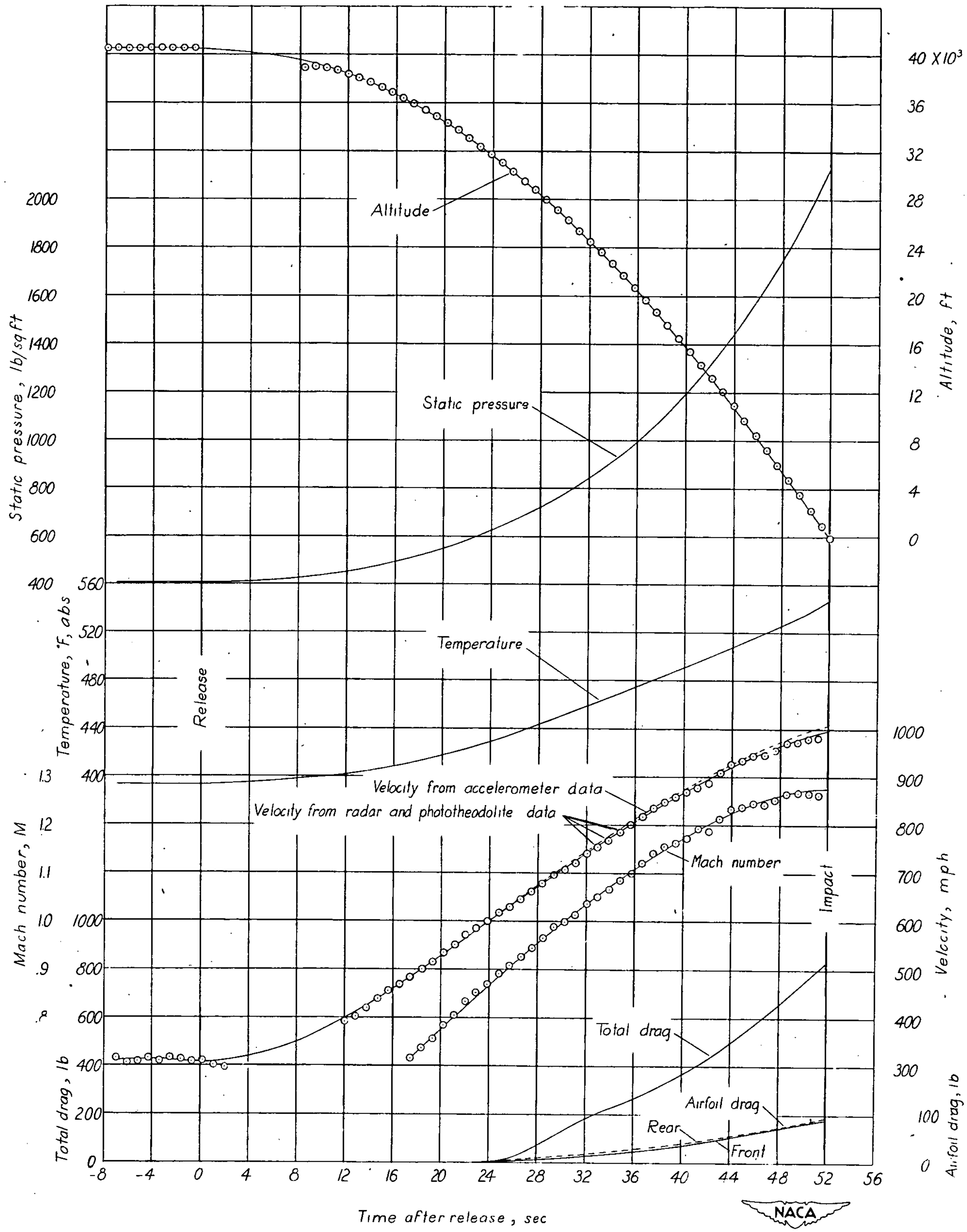


Figure 4.– Time history of free fall of 1310-pound test body equipped with airfoils of sweptback plan form. (NACA 65-009 section.)

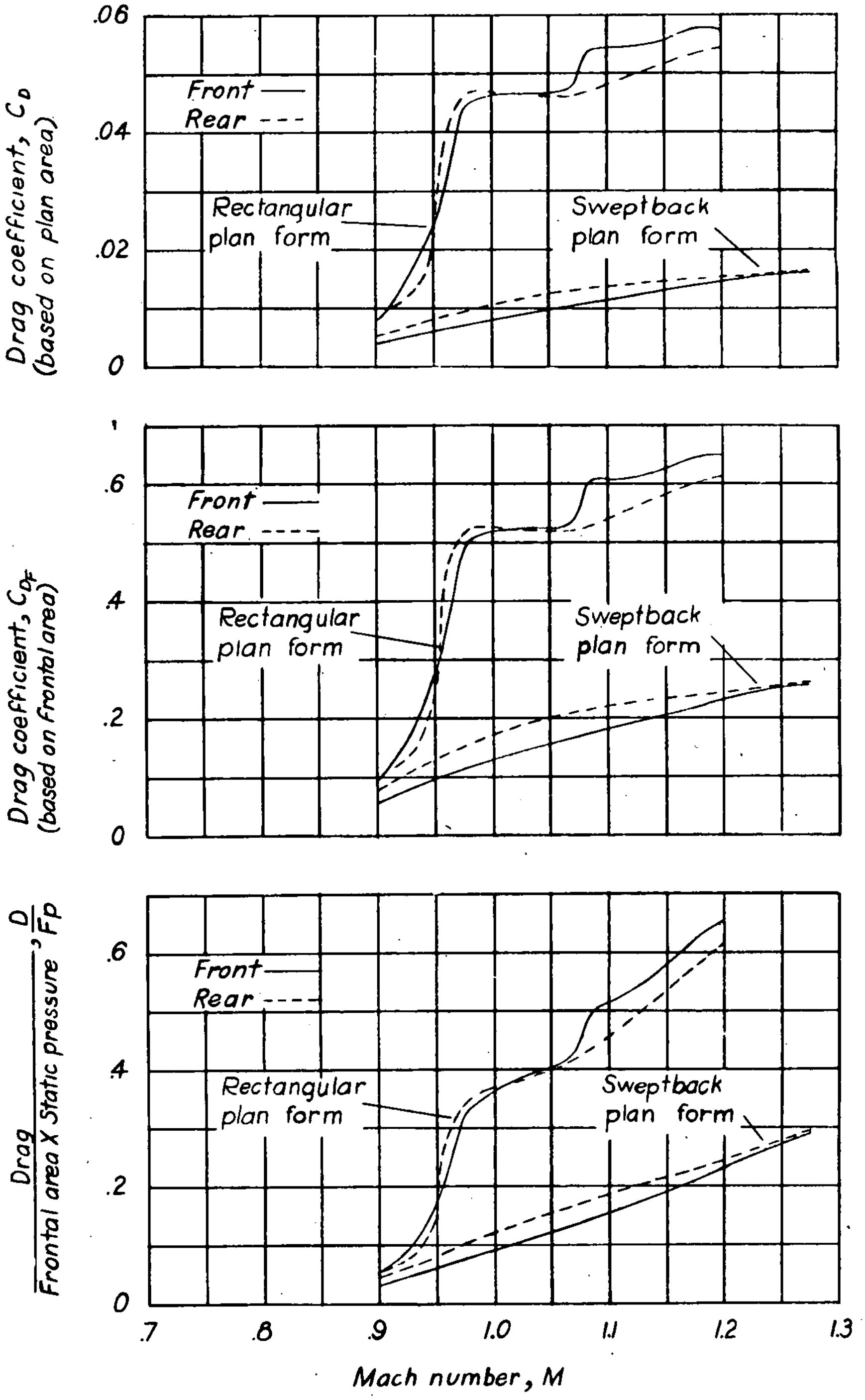


Figure 5.- Variation with Mach number of airfoil drag coefficients and D/Fp for airfoils of conventional rectangular plan form and sweptback plan form.

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