NACA

RESEARCH MEMORANDUM

DRAG MEASUREMENTS AT TRANSONIC SPEEDS OF

NACA 65-009 AIRFOILS MOUNTED ON A FREELY

FALLING BODY TO DETERMINE THE EFFECTS

OF SWEEPBACK AND ASPECT RATIO

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SUMMARY

Drag measurements at transonic speeds on rectangular
airfoils and on airfoils swept back 45° are reported.
These airfoils, which were mounted on cylindrical test
bodies, are part of a series being tested in free drops
from high altitude to determine the effect of variation
of basic airfoil parameters on airfoil drag characteristics
at transonic speeds. These rectangular and swept-back
airfoils had the same span, airfoil section (NACA 65-009),
and chord perpendicular to the leading edge. The tests
were made to compare the drag of rectangular and swept-
back airfoils at a higher aspect ratio than had been used
in a similar comparison reported previously.

The results showed that the drag of the swept-back
airfoil was less than 0.15 that of the rectangular airfoil
at a Mach number of 1.00 and less than 0.30 that of the
rectangular airfoil at a Mach number of 1.17.

A comparison of these swept-back airfoils with
similar airfoils of lower aspect ratio previously tested
by the same method indicated that in the investigated
speed range reduction in aspect ratio results in increased
drag. In the highest part of the investigated speed range,
however, the drag coefficient of the high-aspect-ratio
swept-back airfoils showed a tendency to approach that of
the lower-aspect-ratio swept-back airfoils. A similar
comparison for the rectangular airfoils showed

that delay in the drag rise and a reduction in drag at
supercritical speeds can be realized through reduction
in aspect ratio. These results confirm those reported
in NACA ACR No. L5J16.

INTRODUCTION

A serious limitation on practical flight in the
transonic-speed range results from the large abrupt
increases in drag of conventional airplane configurations
as sonic speed is approached. Because of the impor-
tance of this problem, a series of tests is being conducted
at the Langley Memorial Aeronautical Laboratory of the
NACA to determine aerodynamic shapes and configurations
that have a minimum of drag at transonic speeds. In these
tests, data are telemetered from special test configurations
during free fall from high altitude. Previous tests in
which this method was employed were reported in references 1
and 2. The object of the present tests was to compare
the drag of rectangular and swept-back airfoils at a higher
aspect ratio than had been used in a similar comparison
reported in reference 2.

For the tests reported herein drag measurements
were made on rectangular airfoils and on airfoils having
45° sweepback. These airfoils incorporated NACA 65-009
sections of equal chord perpendicular to the leading edge
and differed from the airfoils of reference 2 only by an
increase in span. The subscript 1 has been deleted from
the designation of NACA 6-series airfoils with thickness
ratios less than 0.12 of the chord. The airfoil designated
65-009 in the present paper, therefore, is the airfoil
section designated 65_1-009 in reference 2.

The results of the tests on these airfoils are pre-
sented as curves showing the variation of drag coeffi-
cient with Mach number in the transonic-speed range.
Comparable curves are also presented for the airfoils of
reference 2.

APPARATUS AND METHOD

Test configurations.- The general arrangement of the
two test configurations is shown in figure 1, and details
and dimensions are shown in figure 2. The airfoils were
mounted on bodies identical with those of reference 2.
These bodies were cylinders of $10\frac{3}{4}$-inch diameter and were
fitted with a pointed nose and a small tail fairing.
The airfoils were located near the rear of the cylin-
drical part of the body and entered the body through
rectangular slots $9\frac{1}{2}$ inches long and 1 inch wide. The
airfoils were staggered so that front and rear airfoil sets
could be mounted on separate spring balances. This
arrangement has the additional advantage of reducing the
interference effects of the rear airfoil on the front
airfoil.

Both the rectangular airfoils and the airfoils having
$45°$ sweepback had NACA 65-009 sections of 8-inch chord
perpendicular to the leading edge and equal spans of
25 inches outboard of the body as compared with 15 inches
for the otherwise identical airfoils of reference 2.

The nominal aspect ratio b^2/S for the present
swept-back airfoils was 5.4 as compared with 3.6 for the
swept-back airfoils previously tested, where b is the
over-all span of each airfoil set and S is the plan area
of each airfoil set including that within the body.
Corresponding nominal aspect ratios for the rectangular
airfoils were 7.6 and 5.1, respectively.

Measurements.- Measurement of the desired quantities
was accomplished as in the previous tests (reference 2)
through use of the NACA radio-telemetering system and
radar and phototheodolite equipment. The following
quantities were recorded at two separate ground stations
by the telemetering system:

(1) The force exerted on the body by each set of
airfoils as measured by a spring balance

(2) The total retardation of the body and airfoils
as measured by a sensitive accelerometer alined with the
longitudinal axis of the body

(3) The local static pressure at a station on the body $1\frac{1}{2}$ chords ahead of the front airfoil as measured by four orifices connected to an aneroid pressure cell (see fig. 2).

A time history of the position of the body during its fall was recorded with respect to ground axes by the radar and phototheodolite equipment, and a survey of atmospheric conditions applying to each test was obtained from synchronized records of atmospheric pressure, temperature, and geometric altitude taken during the descent of the airplane from which the bodies were dropped.

Reduction of data.- As in the previous tests the velocity V of the body during its fall was obtained both by differentiation of the flight path as determined from radar and phototheodolite records and by integration of the vector sums of gravitational acceleration and the directed retardation as measured by the accelerometer. The drag D of each set of airfoils was obtained from the relation

$$D = R + W_t a_e$$

where

R   measured reaction between airfoil and body, pounds

W_t weight of airfoil assembly, pounds

a_e reading of accelerometer (retardation), g

The atmospheric pressure p, the temperature T, and the airfoil frontal area F were combined with the simultaneous values of velocity and airfoil drag to obtain Mach number M and the ratio D/Fp. A curve of this parameter D/Fp against Mach number affords a simple and convenient means for expressing drag in the transonic-speed range as a function of Mach number, altitude, and size.

Values of conventional drag coefficient based on frontal area C_{D_F} were obtained from 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.
Drag coefficient C_D based on plan area was obtained by
multiplying values of C_{D_F} by the ratio of frontal area
to plan area. Areas used did not include those within
the body.

RESULTS AND DISCUSSION

Time histories of the pertinent quantities obtained
from each test are given in figures 3 and 4. A check on
the over-all accuracy of the velocity and retardation
measurements is provided in these figures by a comparison
of the velocity obtained from flight-path data (test
points and solid fairing) with the velocity obtained from
acceleration data (dashed fairing). The maximum discrep-
ancy in velocity obtained by these two independent
methods may be seen to be about 10 miles per hour. If the
source of this error is wholly in the measurement of
retardation, the corresponding mean accelerometer error
would be of the order of 0.01g, which is within the
expected limit of accuracy of this instrument. The
velocities used to compute the Mach number were those
taken from the fairing of the flight-path data. The
acceleration data, however, were used as a guide for this
fairing, particularly in the fairing of the last few
seconds of the data shown in figure 3, where photographs
used for correcting small errors in pointing of the photo-
theodolite were not obtained.

Figures 3 and 4 also afford a comparison between
the variations of atmospheric pressure and local static
pressure $1\frac{1}{2}$ chords ahead of the front airfoil. Except
in the immediate vicinity of Mach number 1.00, where
abrupt changes in local static pressure are quite defi-
nitely indicated, the two pressure measurements agree
within the probable limit of accuracy of the telemetering
system. Because of this limitation on accuracy, further
tests must be made before the validity of the smaller
differences can be definitely established. The differ-
ences between the subsonic values of atmospheric and
local static pressure in figure 3, however, suggest the
presence of a blocking effect caused by the airfoils,
although the magnitude of this error is larger than would
normally be encountered at low subsonic speeds.

The results of the tests are summarized in figure 5, where curves are presented that show the variations of D/F_p and C_D with flight Mach number for the rectangular and for the swept-back airfoils. The results for the front and rear airfoils are presented separately because interference effects between body and airfoils and between airfoils may cause the small discrepancies. Because of the possibility of interference effects, data for the front airfoils should be the more reliable, particularly at supersonic speeds.

The accuracy of the values of D/F_p shown in figure 5 varies throughout the drop from about ± 0.02 at $M = 0.85$ to about ± 0.006 at $M = 1.20$. This variation is due to the increase in atmospheric pressure during the fall of the test bodies and to the fact that the airfoil drag was determined with constant accuracy (± 3 lb). Corresponding values for the accuracy of C_D are about ± 0.0035 at $M = 0.85$ and about ± 0.0005 at $M = 1.20$. The accuracy with which flight Mach number was determined was about ± 0.01, but since the velocity was determined with respect to ground reference the effect of wind has been neglected. This effect may cause the Mach number determination to be slightly more inaccurate than is indicated by the foregoing value at the lowest Mach number for which results are presented. Such error rapidly becomes negligible with increase in Mach number because the flight path of the test body quickly departs from horizontal during its fall, and, in general, wind velocities are less at the lower altitudes.

The curves of D/F_p in figure 5 show that for the rectangular airfoil the drag per square foot of frontal area increased abruptly from 0.04 of atmospheric pressure at a flight Mach number of 0.85 to 0.42 of atmospheric pressure at a Mach number of 1.00 and then increased at a slower rate to 0.61 at a Mach number of 1.17. For the swept-back airfoil the drag per square foot of frontal area increased from 0.02 of atmospheric pressure at a flight Mach number of 0.85 to 0.26 of atmospheric pressure at a Mach number of 1.25 without evidencing the abrupt drag rise characteristic of the rectangular airfoil. The drag per square foot of frontal area for the swept-back airfoil was less than 0.15 that for the rectangular airfoil at a Mach number of 1.00 and less than 0.30 that of the rectangular airfoil at a Mach number of 1.17. The measured difference in total drag of the two bodies agrees with the

measured difference in airfoil drag within the limits of
accuracy of the accelerometer (±0.09 in D/Fp at a Mach
number of 0.85 and ±0.025 in D/Fp at a Mach number of
1.20).

Figure 6 shows the effect of aspect ratio on the
drag characteristics of rectangular and swept-back air-
foils. The variations of D/Fp with Mach number for
the present rectangular airfoils and for the rectangular
airfoils of reference 2 are given in figure 6(a). These
curves show that increase of the nominal aspect ratio
from 5.1 to 7.6 reduced the Mach number at which the drag
rise started by about 0.02 and increased the values
of D/Fp above the drag rise by about 0.03. This effect
of aspect ratio verifies the results of reference 3, which
indicate that a delay in the drag rise and a reduction in
drag at supercritical speeds can be realized for rectangular
wings through decrease in aspect ratio.

Similar variations of D/Fp with Mach number for
the present swept-back airfoils and for the swept-back
airfoils of reference 2 are given in figure 6(b). These
curves show that increase in aspect ratio of the swept-
back airfoils from 3.6 to 5.4 resulted in a decrease in
D/Fp in the investigated speed range. This condition
may indicate flow disturbances at the root or tip of the
airfoils where the ideal three-dimensional flow conditions
around a swept-back airfoil of infinite span do not exist.
The drag resulting from disturbances at the root or tip
would be a greater part of the total drag for the low-
aspect-ratio airfoil. It may be noted from the curves
in figure 6(b), however, that the values of D/Fp for
the high-aspect-ratio airfoils show a tendency to approach
those of the low-aspect-ratio airfoils at the highest Mach
number investigated.

CONCLUDING REMARKS

Drag measurements at transonic speeds attained in free
fall from high altitude have been made on rectangular airfoils
and on airfoils swept back 45°. These airfoils had NACA 65-009
sections, a $60\frac{3}{4}$-inch span, and an 8-inch chord perpendicular
to the leading edge. They were mounted on a $10\frac{3}{4}$-inch-

diameter cylindrical body. The results of the tests
showed that the drag per square foot of frontal area for
the swept-back airfoil was less than 0.15 that for the
rectangular airfoil at a Mach number of 1.00 and less
than 0.30 that of the rectangular airfoil at a Mach
number of 1.17.

A comparison of these results with the results of
the previous tests on $40\frac{3}{4}$-inch-span NACA 65-009 airfoils
having 8-inch chord shows that

(1) For the airfoils swept back 45° increase in
aspect ratio from 3.6 to 5.4 produced an appreciable
reduction in drag between Mach numbers of 0.95 and 1.2
but only a slight reduction at the highest Mach number
(1.25) reached in the tests.

(2) For the rectangular airfoils an increase in
aspect ratio from 5.1 to 7.6 reduced the Mach number
at which the drag rise started by about 0.02 and resulted
in somewhat higher drag throughout the speed range investi-
gated.

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REFERENCES

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       Jim Rogers: Drag Measurements at Transonic Speeds
       on a Freely Falling Body. NACA ACR No. L5E03, 1945.

2. Mathews, Charles W., and Thompson, Jim Rogers: Com-
       parative Drag Measurements at Transonic Speeds of
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       No. L5G30, 1945.

3. Stack, John, and Lindsey, W. F.: Characteristics of
       Low-Aspect-Ratio Wings at Supercritical Mach
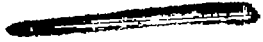   Numbers. NACA ACR No. L5J16, 1945.

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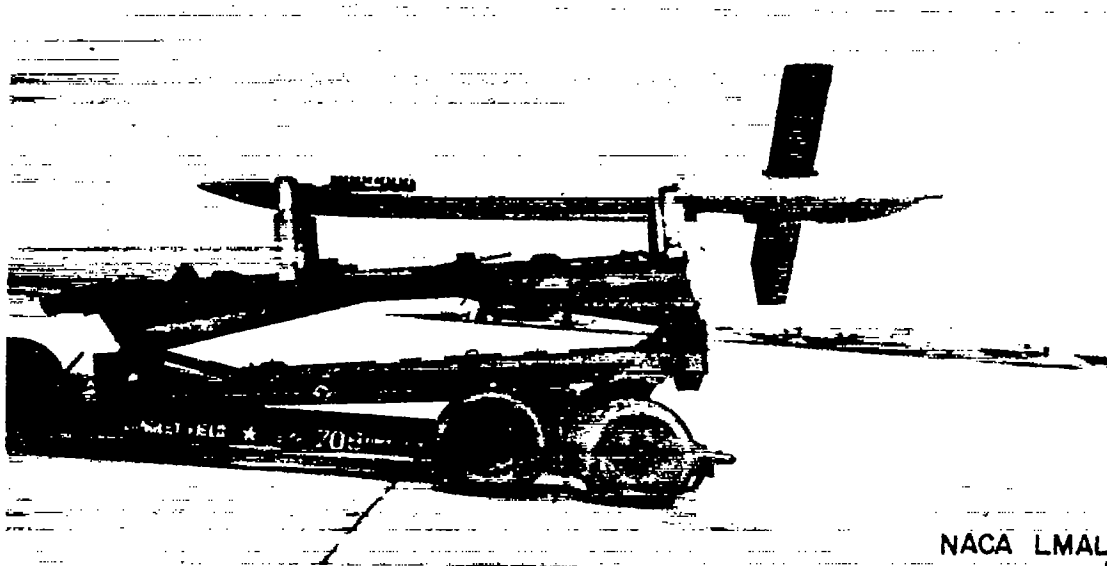
(a) Rectangular airfoil.
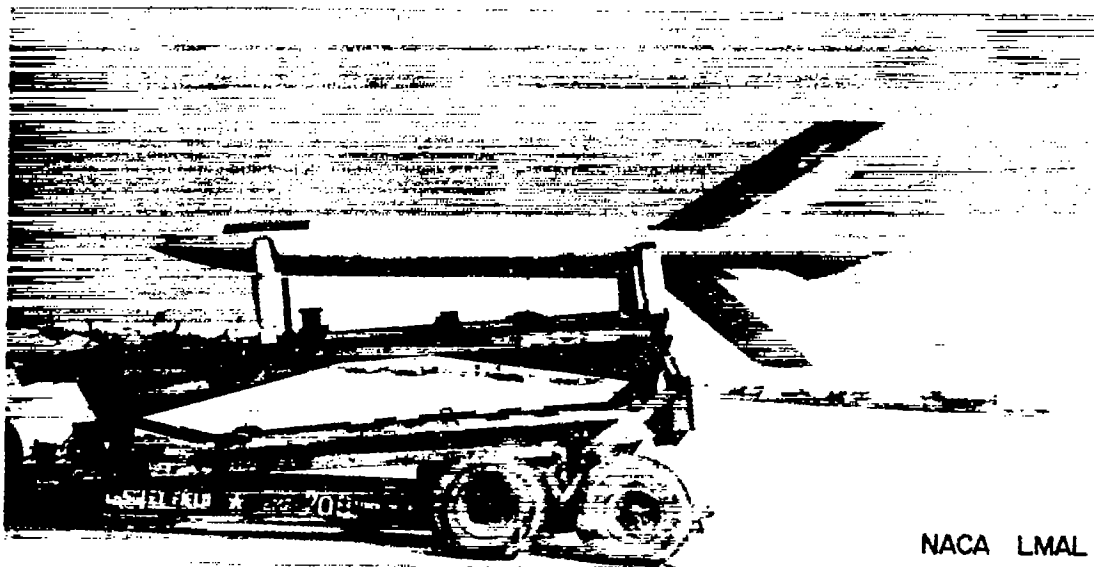
(b) Swept-back airfoil.

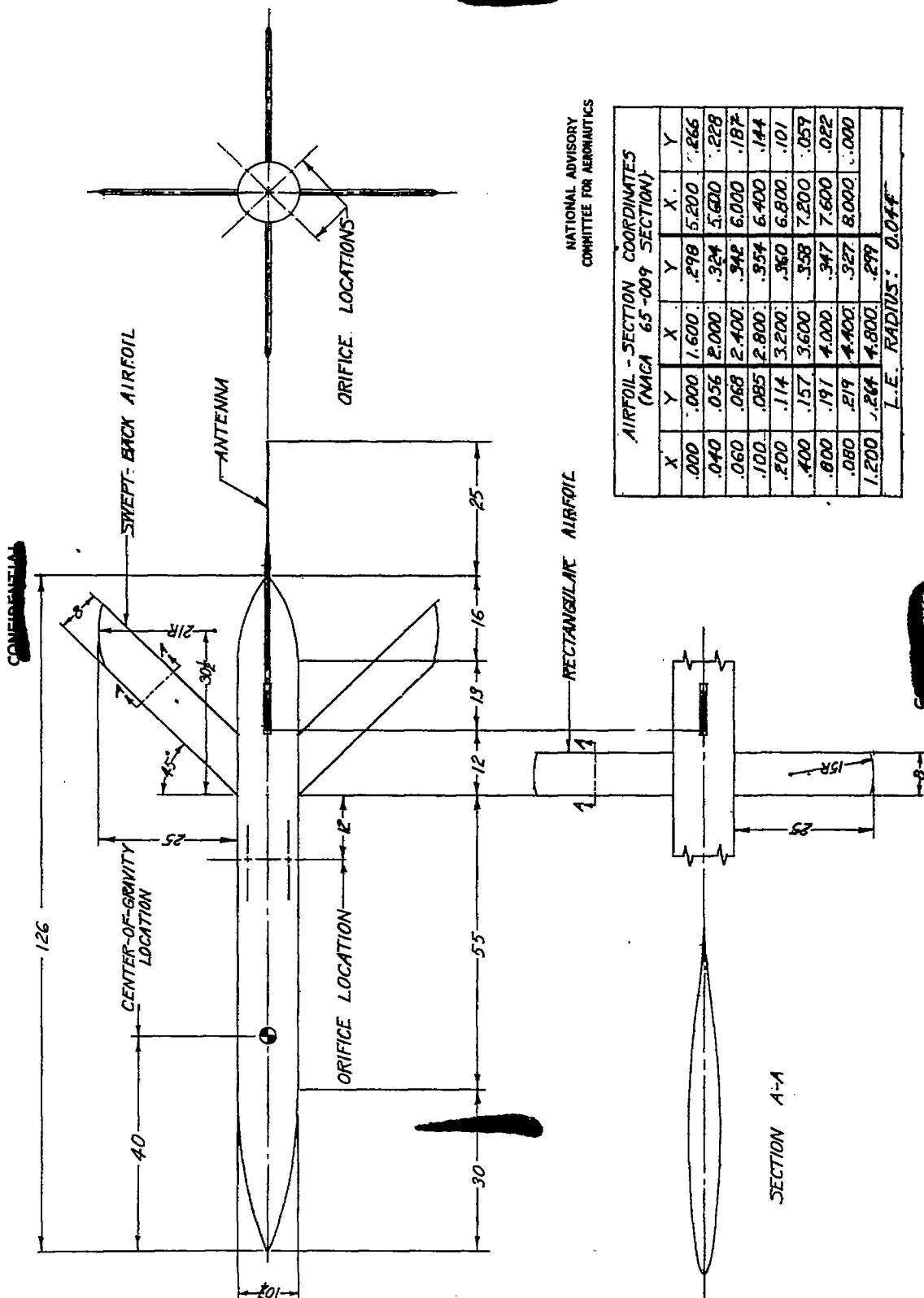Figure 1.- General views of airfoil test bodies.

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AIRFOIL-SECTION COORDINATES (NACA 65-009 SECTION)						
X	Y	X	Y	X.	Y	
.000	.000	1.600	.298	5.200	.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	.057	
.600	.191	4.000	.347	7.600	.022	
.080	.219	4.400	.327	8.000	.000	
1.200	.244	4.800	.299			

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Figure 2.- General arrangements and dimensions of airfoil test bodies. All dimensions are in inches.

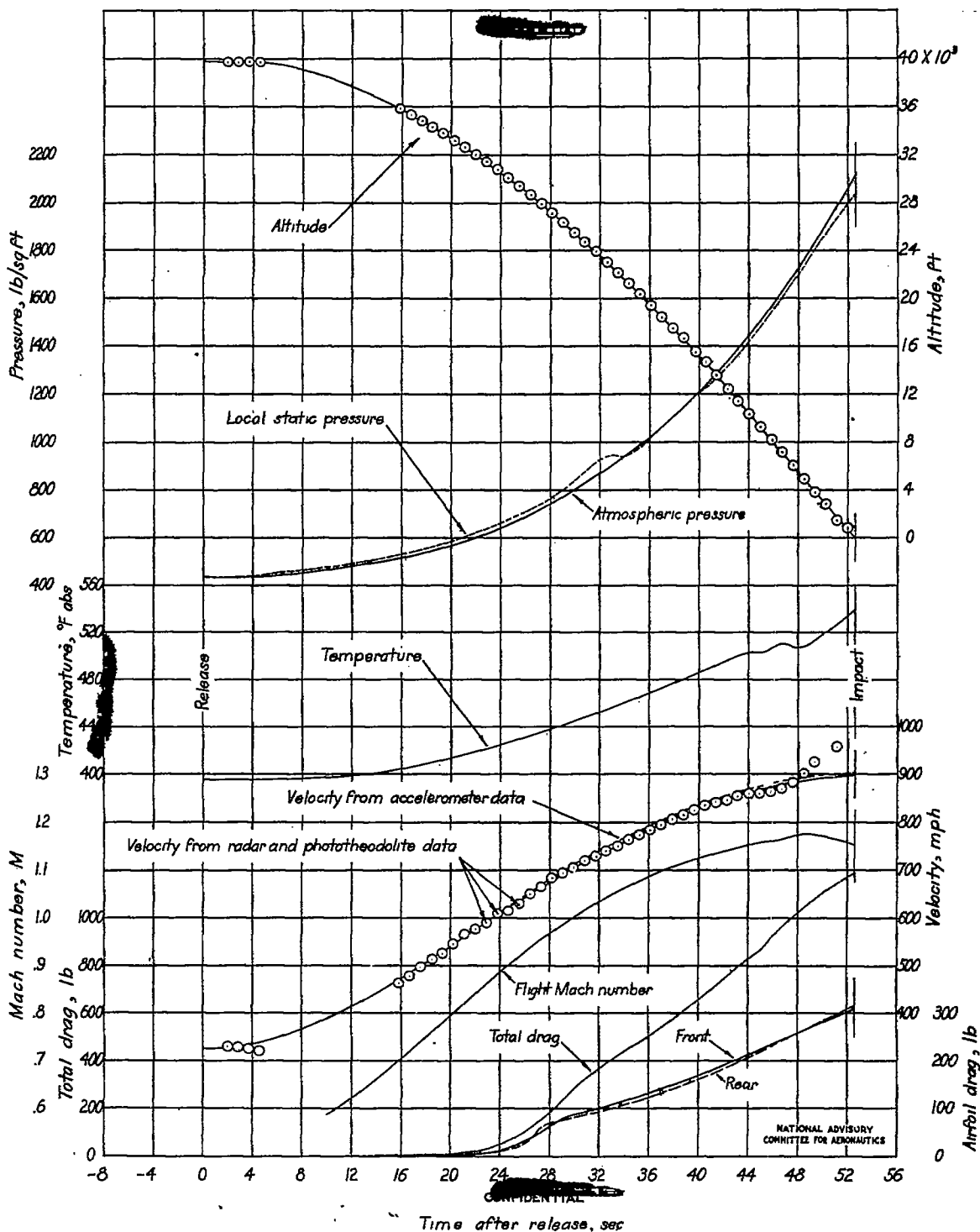Fig. 3   NACA RM No. L6K08c

Figure 3.- Time history of free fall of 1322-pound test body
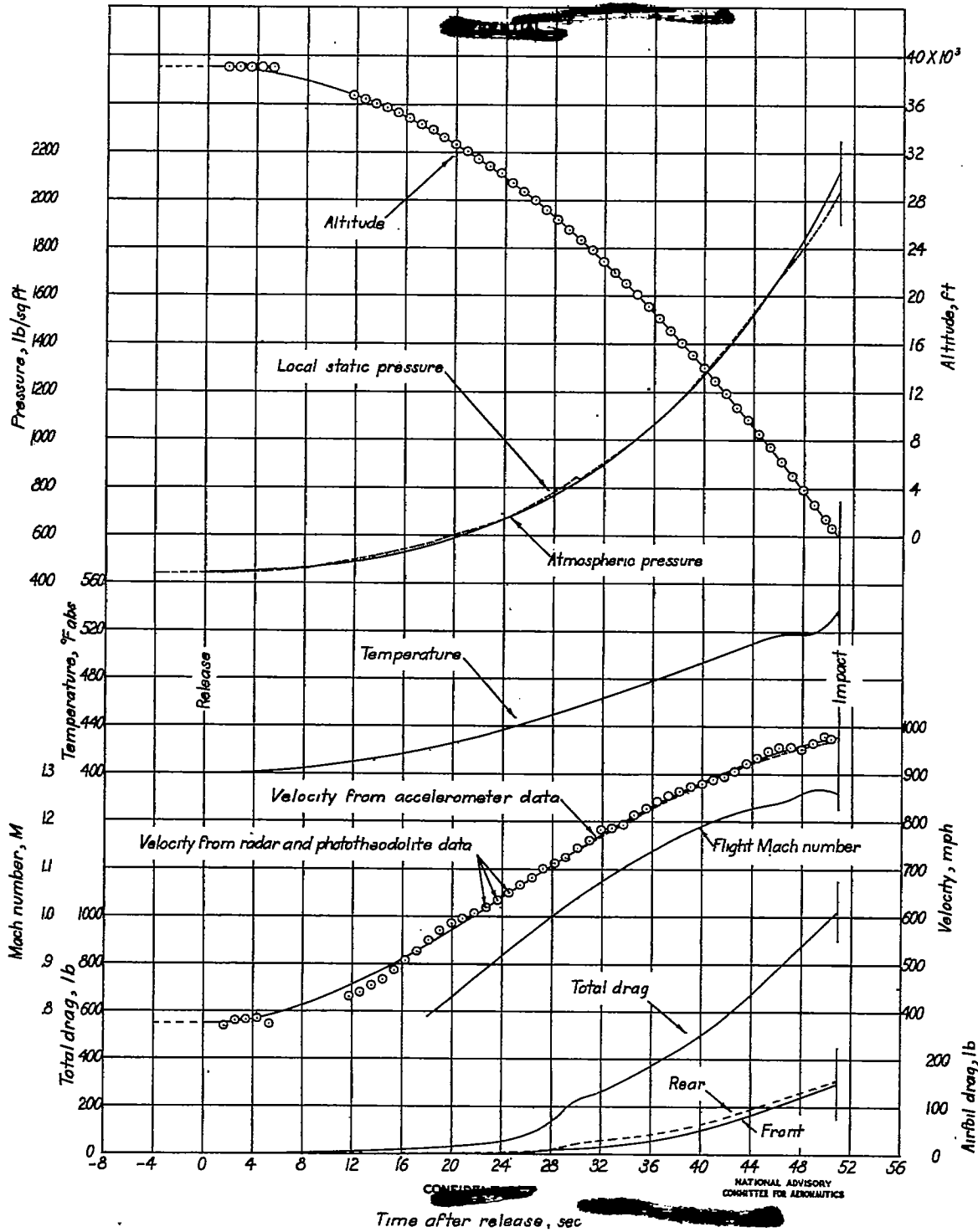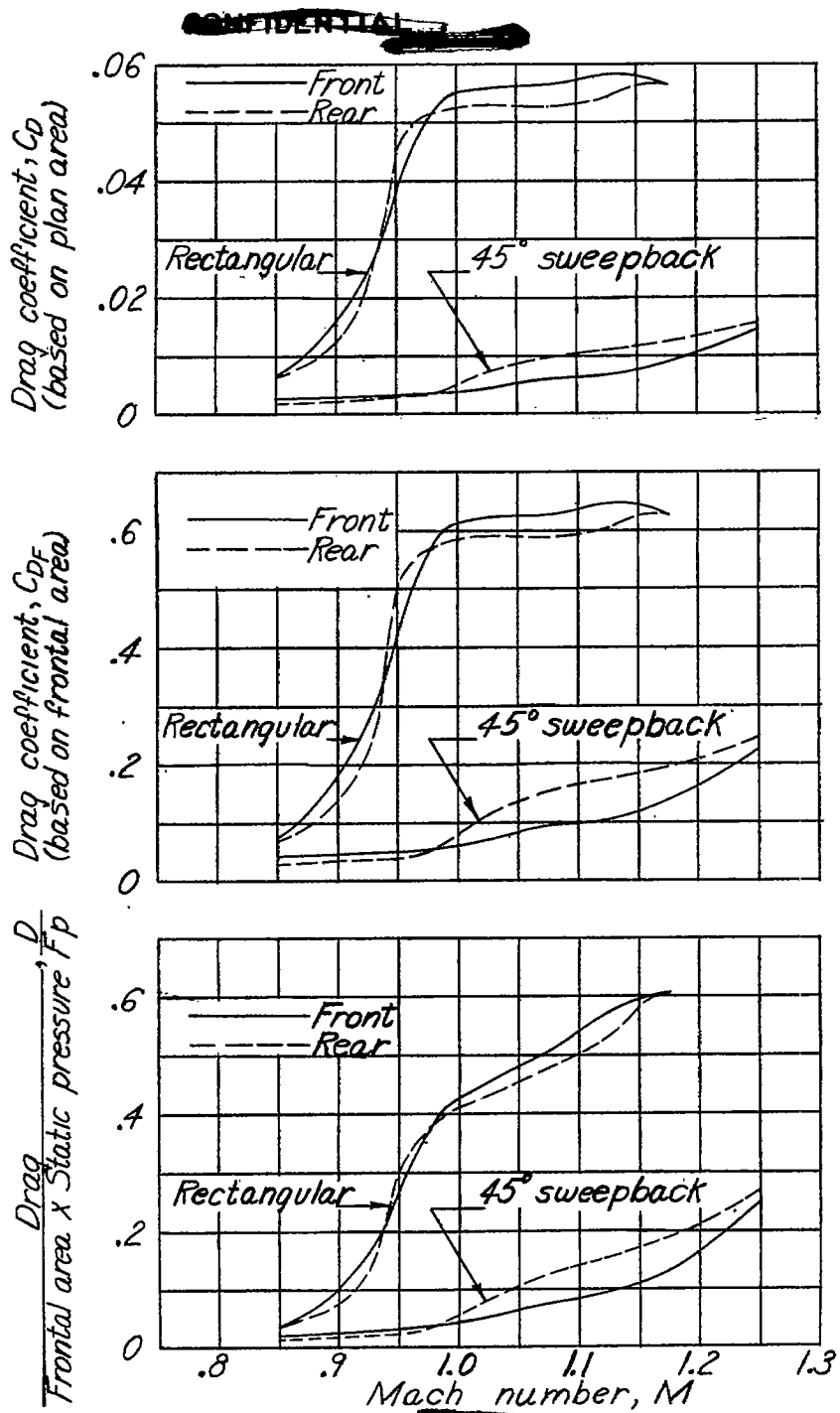mounting rectangular airfoils. NACA 65-009 airfoil sec-
tion.

Figure 4.- Time history of free fall of 1330-pound test body
mounting airfoils having 45° sweepback. NACA 65-009 air-
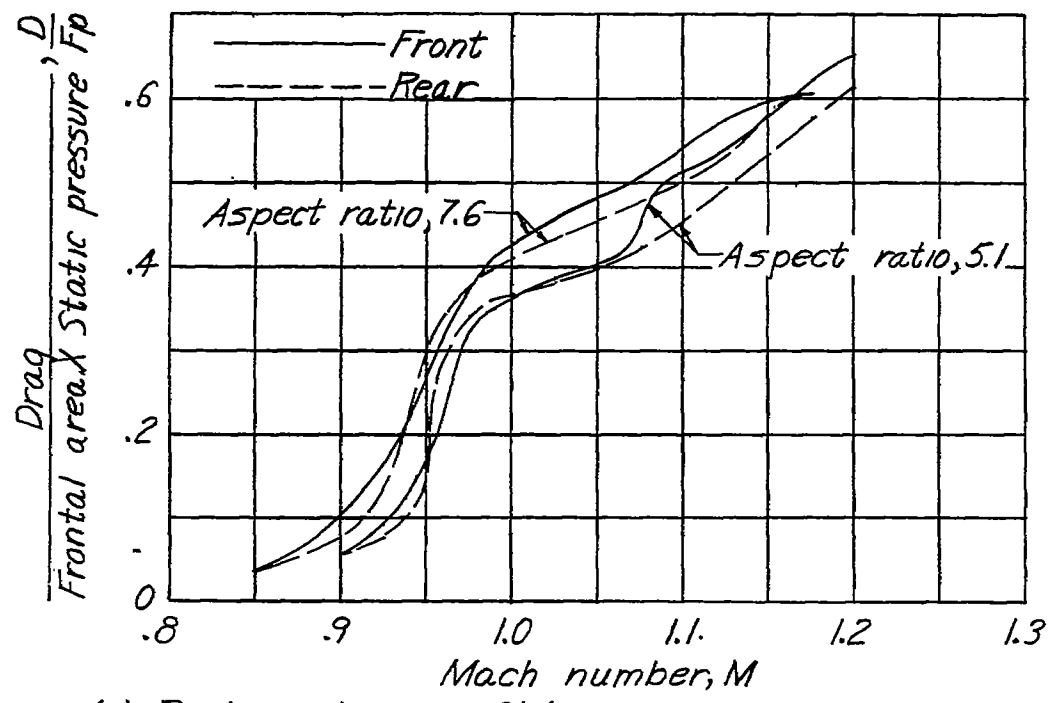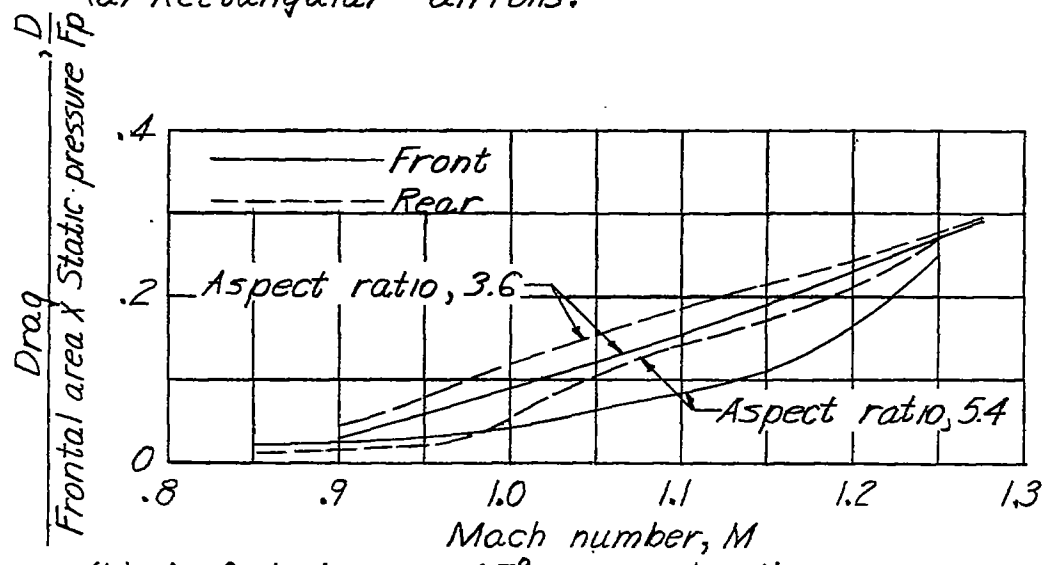foil section.

Fig. 5　　　　　　　　　　　　　　　NACA RM No. L6K08c

Figure 5.- Variation of airfoil drag coefficients and D/Fp
with Mach number for rectangular airfoils and airfoils
having 45° sweepback.

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(a) Rectangular airfoils.

(b) Airfoils having 45° sweepback.

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Figure 6.- Effects of aspect ratio on variation of D/Fp with
    Mach number for rectangular airfoils and airfoils having
    45° sweepback.