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MEASUREMENTS IN FLIGHT OF THE LONGITUDINAL CHARACTERISTICS OF TWO JET AIRCRAFT, ONE WITH A DIVING TENDENCY AND THE OTHER WITH A CLIMBING TENDENCY AT HIGH MACH NUMBERS

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Flight tests were conducted on two straight-wing jet airplanes of generally similar configuration, one exhibiting a diving tendency and the other a climbing tendency, in order to investigate the cause for the particular type of behavior of each airplane at high Mach numbers.

The results showed that the diving tendency experienced by the one airplane was due to the predominant effect of an increased angle of attack of the horizontal tail. This diving tendency persisted throughout the test lift-coefficient range from 0 to 0.4. The climbing tendency exhibited by the other airplane, prominent only at the lower values of lift coefficient, resulted from an overpowering increase in wing pitching moment.

INTRODUCTION

In flight at supercritical speeds, a number of airplanes have experienced severe changes in stability and trim. As a result, difficulty in control has occurred in a number of cases, due to the development of either a strong diving tendency or climbing tendency. The foregoing trim changes become particularly significant when, in level flight, the pilot is unable to prevent a "tuck-under" or "tuck-up" because of insufficient elevator angle for balance or because of large control forces. Both the problem of the diving tendency and the climbing tendency are of interest to the designer in that either tendency can limit the tactical high speed and greatly detract from the maneuverability of an airplane.

In reference 1, the diving tendency was shown to be primarily the result of an increased angle of attack of the horizontal tail surface due to a reduction in lift-curve slope for the wing, a reduction in downwash in the vicinity of the tail, and for cambered wings a positive shift in the angle of attack for zero lift. The factors promoting a climbing tendency have been pointed out in a number of reports. Reference 2 attributed the climbing tendency encountered by a fighter-type aircraft at low values of lift coefficient and high Mach numbers primarily to a negative shift in the airplane angle of attack for zero lift. The results of reference 3 showed that the downwash and tail-off airplane pitching moment, which were producing a climbing tendency, were influenced by negative deflection of the wing flaps. Other factors, such as a change in stabilizer setting (reference 4) or a change in the vertical location of the horizontal tail, have been shown to alter the direction and magnitude of the longitudinal trim change at high Mach numbers.

Although the various factors affecting the longitudinal control at high Mach numbers are recognized and qualitatively understood, there is still considerable difficulty in predicting the longitudinal trim characteristics of an airplane at high Mach numbers due to the fact that the magnitude and direction of the trim change depends upon a relatively small difference between several large quantities. These relatively small differences are reflected as large changes in control force at high dynamic pressure and corresponding significant changes insofar as the pilot is concerned in the variation of trim with Mach number. An example of this is presented by the two airplanes discussed in this report. These airplanes were generally similar in regard to wing and tail configuration, but one exhibited a climbing tendency sufficiently severe at low altitudes to limit its maximum operating speed, while the other airplane exhibited a diving tendency. The flight tests reported herein were run for the purpose of identifying the aerodynamic factors which contribute to the difference in longitudinal control behavior.

SYMBOLS

A_Z ratio of net aerodynamic force along airplane Z axis (positive when directed upward) to weight of airplane ($A_Z = 1$ corresponds to 1g)

c local wing chord, feet

$\bar{c}$ wing mean aerodynamic chord, feet

C_L airplane lift coefficient $\left(\frac{WA_Z}{q_oS}\right)$

C_m	pitching-moment coefficient about quarter M.A.C. point $\left(\frac{\text{pitching moment}}{q_oS\bar{c}}\right)$
c_{m_w}	wing section pitching-moment coefficient about quarter-chord point
F_e	elevator control force, pounds
h_p	average altitude, feet
M	free-stream Mach number
P	pressure coefficient $\left[\frac{(p-p_o)}{q_o}\right]$
P_L	pressure coefficient on lower wing surface
P_U	pressure coefficient on upper wing surface
p	static orifice pressure, pounds per square foot
p_o	free-stream static pressure, pounds per square foot
q_o	free-stream dynamic pressure, pounds per square foot
S	total wing area, square feet
W	airplane weight, pounds
α_w	wing (fuselage reference line) angle of attack, degrees
α_t	horizontal tail (chord line) angle of attack, degrees
δ_e	elevator angle (stabilizer chord line), degrees

AIRPLANES

The airplane identified with a diving tendency is designated as airplane 1 and the airplane with a climbing tendency as airplane 2.

Three-view drawings of airplanes 1 and 2 are shown in figure 1, and three-quarter rear-view photographs of the airplanes as instrumented for flight tests are shown in figure 2. The geometric details of the airplanes are given in table I. The ordinates of the airfoils used on airplanes 1 and 2 are given in table II.

INSTRUMENT INSTALLATION

Standard NACA continuously recording instruments were used to record the various quantities measured.

Measurements of airspeed were made by airspeed heads mounted on booms two chord lengths ahead of the wing tip. Compressibility corrections for the position error due to the presence of the wing and for the head itself were applied to the airspeed readings.

Wing section pressure-distribution data were obtained from flush-type orifices mounted on the upper and lower surfaces at the 65- and 76-inch wing station for airplanes 1 and 2, respectively.

Control position recorders were connected directly to the elevator to record the deflections of the surface.

TESTS

Tests on both airplanes were conducted in the power-on clean condition for airplane 1, at altitudes of approximately 7,000 feet and 37,000 feet in a Mach number range of 0.56 to 0.85; and for airplane 2 at altitudes of approximately 15,000 feet and 35,000 feet in a Mach number range of 0.5 to 0.87. The center-of-gravity location was in the rearward position (approximately 29-percent M.A.C.) during the tests of both airplanes.

The maximum test Mach number for airplane 1 was limited by large amplitude aileron flutter (compressibility buzz), and for airplane 2, by a combination of large elevator control forces required for balance and by a wing-dropping tendency.

RESULTS AND DISCUSSION

The difference in the longitudinal behavior of the two airplanes was most noticeable to the pilot in steady 1g flight. The elevator angle and stick force required in this regime at both high and low altitudes are shown in figure 3. Airplane 1 required an increasing up-elevator deflection and increasing pull forces for balance with increasing Mach number to counteract a diving tendency at the higher Mach numbers. Insofar as the pilot was concerned, this airplane had a mild, easily controllable diving tendency over the Mach number range investigated which did not extend to as high Mach numbers as that for airplane 2. In contrast, airplane 2 exhibited a climbing tendency at Mach numbers above approximately 0.81. This climbing tendency was sufficiently severe at low altitudes to limit the maximum operating speed of the airplane. In an effort to minimize the push force required for trim at the higher Mach numbers of the tests reported herein, the pilot chose to trim the airplane upon entering the dive with full nose-down tab.

The change in longitudinal trim, indicated by the variation of elevator angle and elevator control force in figure 3 for both the high and low altitude tests, occurs at approximately the same Mach number for each airplane regardless of the difference in dynamic pressure. This indicates that the aeroelastic effects were not the primary cause of the longitudinal trim change although they had some modifying influence on this change.[1]

As indicated in the Introduction, the aerodynamic factors contributing to the trim change with Mach number are anticipated to be a change in wing angle of attack required to maintain a given lift coefficient, with a corresponding change in tail angle of attack, and a variation of pitching moment of the wing. Figure 4 presents the variation of these parameters with Mach number for both airplanes for constant values of lift coefficient from 0 to 0.4. The section pitching-moment values presented were derived from pressure-distribution measurements. Also shown is the resultant elevator angle required to maintain constant values of C_L. The cross-plotted value for steady flight at an A_Z of 1.0 is the same as that shown on figure 3. An examination of figure 4 indicates that the difference between the two airplanes is confined to the range of lift coefficients of 0.2 or less. At the higher lift coefficients, both airplanes exhibited a diving tendency which, on the basis of elevator angle required for balance, is very similar. The difference between the two airplanes in the lower lift-coefficient range apparently lies in the relative magnitudes of the moment changes produced by the wing and the tail. This point is demonstrated in figure 5 in

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[1] Some indication of aeroelastic effects in the form of stabilizer twist which would reduce the elevator effectiveness was noted for airplane 2. By comparing the values of α_t measured by a boom at the stabilizer tip over similar C_L and Mach number ranges but widely different dynamic pressure ranges (tests at 15,000 and 35,000 feet), it was found that an increase in dynamic pressure caused a decrease in measured α_t of approximately 1.3° at the highest Mach number of 0.83.

which the computed increment in δ_e (from the trim value at $M=0.7$) required for balance in steady, straight flight at $A_Z=1$ is shown. The values of δ_e were calculated using horizontal tail characteristics obtained from wind-tunnel results and the measured variations of α_t and c_{m_W} values.

The initial trend for both airplanes at Mach numbers above the trim value of 0.7 is a diving tendency produced by the predominance of the diving-moment increment due to the wing over the climbing-moment increment produced by the change in tail angle of attack. The trend of each of these factors reverses at a Mach number of about 0.75 on airplane 1 and 0.8 on airplane 2. It is at these Mach numbers that the presence of an intense shock wave is first apparent from the wing pressure distribution of both airplanes. An increase in angle of attack to maintain a given lift coefficient becomes necessary on both airplanes above this Mach number, and the tail contribution thus is a progressively increasing diving moment (as discussed in reference 2) which, for airplane 1, more than counterbalances the opposite trend of the wing pitching moment.

On airplane 2, the pitching-moment contribution of the wing predominates and, as the Mach number is increased beyond 0.8, the net result is a reversal in the trend of elevator required for balance at Mach numbers up to approximately 0.85. This net difference, although relatively small compared to the two factors involved, is the cause of the climbing tendency on airplane 2, which is reflected insofar as the pilot is concerned by a large change in force required to maintain 1g flight over the Mach number range from 0.80 to 0.85.

Wing pressure distributions of both airplanes were examined in an attempt to isolate the reason for the more abrupt and more sustained change in the pitching moment of the wing on airplane 2, to which the climbing tendency is attributable. The pressure distributions on the wing of airplane 2 (fig. 6) indicate a relatively large rearward movement of the lower surface wing shock wave combined with a small forward movement of the upper surface shock wave with increasing Mach number. The resultant redistribution of lift produces the more extreme climbing-moment.

The relatively limited Mach number range to which the climbing tendency of airplane 2 is confined is evident from figure 5. At Mach numbers above 0.85, the trend of elevator angle required for balance reverses abruptly so that a diving tendency once again is indicated. This is due in part to an added increase in angle of attack at the tail and a reduction in the climbing moment trend produced by the wing.

The lack of the climbing tendency above lift coefficients of 0.2 is attributable to the magnitude of the change in angle of attack at the tail which is such as to produce a diving moment which is larger at the higher values of C_L, while the change in pitching moment due to the wing was approximately the same for all values of C_L.

CONCLUDING REMARKS

The results of flight tests on two jet aircraft of generally similar configuration, one exhibiting a diving tendency and the other a climbing tendency, showed the following as the significant factors governing the longitudinal behavior at high Mach numbers.

The differences in longitudinal control of the two aircraft appear to be due to the balance between two opposing moments: (1) a diving moment produced by an increased angle of attack at the tail, and (2) a climbing moment due to the pitching-moment characteristics of the wing.

Thus, for airplane 1 it was found that the diving tendency due to an increase in angle of attack at the tail predominated over the entire C_L range.

The climbing tendency of airplane 2 existing only at the lower values of C_L (in the range of steady 1g flight) was due to the dominance of the pitching moment of the wing.

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REFERENCES

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2. Turner, William N., Steffen, Paul J., and Clousing, Lawrence A.: Compressibility Effects on the Longitudinal Stability and Control of a Pursuit-Type Airplane as Measured in Flight. NACA Rep. 854, 1946. (Formerly NACA MR A5E26, 1945.)

3. White, Maurice D., Sadoff, Melvin, Clousing, Lawrence A., and Cooper, George E.: A Flight Investigation of the Effect of Flap Deflection on High-Speed Longitudinal-Control Characteristics. NACA RM A9D08, 1949.

4. Barlow, William H., and Lilly, Howard C.: Stability Results Obtained with Douglas D-558-I Airplane (BuAero No. 37971) in Flight Up to a Mach Number of 0.89. NACA RM L8K03, 1949.

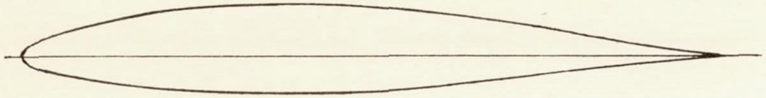
TABLE I.- DETAILS OF TEST AIRPLANES

Item	Airplane 1	Airplane 2
Gross weight, pounds (Av. in flt.) ...	9900	10,900
Wing		
Area, square feet	237.0	260
Span, feet	38.90	36.42
Aspect ratio	6.39	5.10
Airfoil section		
Root	NACA 65_1-213 (a = 0.5)	Republic R-4 45-1512-.9
Tip	NACA 65_1-213 (a = 0.5)	Republic R-4 45-1512-.9
M.A.C., inches	80.6	88.6
Incidence (root)	1.0°	0°
Twist	-1.5°	-2°
Horizontal tail		
Area, square feet	43.5	48.5
Span, feet	15.6	14.95
Aspect ratio	5.6	4.6
Airfoil section		
Root	NACA 65-010	Republic R-4 40-010
Tip	NACA 65-010	Republic R-4 40-010
Incidence	1.5°	0°
Elevator area, square feet	8.5	13

TABLE II.—AIRFOIL ORDINATES

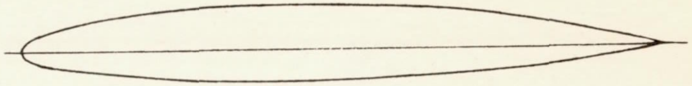
[All stations and ordinates in percent chord]

Airplane 1.— NACA 65_1-213 (a = 0.5)

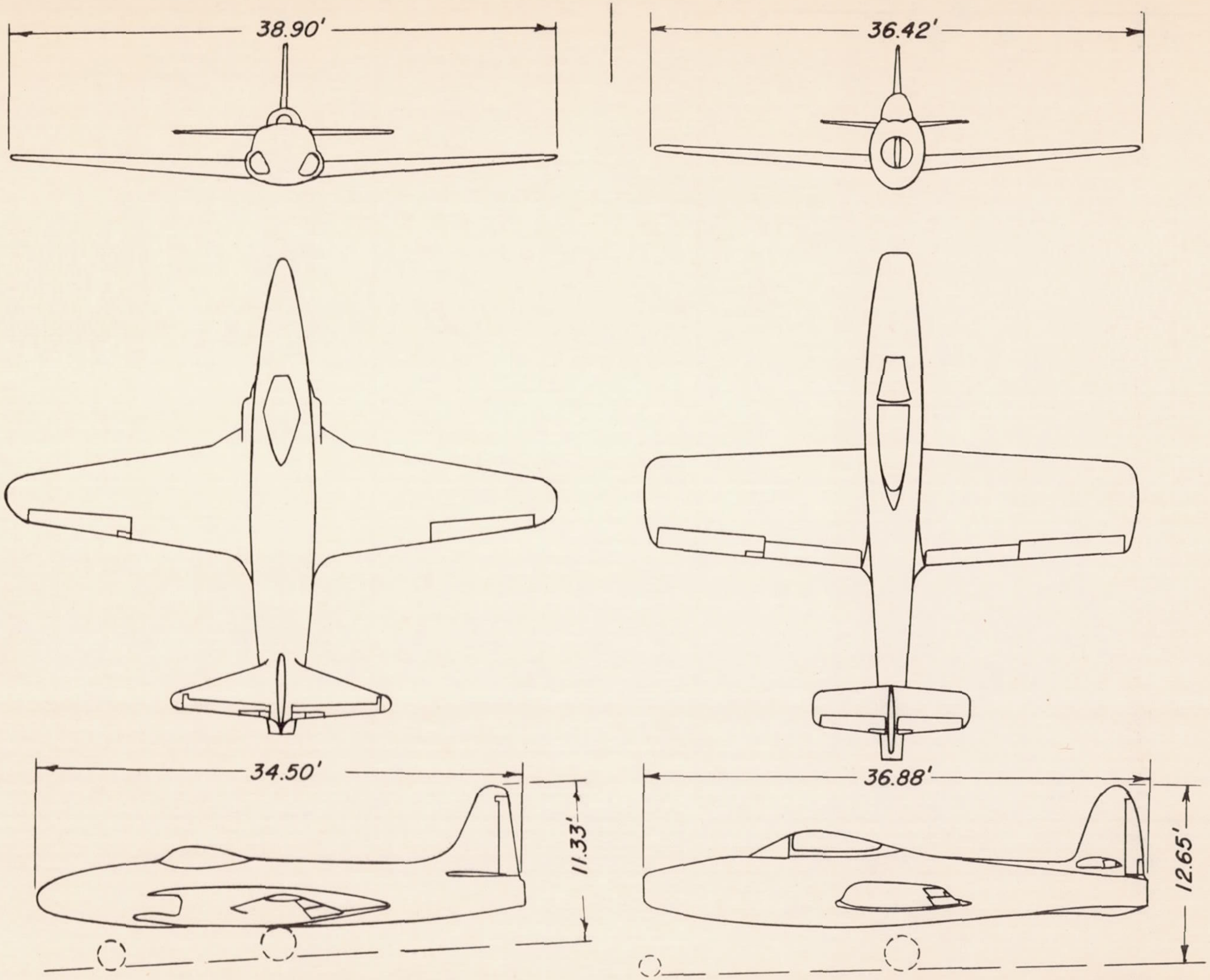


Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.38	1.06	.62	-.92
.62	1.29	.88	-1.10
1.10	1.64	1.40	-1.35
2.34	2.28	2.66	-1.76
4.81	3.26	5.19	-2.38
7.31	4.02	7.69	-2.84
9.80	4.67	10.20	-3.22
14.81	5.71	15.19	-3.82
19.83	6.51	20.17	-4.26
24.86	7.12	25.14	-4.59
29.89	7.56	30.11	-4.82
34.92	7.85	35.08	-4.96
39.96	7.98	40.04	-5.01
45.01	7.94	44.99	-4.95
50.07	7.71	49.93	-4.77
55.11	7.26	54.89	-4.47
60.13	6.63	59.87	-4.07
65.14	5.89	64.86	-3.60
70.13	5.04	69.87	-3.06
75.11	4.14	74.89	-2.49
80.09	3.19	79.91	-1.88
85.06	2.24	84.94	-1.29
90.04	1.33	89.97	-.72
95.01	.53	94.99	-.24
100.00	0	100.00	0

Airplane 2.— REPUBLIC R-4, 45-1512-.9



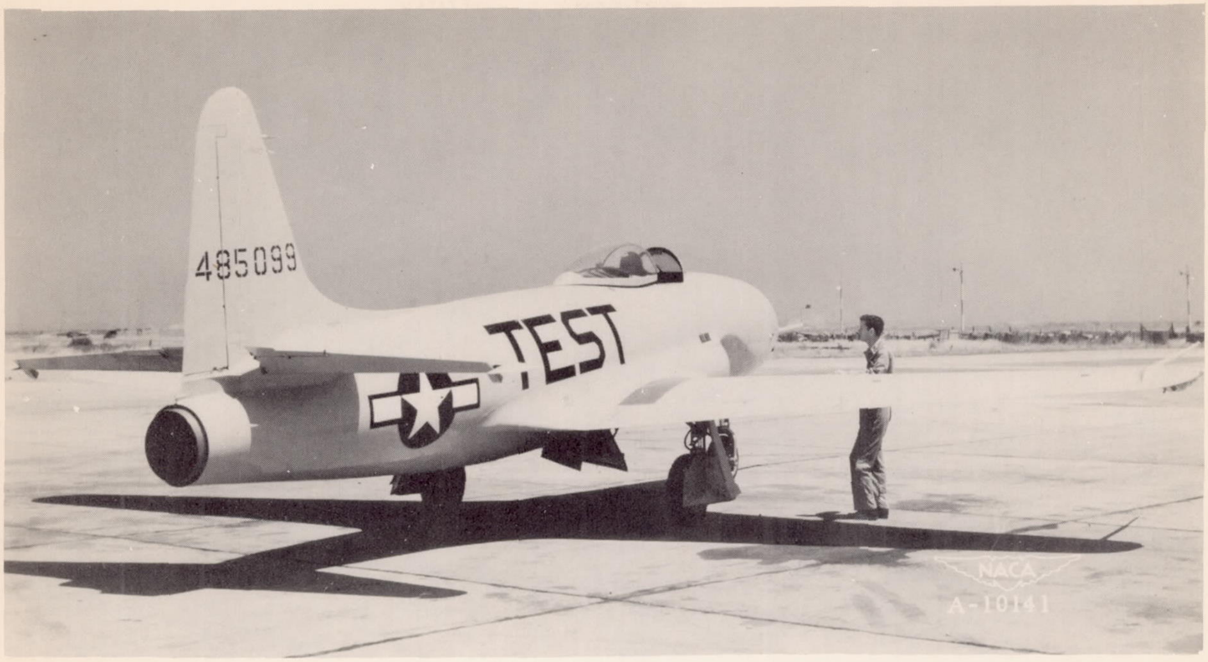
Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.5	.905	.5	-.905
1.0	1.33	1.0	-1.20
2.0	1.865	2.0	-1.665
3.0	2.305	3.0	-2.035
4.0	2.665	4.0	-2.315
5.0	2.960	5.0	-2.55
10.0	4.20	10.0	-3.41
15.0	5.025	15.0	-4.015
20.0	5.60	20.0	-4.40
25.0	6.09	25.0	-4.72
30.0	6.46	30.0	-4.94
35.0	6.72	35.0	-5.08
40.0	6.86	40.0	-5.17
45.0	6.94	45.0	-5.15
50.0	6.90	50.0	-5.07
55.0	6.81	55.0	-4.94
60.0	6.51	60.0	-4.67
65.0	6.11	65.0	-4.27
70.0	5.57	70.0	-3.73
75.0	4.89	75.0	-3.21
80.0	4.08	80.0	-2.56
85.0	3.13	85.0	-1.73
90.0	2.13	90.0	-1.14
95.0	1.01	95.0	-.40
100.0	0	100.0	0



(a) Airplane 1.

(b) Airplane 2.

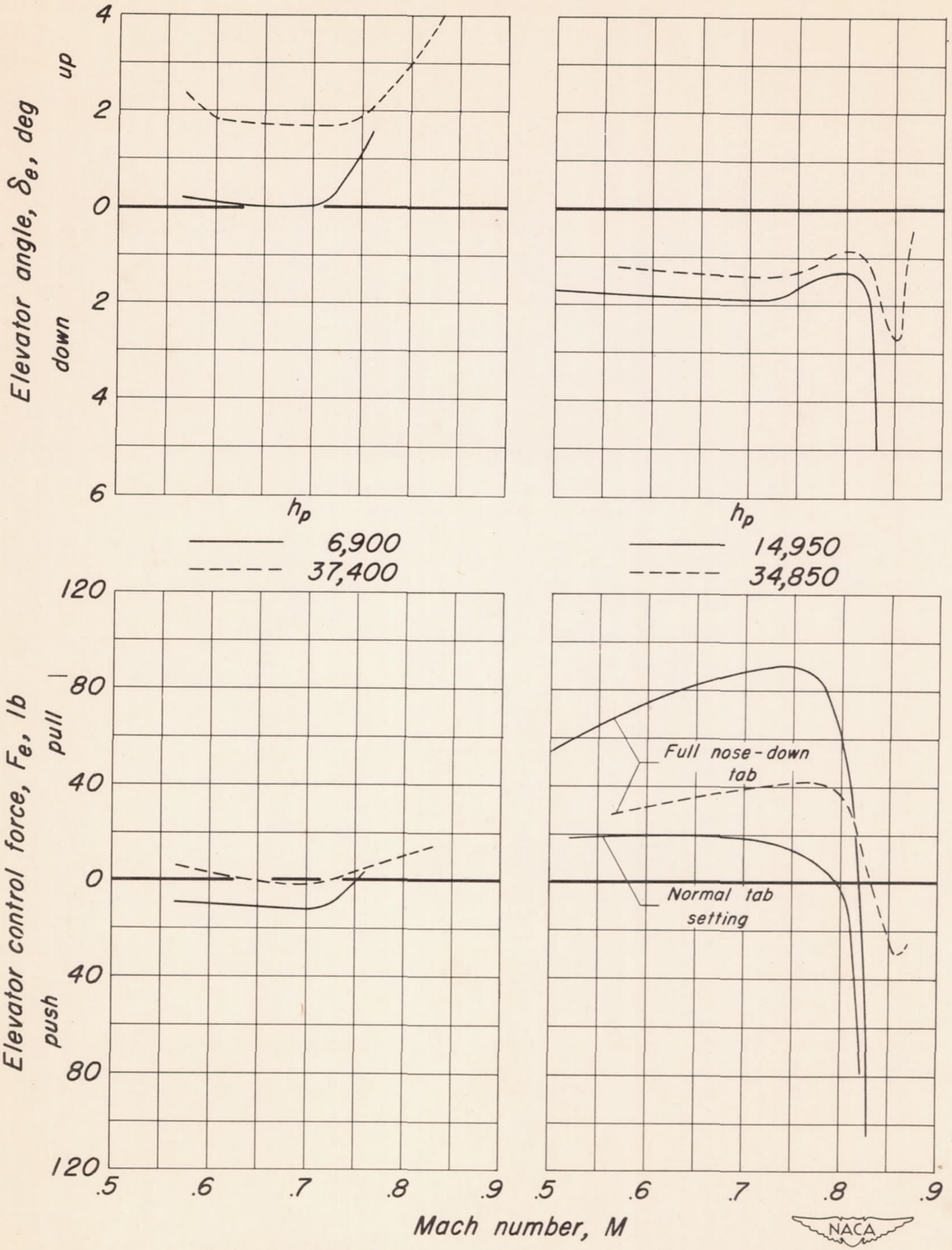
Figure 1.- Three-view drawings of airplanes 1 and 2.



(a) Airplane 1.

(b) Airplane 2.

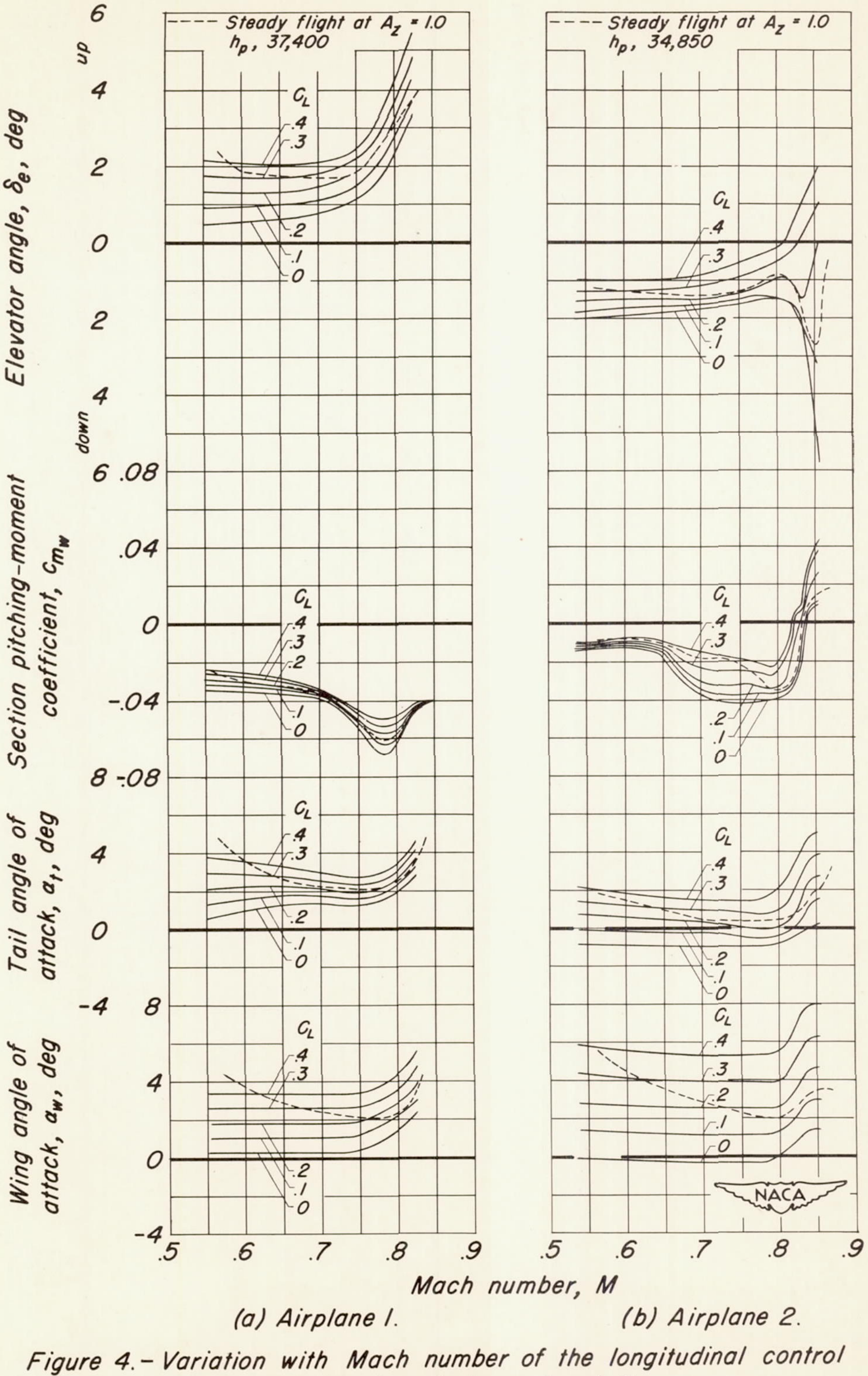
Figure 2.- Three-quarter rear view of test airplanes.



(a) Airplane 1.

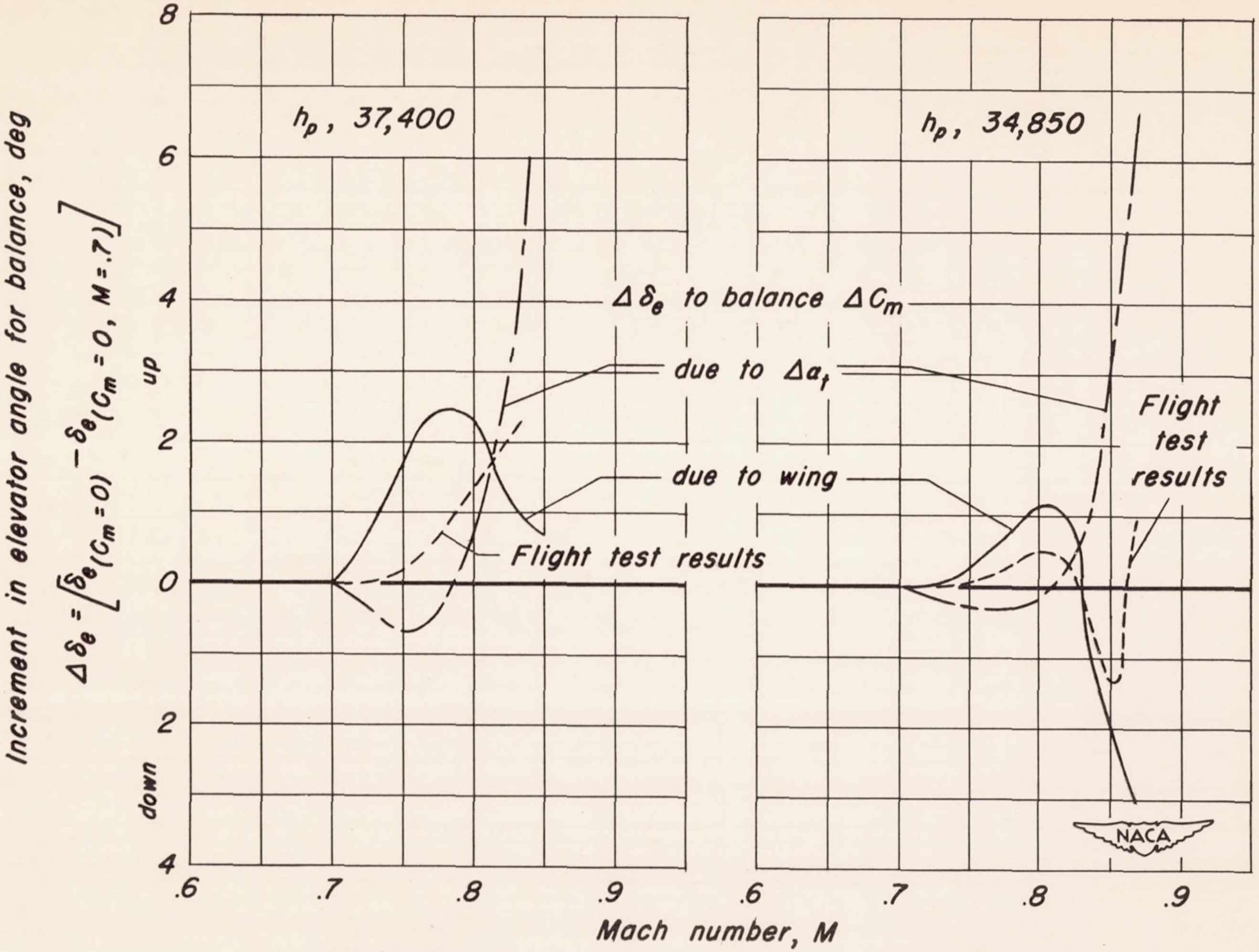
(b) Airplane 2.

Figure 3.- Static longitudinal stability characteristics for airplanes 1 and 2 at high and low altitude.



(a) Airplane 1. (b) Airplane 2.

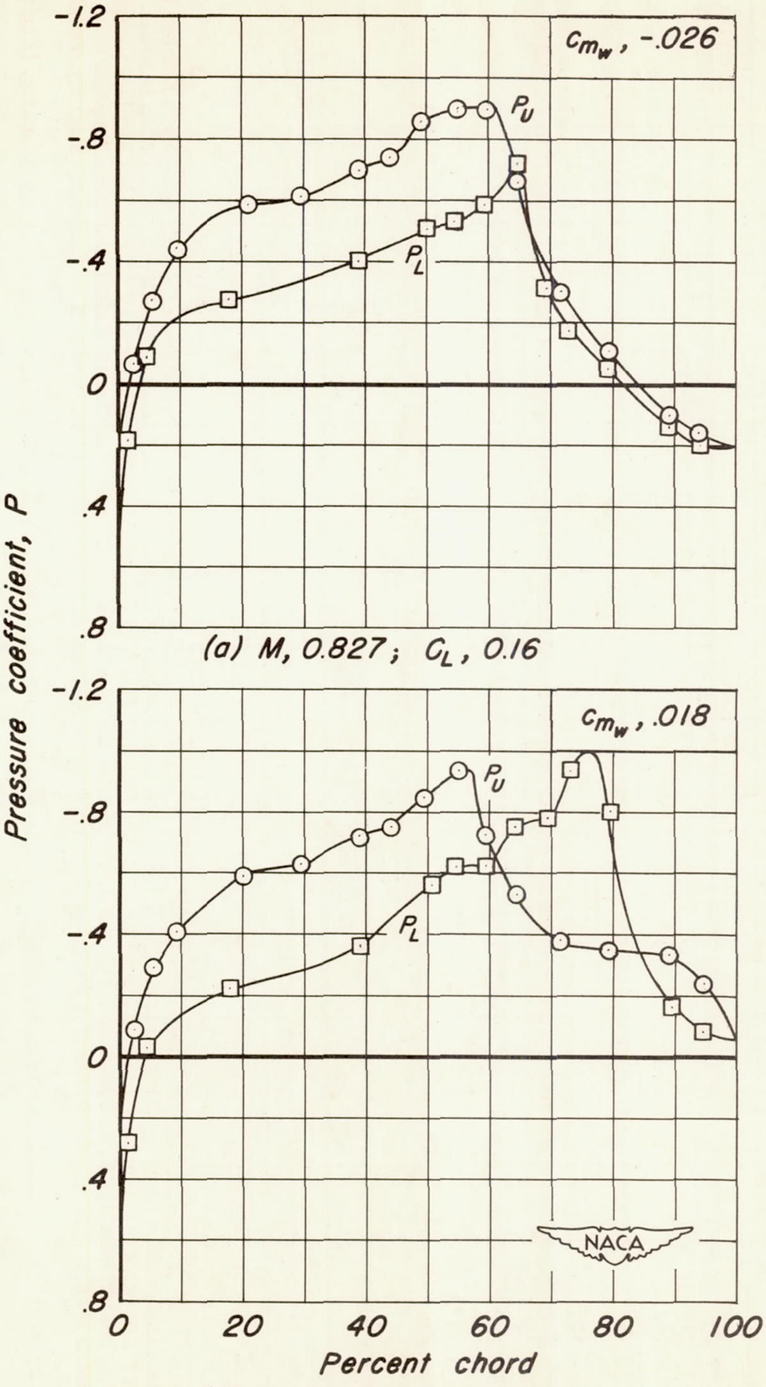
Figure 4.- Variation with Mach number of the longitudinal control characteristics for airplanes 1 and 2.



(a) Airplane 1.

(b) Airplane 2.

Figure 5.– Variation with Mach number of the increment in elevator angle required for balance for airplanes 1 and 2.



(b) M, 0.870; C_L, 0.15

Figure 6.- Pressure distribution at various Mach numbers. Pressure altitude, 35,000 feet. Airplane 2.