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RESEARCH MEMORANDUM

EFFECT OF TAPER RATIO ON LIFT, DRAG, AND PITCHING-MOMENT CHARACTERISTICS OF THIN WINGS OF ASPECT RATIO 3 WITH 53.1° SWEEPBACK OF LEADING EDGE AT SUBSONIC AND SUPERSONIC SPEEDS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EFFECT OF TAPER RATIO ON LIFT, DRAG, AND PITCHING-MOMENT CHARACTERISTICS OF THIN WINGS OF ASPECT RATIO 3 WITH 53.1° SWEEPBACK OF LEADING EDGE AT SUBSONIC AND SUPERSONIC SPEEDS

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SUMMARY

The results of a wind-tunnel investigation are presented which show the effect of the variation of taper ratio on the lift, drag, and pitching-moment characteristics of thin wings of aspect ratio 3 with 53.1° sweepback of the leading edge. Three wings, with taper ratios of 0, 0.2, and 0.4, in combination with a high-fineness-ratio body were studied in the investigation.

Measurements of the forces and moments on the wing-body combinations were obtained throughout an angle-of-attack range from -4° to a maximum of +17° at Mach numbers of 0.6 to 0.9 and 1.2 to 1.9. All models were tested at a Reynolds number of 3.0 million per foot at all Mach numbers. (This corresponds to Reynolds numbers varying from 2.9 to 3.6 million when based on the mean aerodynamic chords of the models.) In addition, the models were tested at Reynolds numbers of 4.0 million per foot at all subsonic Mach numbers and 6.0 million per foot at Mach numbers of 0.8 and 0.9.

Static longitudinal stability at subsonic speeds was reduced near a lift coefficient of 0.5 for the wings with taper ratios of 0.2 and 0.4. Variation of taper ratio did not affect the minimum drag coefficient at subsonic speeds. At supersonic speeds increasing the taper ratio resulted in a slight reduction in the minimum drag coefficient. Drag due to lift was decreased at all Mach numbers by an increase in taper ratio from 0 to 0.2.

INTRODUCTION

As part of the continuing investigation of low-aspect-ratio wings by the NACA, the effects of taper ratio on the aerodynamic characteristics of swept wings of aspect ratio 3 at subsonic and supersonic speeds have been investigated in the Ames 6- by 6-foot supersonic wind tunnel. This report is devoted to the presentation and discussion of the results obtained during this study.

NOTATION

b wing span

$\bar{c}$ mean aerodynamic chord, $\dfrac{\int_0^{b/2} c^2 dy}{\int_0^{b/2} c\ dy}$

c local chord

C_D drag coefficient, $\dfrac{\text{drag}}{qS}$

C_L lift coefficient, $\dfrac{\text{lift}}{qS}$

C_m pitching-moment coefficient, measured about the quarter point of the mean aerodynamic chord, $\dfrac{\text{pitching moment}}{qS\bar{c}}$

$\dfrac{L}{D}$ lift-drag ratio

M free-stream Mach number

q free-stream dynamic pressure

R Reynolds number

S wing area, including area formed by extending the leading and trailing edges to the plane of symmetry

y distance perpendicular to plane of symmetry

α angle of attack of body axis, deg

λ taper ratio, the ratio of the chord at the tip to the chord at the plane of symmetry

APPARATUS AND MODELS

The investigation was performed in the Ames 6- by 6-foot supersonic wind tunnel. This wind tunnel, which is fully described in reference 1, has a closed section and is of the variable-pressure type. It can be operated at Mach numbers varying from 0.6 to 0.9 and from 1.2 to 1.9. Model wing-body combinations are sting-mounted in the wind tunnel, and the aerodynamic forces on the models are measured with an internal electrical strain-gage balance. A typical model installation is shown in figure 1.

Three wing-body combinations were used during the investigation. Sketches of the models are presented in figure 2. All of the wings were of aspect ratio 3 and had 53.1° sweepback of the leading edge. All had an NACA 0003-63 airfoil section in a streamwise plane and had the same plan-form area. The taper ratios of the wings were varied from 0 (a triangular wing) to 0.4. All of the wings were tested in combination with the same circular body. The equation of the body is included on figure 2. The wing panels were constructed of steel, painted, and hand-sanded to a smooth finish. The smooth finish was maintained throughout the tests.

TESTS AND PROCEDURES

Range of Test Variables

Lift, drag, and pitching moment were measured throughout an angle-of-attack range varying from -4° to a maximum of +17° at Mach numbers of 0.6 to 0.9 and 1.2 to 1.9. All models were tested at a Reynolds number of 3.0 million per foot at all Mach numbers. In addition they were tested at Reynolds numbers of 4.0 million per foot at all subsonic Mach numbers and 6.0 million per foot at Mach numbers of 0.8 and 0.9. The following table presents the corresponding Reynolds numbers based on the mean aerodynamic chord.

$R \times 10^{-6}$, per ft	$R \times 10^{-6}$, based on mean aerodynamic chord		
	$\lambda = 0$	$\lambda = 0.2$	$\lambda = 0.4$
3.0	3.6	3.1	2.9
4.0	4.8	4.1	3.8
6.0	7.2	6.2	5.7

Reduction of Data

Data presented in this report have been reduced to NACA coefficient form. The pitching moment has been referred to the quarter point of the mean aerodynamic chord. The data have been corrected to account for the differences known to exist between measurements made in the wind tunnel and in a free stream. The corrections applied account for the following factors:

1. The increase in airspeed in the vicinity of the model at subsonic speed as a result of constriction of the air stream by the walls of the wind tunnel.

2. The change in angle of attack of the model induced by the walls of the wind tunnel at subsonic speeds as a consequence of lift on the model. The corrections to the data amounted to:

$$\Delta\alpha = 0.554\ C_L,\ \text{deg}$$

$$\Delta C_D = 0.0097\ C_L^2$$

$$\Delta C_m = 0$$

3. The inclination of the air stream in the wind tunnel. These corrections were of the order of -0.13° and -0.10° at subsonic and supersonic speeds, respectively.

4. The effect on the drag measurements due to the longitudinal variation of static pressure in the test section.

5. The effect on the drag measurements caused by mounting the models on a sting. The base pressure was measured and the drag data adjusted to correspond to a base pressure equal to the static pressure of the free stream.

RESULTS AND DISCUSSION

Lift, drag, and pitching-moment coefficients are presented in tables I, II, and III for the wings with taper ratios of 0, 0.2, and 0.4, respectively. The tabulations include data for all test conditions. For the purpose of analysis, only a portion of these data is presented in graphical form. The largest part of the discussion is devoted to the results obtained at a Reynolds number of 3.0 million per foot, since that was the highest Reynolds number at which data could be obtained throughout the entire Mach number range. It will be shown, however, that the conclusions drawn from results obtained at that Reynolds number also apply at a Reynolds number of 6.0 million per foot at Mach numbers of 0.8 and 0.9.

Lift

The effect of taper ratio on the variation of the lift coefficient with angle of attack is shown in figure 3. Increasing the taper ratio from 0 to 0.4 had only small effect on the lift-curve slope at zero lift. At angle of attack, however, variation of taper ratio resulted in large differences in the lift coefficients obtained at subsonic speeds. Increases in lift-curve slope at low to moderate angles of attack, such as are shown in the present results, particularly for the wings with taper ratios of 0.2 and 0.4, have been shown by previous tests of low-aspect-ratio wings with thin airfoil sections (e.g., refs. 2 and 3) to be concomitant with flow separation near the leading edge. Although such flow separation results in a reduction in the leading-edge pressures, it generally increases the lifting pressures over the rearward portions. The chordwise extent of the effect of separation generally increases with increasing spanwise distance from the plane of symmetry. For the wings of the present investigation the increases in lift-curve slope at moderate angles of attack generally were reduced as Reynolds number was increased, as will be shown in the portion of the discussion devoted to the effect of Reynolds number. Examination of the lift and moment data at the higher angles of attack indicated that stalled flow must have occurred at the tip sections and that unusually high loading occurred on the inboard sections.

Pitching Moment

The effect of taper ratio on the variation of pitching-moment coefficient with lift coefficient is presented in figure 4. Increasing the taper ratio caused a deterioration of the static longitudinal stability at subsonic speeds, as indicated by the nonlinear variations of the pitching-moment coefficient with lift coefficient for the wings with taper ratios of 0.2 and 0.4. The increased static longitudinal stability for these wings in the low lift-coefficient range, corresponding to the range in which the lift-curve slope increased with increasing angle of attack, offers additional indication of the probable occurrence of leading-edge flow separation.

Of considerably more importance, however, was the reduction of the static longitudinal stability of the wings with taper ratios of 0.2 and 0.4 near a lift coefficient of 0.5 at subsonic speeds. As indicated previously, this reduction of the longitudinal stability must have resulted from stalled flow at the tip sections. The degree of instability increased with increasing taper ratio. Serious pitch-up occurred for the wing with taper ratio 0.4 at a Mach number of 0.6 when the moment center was located at the quarter point of the mean aerodynamic chord. At supersonic speeds the variation of the pitching-moment coefficient with lift coefficient for the wings with taper ratios of 0.2 and 0.4 also showed a decrease in static longitudinal stability at the higher lift coefficients. This decrease was measured for the wing with taper ratio of 0.4 even at a Mach number of 1.9.

Nonlinear variations of the pitching-moment coefficient with lift coefficient, similar to those obtained for the wing with taper ratio of 0.2, can be minimized by locating a horizontal tail in a position which takes advantage of the characteristics of the flow field behind the wing (see ref. 4). It is unlikely, however, that an acceptable variation of pitching-moment coefficient with lift coefficient can be obtained for an aircraft utilizing the wing with taper ratio 0.4 without some modification of the wing to delay stalling of the wing tips.

Drag

The effect of taper ratio on the variation with lift coefficient of the drag coefficient is shown in figure 5. Increasing the taper ratio from 0 to 0.2 resulted in a reduction of the drag coefficients measured at moderate to high lift coefficients and had only small effect on the minimum drag. These effects have been summarized in figure 6, in which the variation of drag coefficient with Mach number has been presented for various lift coefficients. Increasing the taper ratio to 0.4 resulted in no significant reductions of the drag coefficient. The latter result is in agreement with the results obtained during an investigation of swept wings with taper ratios varying from 0.3 to 1.0 (ref. 5). Results presented in the referenced report showed that at high subsonic speeds the drag due to lift was only slightly decreased by increasing taper ratio beyond 0.3.

As a result of the reduction of drag due to lift when taper ratio was increased, the lift-drag ratios of the wings with taper ratios of 0.2 and 0.4 were generally higher than the ratios for the wing with taper ratio of 0 at both subsonic and supersonic speeds, as shown in figure 7. At subsonic speeds the highest lift-drag ratios were obtained for the wing with taper ratio of 0.2. The maximum lift-drag ratios measured at supersonic speeds were those for the wing with taper ratio of 0.4. These maximums were, however, only slightly higher than those for the wing with taper ratio of 0.2.

In recapitulation, increasing the taper ratio from 0 to 0.2 resulted in a significant improvement of the drag characteristics. Since increasing the taper ratio to 0.4 generally did not result in further significant improvement but led to severe pitch-up, it appears that the optimum taper ratio is about 0.2.

Effect of Reynolds Number

The effect of variation of Reynolds number on the lift, drag, and pitching-moment coefficients at high subsonic speeds is illustrated in figure 8, in which results obtained at a Mach number of 0.8 are presented. Increasing the Reynolds number from 3.0 to 6.0 million per foot alleviated the effect of leading-edge separation on the lift and pitching-moment characteristics of the wings with taper ratios of 0.2 and 0.4. At a Reynolds number of 6.0 million per foot, the lift curves were linear over a wider range of angles of attack, and the increases in static longitudinal stability at low lift coefficients were smaller than at a Reynolds number of 3.0 million per foot. Because of structural limitations of the models, tests at the highest Reynolds number were not conducted in the range of lift coefficients in which reduced stability occurred for the wings with taper ratios of 0.2 and 0.4.

Since the effect of taper ratio on the variation of the drag coefficient with lift coefficient was shown to be significant at a Reynolds number of 3.0 million per foot, figure 9 has been included to show the variation with Reynolds number of the drag coefficients at various lift coefficients for Mach numbers of 0.8 and 0.9. Comparison of the results for the three wings indicates that increasing the Reynolds number did not affect materially the reductions in drag coefficient obtained as a result of increasing taper ratio.

CONCLUDING REMARKS

A wind-tunnel investigation has been conducted in order to determine the effect of varying the taper ratio on the lift, drag, and pitching-moment characteristics of thin wings of aspect ratio 3 and with 53.1° sweepback of the leading edge. Three wings, with taper ratios of 0, 0.2, and 0.4, were tested.

All wings showed the effect at subsonic speeds of flow separation at the wing tips; the effects of separated flow were shown to increase with increasing taper ratio. The static longitudinal stability at subsonic speeds was reduced near a lift coefficient of 0.5 for the wings with taper ratios of 0.2 and 0.4. Although the most satisfactory variation of pitching-moment coefficient with lift coefficient was obtained for the triangular wing, used to investigate a taper ratio of 0, the degree of instability for the wing with taper ratio of 0.2 was much less severe than that for the wing with taper ratio of 0.4.

Variation of taper ratio did not affect the minimum drag coefficient at subsonic speeds, while at supersonic speeds an increase in taper ratio resulted in a slight reduction in the minimum drag coefficient. Drag due to lift was decreased at all Mach numbers by an increase in taper ratio from 0 to 0.2.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Oct. 20, 1954.

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TABLE I.- AERODYNAMIC CHARACTERISTICS OF TRIANGULAR WING

(a) R = 3.0 million per foot

M	α	C_L	C_D	C_m
0.60	-0.41	-0.022	0.0067	0.003
	-.68	-.037	.0073	.005
	-1.22	-.065	.0082	.008
	-2.31	-.127	.0109	.015
	-3.38	-.191	.0158	.022
	-4.47	-.253	.0230	.028
	.05	0	.0066	.001
	.33	.020	.0067	-.002
	.87	.050	.0076	-.005
	1.96	.111	.0101	-.012
	3.04	.173	.0145	-.019
	4.11	.234	.0213	-.025
	6.34	.361	.0428	-.034
	8.48	.477	.0717	-.039
	10.63	.591	.1106	-.047
	12.77	.704	.1588	-.054
	14.90	.804	.2129	-.062
	17.01	.884	.2683	-.069
	18.06	.921	.2975	-.073
0.70	-.42	-.022	.0067	.004
	-.69	-.037	.0072	.005
	-1.17	-.068	.0080	.009
	-2.26	-.132	.0111	.017
	-3.34	-.196	.0161	.024
	-4.42	-.263	.0239	.031
	.05	0	.0064	.001
	.33	.022	.0068	-.002
	.88	.052	.0077	-.005
	1.98	.117	.0105	-.014
	3.06	.182	.0153	-.021
	4.15	.246	.0224	-.028
	6.39	.374	.0448	-.038
	8.55	.491	.0748	-.042
	10.71	.614	.1162	-.056
	12.87	.723	.1644	-.061
	14.99	.808	.2154	-.069
	17.10	.891	.2726	-.081
	18.14	.921	.3000	-.086
0.80	-.34	-.023	.0066	.003
	-.63	-.038	.0069	.006
	-1.18	-.071	.0079	.010
	-2.28	-.139	.0110	.019
	-3.38	-.209	.0169	.028
	-4.47	-.276	.0250	.036
	.05	.002	.0061	.001
	.34	.025	.0063	-.002
	.90	.058	.0074	-.006
	2.00	.125	.0104	-.016
	3.09	.192	.0156	-.024
	4.28	.260	.0234	-.032
	6.37	.397	.0469	-.045
	8.61	.506	.0785	-.048
	10.79	.636	.1225	-.069
0.80	12.94	0.743	0.1713	-0.080
	15.06	.823	.2217	-.093
	17.11	.913	.2811	-.109
	18.15	.941	.3097	-.118
0.90	-.36	-.027	.0065	.005
	-.63	-.041	.0069	.007
	-1.19	-.076	.0080	.012
	-2.30	-.153	.0120	.025
	-3.41	-.230	.0187	.036
	-4.51	-.305	.0281	.046
	.05	.002	.0062	.001
	.35	.027	.0065	-.002
	.91	.063	.0076	-.008
	2.02	.138	.0109	-.020
	3.13	.212	.0170	-.031
	4.24	.291	.0261	-.042
	6.44	.431	.0524	-.058
	8.63	.561	.0887	-.074
1.20	-.34	-.021	.0107	.005
	-.61	-.037	.0111	.010
	-1.15	-.070	.0122	.018
	-2.22	-.141	.0159	.036
	-3.28	-.212	.0217	.054
	-4.36	-.298	.0311	.073
	.06	.004	.0106	-.001
	.34	.027	.0106	-.006
	.88	.062	.0117	-.015
	1.94	.128	.0152	-.031
	3.01	.198	.0207	-.049
	4.06	.267	.0283	-.066
	6.20	.405	.0510	-.100
	8.33	.541	.0838	-.133
1.30	-.34	-.020	.0119	.005
	-.61	-.035	.0123	.009
	-1.15	-.066	.0131	.017
	-2.21	-.127	.0168	.032
	-3.27	-.192	.0224	.048
	-4.33	-.256	.0299	.064
	.05	.004	.0120	-.001
	.33	.024	.0122	-.005
	.88	.057	.0131	-.013
	1.93	.116	.0165	-.028
	3.00	.181	.0219	-.044
	4.06	.243	.0292	-.060
	6.17	.362	.0493	-.089
	8.23	.480	.0782	-.116
	10.40	.586	.1145	-.140
	12.50	.684	.1566	-.162
1.50	-.30	-.017	.0115	.004
	-.57	-.030	.0116	.008
	-1.11	-.058	.0123	.014
1.50	-2.17	-0.113	0.0163	0.028
	-3.23	-.168	.0215	.042
	-4.27	-.220	.0280	.055
	.09	.005	.0115	-.001
	.36	.022	.0117	-.005
	.90	.051	.0122	-.012
	1.96	.104	.0155	-.026
	3.01	.158	.0207	-.039
	4.07	.211	.0271	-.052
	6.17	.312	.0447	-.076
	8.27	.413	.0698	-.100
	10.37	.508	.1011	-.124
	12.46	.600	.1390	-.146
	14.56	.681	.1816	-.163
	15.61	.721	.2054	-.170
1.70	-.30	-.015	.0113	.004
	-.57	-.027	.0116	.007
	-1.10	-.051	.0126	.013
	-2.16	-.099	.0158	.024
	-3.21	-.147	.0203	.035
	-4.25	-.193	.0261	.046
	.08	.004	.0113	-.001
	.36	.019	.0113	-.005
	.90	.045	.0123	-.011
	1.95	.092	.0150	-.022
	3.00	.140	.0194	-.034
	4.04	.185	.0251	-.044
	6.13	.273	.0406	-.065
	8.22	.361	.0623	-.086
	10.31	.446	.0901	-.106
	12.40	.527	.1236	-.126
	14.49	.605	.1624	-.143
	16.58	.678	.2067	-.157
	17.62	.714	.2311	-.163
1.90	-.30	-.015	.0127	.003
	-.57	-.026	.0129	.006
	-1.10	-.047	.0135	.011
	-2.14	-.090	.0160	.021
	-3.19	-.134	.0199	.031
	-4.23	-.175	.0253	.041
	.08	.001	.0125	0
	.35	.014	.0126	-.004
	.88	.037	.0130	-.009
	1.94	.078	.0151	-.019
	2.97	.121	.0185	-.029
	4.02	.162	.0234	-.038
	6.10	.240	.0368	-.057
	8.17	.318	.0557	-.075
	10.25	.396	.0807	-.092
	12.33	.468	.1100	-.109
	14.41	.539	.1450	-.124
	16.50	.609	.1855	-.137
	17.54	.645	.2080	-.143

TABLE I.- AERODYNAMIC CHARACTERISTICS OF TRIANGULAR WING - Concluded

(b) R = 4.0 million per foot

M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m
0.60	-0.43	-0.025	0.0070	0.003	0.70	-3.40	-0.202	0.0166	0.024	0.80	2.10	0.130	0.0114	-0.017
	-.71	-.042	.0075	.004		-4.57	-.266	.0247	.030		3.22	.197	.0158	-.025
	-1.25	-.069	.0085	.008		.05	-.001	.0066	0		4.33	.266	.0238	-.033
	-2.35	-.131	.0114	.015		.34	.021	.0068	-.002		6.56	.405	.0484	-.046
	-3.44	-.194	.0162	.022		.90	.055	.0080	-.007		8.82	.512	.0805	-.049
	-4.53	-.255	.0232	.028		2.01	.118	.0108	-.014		11.03	.640	.1239	-.069
	.33	.019	.0068	-.005		3.11	.181	.0153	-.021		13.22	.751	.1758	-.082
	.89	.052	.0080	-.006		4.21	.249	.0226	-.028					
	1.99	.113	.0104	-.013		6.49	.377	.0454	-.039	0.90	-.36	-.021	.0069	.003
	3.07	.172	.0146	-.020		8.68	.494	.0757	-.041		-.58	-.041	.0073	.006
	4.17	.237	.0215	-.026		10.83	.609	.1171	-.055		-1.15	-.078	.0085	.012
	6.42	.365	.0436	-.036		13.06	.725	.1670	-.061		-2.28	-.152	.0119	.023
	8.60	.480	.0729	-.039		15.19	.803	.2167	-.069		-3.40	-.231	.0182	.035
	10.78	.600	.1135	-.048							-4.53	-.305	.0275	.045
	12.96	.716	.1636	-.055	0.80	-.36	-.023	.0068	.003		.14	.010	.0068	-.001
	15.11	.811	.2164	-.063		-.64	-.040	.0072	.005		.43	.029	.0071	-.004
	17.23	.892	.2736	-.070		-1.13	-.072	.0080	.010		1.02	.070	.0083	-.010
	18.30	.932	.3049	-.074		-2.24	-.138	.0110	.018		2.14	.145	.0116	-.022
						-3.35	-.205	.0162	.027		3.27	.223	.0173	-.034
0.70	-.43	-.027	.0071	.003		-4.47	-.277	.0245	.035		4.40	.297	.0264	-.043
	-.71	-.043	.0074	.005		.13	.006	.0067	-.001		6.66	.449	.0549	-.064
	-1.27	-.074	.0084	.009		.42	.025	.0068	-.003		8.89	.588	.0971	-.084
	-2.30	-.137	.0115	.017		.99	.062	.0079	-.008					

(c) R = 6.0 million per foot

M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m
0.80	-0.38	-0.024	0.0071	0.003	0.90	-0.39	-0.028	0.0065	0.004
	-.68	-.044	.0075	.005		-.81	-.046	.0073	.007
	-1.18	-.077	.0085	.010		-1.21	-.084	.0084	.013
	-2.33	-.143	.0112	.019		-2.39	-.160	.0119	.025
	-3.48	-.211	.0166	.027		-3.56	-.236	.0185	.035
	-4.64	-.288	.0256	.036		-4.75	-.313	.0272	.043
	.15	.012	.0070	-.001		.16	.016	.0068	-.002
	.46	.032	.0073	-.004		.48	.037	.0072	-.005
	1.04	.065	.0081	-.008		1.01	.074	.0079	-.010
	2.18	.134	.0107	-.017		2.24	.149	.0112	-.022
	3.33	.203	.0159	-.026		3.41	.224	.0174	-.033
	4.49	.278	.0246	-.034		4.58	.299	.0266	-.041
	6.80	.411	.0496	-.046		6.97	.464	.0578	-.065
	9.12	.515	.0820	-.046					

TABLE II.- AERODYNAMIC CHARACTERISTICS OF WING WITH TAPER RATIO OF 0.2

(a) R = 3.0 million per foot

M	α	C_L	C_D	C_m
0.6	-0.44	-0.030	0.0070	0.002
	-.64	-.044	.0075	.004
	-1.19	-.075	.0087	.008
	-2.27	-.138	.0116	.014
	-3.35	-.205	.0170	.023
	-4.44	-.279	.0257	.033
	.02	-.006	.0066	.001
	.30	.016	.0068	-.001
	.84	.046	.0073	-.004
	1.94	.111	.0099	-.012
	3.01	.175	.0137	-.020
	4.09	.245	.0209	-.030
	6.26	.388	.0433	-.046
	8.43	.528	.0781	-.054
	10.58	.643	.1196	-.052
	12.73	.759	.1703	-.056
	14.93	.861	.2267	-.057
	17.04	.943	.2842	-.056
	18.09	.979	.3143	-.057
0.70	-.28	-.030	.0064	.003
	-.55	-.044	.0069	.004
	-1.10	-.076	.0081	.008
	-2.36	-.141	.0113	.015
	-3.38	-.210	.0167	.025
	-4.47	-.287	.0259	.036
	.03	-.003	.0062	.001
	.20	.016	.0063	0
	.75	.048	.0070	-.004
	2.03	.112	.0096	-.012
	3.04	.182	.0138	-.021
	4.13	.256	.0213	-.032
	6.32	.405	.0450	-.050
	8.50	.542	.0806	-.054
	10.64	.650	.1215	-.055
	12.80	.772	.1740	-.062
	15.01	.863	.2287	-.060
	17.12	.945	.2875	-.068
	18.17	.979	.3176	-.069
0.80	-.37	-.030	.0060	.003
	-.64	-.045	.0066	.005
	-1.20	-.078	.0079	.009
	-2.29	-.147	.0109	.017
	-3.41	-.223	.0173	.029
	-4.51	-.304	.0266	.041
	.02	-.002	.0059	.001
	.31	.019	.0061	-.001
	.86	.052	.0068	-.005
	1.96	.120	.0095	-.014
	3.06	.193	.0148	-.024
	4.15	.273	.0233	-.037
	6.37	.425	.0483	-.057
	8.55	.559	.0837	-.060
	10.72	.677	.1273	-.071

M	α	C_L	C_D	C_m
0.80	12.85	0.795	0.1805	-0.081
	15.01	.880	.2338	-.083
	17.10	.945	.2883	-.088
	18.18	.990	.3218	-.097
0.90	-.39	-.032	.0062	.004
	-.66	-.045	.0064	.005
	-1.23	-.084	.0081	.011
	-2.33	-.160	.0118	.023
	-3.45	-.246	.0191	.038
	-4.56	-.329	.0297	.052
	.03	-.001	.0059	.001
	.32	.022	.0061	-.001
	.88	.057	.0070	-.006
	1.99	.132	.0098	-.018
	3.10	.214	.0154	-.032
	4.21	.298	.0248	-.047
	6.44	.465	.0536	-.072
	8.65	.604	.0919	-.082
1.20	-.32	-.029	.0099	.008
	-.59	-.044	.0104	.011
	-1.13	-.078	.0117	.019
	-2.18	-.146	.0156	.037
	-3.24	-.219	.0213	.057
	-4.30	-.291	.0290	.076
	.08	0	.0098	0
	.36	.021	.0100	-.005
	.90	.055	.0106	-.013
	1.96	.121	.0141	-.030
	3.02	.192	.0193	-.049
	4.08	.265	.0265	-.068
	6.20	.408	.0482	-.106
	8.32	.547	.0806	-.143
1.30	-.31	-.026	.0113	.007
	-.58	-.040	.0118	.010
	-1.12	-.072	.0130	.018
	-2.18	-.133	.0169	.034
	-3.23	-.199	.0224	.052
	-4.29	-.266	.0298	.070
	.08	.002	.0114	0
	.36	.019	.0114	-.004
	.90	.050	.0119	-.012
	1.96	.113	.0152	-.028
	3.01	.177	.0204	-.045
	4.07	.242	.0272	-.063
	6.18	.371	.0474	-.098
	8.29	.494	.0757	-.131
	10.39	.601	.1111	-.154
	12.49	.703	.1546	-.173
1.50	-.31	-.022	.0114	.006
	-.58	-.036	.0117	.010
	-1.11	-.063	.0124	.017

M	α	C_L	C_D	C_m
1.50	-2.16	-0.118	0.0164	0.032
	-3.22	-.174	.0216	.047
	-4.26	-.230	.0282	.062
	.08	.004	.0114	0
	.36	.019	.0114	-.004
	.89	.047	.0119	-.012
	1.95	.103	.0150	-.027
	3.00	.159	.0202	-.042
	4.05	.214	.0265	-.056
	6.15	.322	.0440	-.085
	8.24	.428	.0691	-.112
	10.34	.525	.1000	-.137
	12.43	.619	.1372	-.159
	14.52	.701	.1802	-.173
	17.01	.782	.2353	-.189
1.70	-.30	-.018	.0112	.006
	-.57	-.030	.0114	.009
	-1.11	-.055	.0125	.015
	-2.16	-.104	.0158	.028
	-3.20	-.151	.0205	.040
	-4.25	-.200	.0265	.052
	.08	.003	.0112	0
	.35	.017	.0113	-.003
	.89	.042	.0118	-.010
	1.95	.091	.0146	-.023
	2.99	.139	.0192	-.035
	4.04	.186	.0248	-.047
	6.13	.281	.0404	-.071
	8.22	.372	.0621	-.093
	10.30	.457	.0894	-.114
	12.39	.540	.1225	-.134
	14.48	.618	.1605	-.150
	16.57	.690	.2040	-.160
1.90	-.30	-.017	.0131	.005
	-.57	-.028	.0134	.008
	-1.10	-.050	.0140	.013
	-2.14	-.094	.0164	.024
	-3.18	-.136	.0203	.034
	-4.22	-.178	.0256	.045
	.08	.002	.0130	0
	.35	.014	.0131	-.003
	.88	.036	.0136	-.009
	1.93	.080	.0157	-.020
	2.97	.122	.0192	-.030
	4.01	.165	.0241	-.041
	6.09	.248	.0378	-.061
	8.16	.327	.0567	-.080
	10.24	.405	.0813	-.097
	12.32	.479	.1107	-.114
	14.39	.557	.1470	-.131
	16.49	.626	.1866	-.141
	17.54	.661	.2095	-.147

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TABLE II.- AERODYNAMIC CHARACTERISTICS OF WING WITH TAPER RATIO OF 0.2 - Concluded

(b) R = 4.0 million per foot

M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m
0.60	-0.45	-0.030	0.0073	0.003	0.70	-1.23	-0.079	0.0087	0.008	0.80	0.32	0.020	0.0065	-0.002
	-.66	-.045	.0076	.005		-2.32	-.142	.0115	.015		.89	.057	.0073	-.006
	-1.21	-.076	.0088	.008		-3.44	-.208	.0169	.024		2.01	.125	.0100	-.014
	-2.30	-.136	.0113	.014		-4.55	-.288	.0261	.035		3.11	.194	.0147	-.024
	-3.39	-.205	.0165	.022		.02	-.006	.0065	.001		4.24	.269	.0225	-.035
	-4.48	-.273	.0246	.031		.31	.016	.0068	-.001		6.47	.424	.0485	-.055
	.02	-.006	.0068	0		.88	.052	.0074	-.005		8.70	.557	.0848	-.060
	.31	.016	.0069	-.001		1.98	.115	.0101	-.012		10.90	.673	.1286	-.069
	.87	.048	.0075	-.004		3.08	.181	.0141	-.021		13.09	.784	.1803	-.077
	1.96	.110	.0100	-.011		4.18	.253	.0212	-.031					
	3.05	.174	.0136	-.019		6.40	.402	.0452	-.049	0.90	-.40	-.032	.0066	.004
	4.14	.246	.0207	-.029		8.62	.538	.0814	-.055		-.69	-.050	.0072	.006
	6.33	.387	.0428	-.045		10.79	.641	.1208	-.053		-1.25	-.087	.0086	.011
	8.53	.520	.0775	-.052		12.99	.765	.1726	-.060		-2.38	-.161	.0123	.022
	10.69	.630	.1171	-.049		15.21	.856	.2280	-.058		-3.50	-.237	.0190	.035
	12.88	.759	.1689	-.054							-4.64	-.327	.0304	.050
	15.10	.854	.2238	-.055	0.80	-.48	-.031	.0068	.004		.02	-.002	.0061	.001
	17.24	.940	.2825	-.054		-.67	-.047	.0073	.005		.33	.023	.0062	-.002
	18.28	.972	.3114	-.053		-2.34	-.082	.0086	.009		.91	.060	.0071	-.007
						-3.46	-.225	.0182	.029		2.03	.135	.0102	-.018
0.70	-.39	-.031	.0070	.003		-4.58	-.302	.0278	.041		3.16	.216	.0154	-.031
	-.67	-.046	.0075	.005		.02	-.003	.0063	.001		4.29	.296	.0242	-.045
											6.58	.469	.0544	-.071

(c) R = 6.0 million per foot

M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m
0.80	-0.50	-0.036	0.0076	0.003	0.90	-0.43	-0.035	0.0075	0.003
	-.72	-.051	.0078	.005		-.73	-.055	.0082	.006
	-1.29	-.083	.0087	.008		-1.31	-.091	.0092	.011
	-2.42	-.146	.0135	.015		-2.48	-.163	.0122	.020
	-3.59	-.226	.0133	.026		-3.65	-.240	.0187	.031
	-4.74	-.294	.0260	.035		-4.85	-.331	.0300	.046
	.02	-.001	.0071	0		.02	-.002	.0072	0
	.35	.025	.0072	-.003		.35	.026	.0073	-.003
	.93	.057	.0078	-.006		.95	.065	.0082	-.008
	2.07	.125	.0100	-.014		2.09	.131	.0105	-.017
	3.21	.191	.0138	-.023		3.29	.219	.0156	-.031
	4.36	.263	.0211	-.032		4.46	.297	.0241	-.043
	6.69	.418	.0481	-.052		6.84	.463	.0548	-.065
	8.95	.533	.0804	-.060					

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TABLE III.- AERODYNAMIC CHARACTERISTICS OF WING WITH TAPER RATIO OF 0.4

(a) R = 3.0 million per foot

M	α	C_L	C_D	C_m
0.60	-0.41	-0.023	0.0078	0
	-.68	-.037	.0084	0
	-1.23	-.068	.0091	.002
	-2.23	-.125	.0112	.005
	-3.31	-.192	.0163	.009
	-4.37	-.264	.0242	.019
	.04	.002	.0070	-.001
	.31	.018	.0074	-.002
	.86	.047	.0085	-.003
	1.95	.108	.0106	-.007
	3.01	.169	.0149	-.011
	4.10	.241	.0221	-.019
	6.26	.385	.0444	-.038
	8.43	.532	.0785	-.053
	10.58	.642	.1189	-.039
	12.71	.740	.1630	-.034
	14.83	.833	.2138	-.026
	16.96	.925	.2734	-.019
	18.00	.956	.3014	-.014
0.70	-.42	-.022	.0078	0
	-.69	-.037	.0085	0
	-1.24	-.066	.0092	.003
	-2.25	-.130	.0113	.006
	-3.28	-.197	.0165	.010
	-4.42	-.274	.0249	.021
	.04	.004	.0071	-.001
	.32	.019	.0075	-.001
	.87	.049	.0085	-.003
	1.95	.112	.0106	-.007
	3.04	.178	.0153	-.012
	4.13	.250	.0228	-.021
	6.31	.403	.0461	-.042
	8.50	.554	.0825	-.057
	10.64	.641	.1197	-.038
	12.78	.750	.1673	-.036
	14.92	.840	.2179	-.031
	17.03	.923	.2756	-.025
	18.08	.954	.3041	-.022
0.80	-.42	-.022	.0077	-.001
	-.69	-.037	.0082	0
	-1.25	-.067	.0088	.003
	-2.26	-.130	.0110	.006
	-3.36	-.199	.0165	.012
	-4.45	-.280	.0255	.026
	.06	.005	.0069	-.001
	.39	.021	.0073	-.001
	.88	.053	.0082	-.003
	1.98	.118	.0102	-.008
	3.06	.185	.0151	-.014
	4.16	.261	.0232	-.025
	6.37	.471	.0477	-.048
	8.55	.555	.0832	-.056
	10.69	.642	.1205	-.042

M	α	C_L	C_D	C_m
0.80	12.86	0.762	0.1719	-0.050
	14.99	.841	.2217	-.040
	17.08	.903	.2735	-.037
	18.13	.931	.3002	-.038
0.90	-.42	-.024	.0070	0
	-.69	-.041	.0077	.001
	-1.19	-.077	.0084	.005
	-2.29	-.148	.0115	.010
	-3.40	-.228	.0185	.021
	-4.50	-.316	.0291	.038
	.05	.007	.0062	-.001
	.33	.024	.0066	-.001
	.89	.060	.0076	-.005
	2.00	.133	.0099	-.012
	3.10	.210	.0158	-.021
	4.21	.294	.0252	-.037
	6.45	.473	.0541	-.067
	8.64	.612	.0921	-.078
1.20	-.31	-.024	.0098	.005
	-.57	-.038	.0105	.008
	-1.11	-.068	.0115	.014
	-2.17	-.135	.0146	.027
	-3.23	-.204	.0195	.041
	-4.29	-.272	.0269	.056
	.08	.006	.0093	-.002
	.36	.025	.0097	-.005
	.90	.058	.0110	-.012
	1.96	.122	.0139	-.025
	3.01	.189	.0185	-.039
	4.08	.257	.0254	-.053
	6.19	.395	.0470	-.088
	8.30	.520	.0763	-.117
1.30	-.30	-.021	.0113	.004
	-.57	-.036	.0118	.007
	-1.11	-.065	.0129	.014
	-2.16	-.128	.0159	.027
	-3.20	-.192	.0208	.042
	-4.27	-.255	.0280	.057
	.08	.006	.0109	-.002
	.36	.023	.0112	-.005
	.89	.054	.0123	-.011
	1.96	.113	.0152	-.024
	3.01	.177	.0197	-.039
	4.07	.240	.0264	-.055
	6.27	.366	.0458	-.087
	8.34	.480	.0726	-.116
	10.36	.584	.1065	-.135
	12.47	.682	.1469	-.151
1.50	-.30	-.019	.0111	.004
	-.56	-.033	.0115	.007
	-1.11	-.059	.0124	.013

M	α	C_L	C_D	C_m
1.50	-2.15	-0.113	0.0153	0.026
	-3.20	-.172	.0203	.041
	-4.25	-.227	.0267	.056
	.07	.006	.0109	-.002
	.34	.021	.0110	-.005
	.89	.050	.0117	-.011
	1.95	.103	.0146	-.024
	2.99	.160	.0192	-.038
	4.04	.215	.0255	-.053
	6.24	.322	.0429	-.082
	8.22	.422	.0661	-.108
	10.31	.519	.0958	-.130
	12.40	.606	.1309	-.146
	14.48	.682	.1718	-.155
	16.58	.757	.2198	-.168
1.70	-.30	-.017	.0110	.004
	-.55	-.030	.0112	.006
	-1.09	-.053	.0122	.012
	-2.14	-.102	.0151	.024
	-3.18	-.153	.0198	.037
	-4.22	-.201	.0258	.049
	.08	.007	.0107	-.002
	.35	.018	.0109	-.005
	.88	.043	.0115	-.011
	1.93	.093	.0141	-.023
	2.97	.143	.0185	-.035
	4.01	.190	.0243	-.047
	6.10	.284	.0396	-.071
	8.18	.373	.0606	-.092
	10.25	.456	.0867	-.112
	12.33	.538	.1187	-.129
	14.41	.614	.1553	-.142
	16.48	.682	.1966	-.148
	17.53	.716	.2212	-.152
1.90	-.30	-.018	.0125	.004
	-.55	-.029	.0127	.006
	-1.09	-.052	.0133	.012
	-2.13	-.096	.0158	.023
	-3.17	-.140	.0198	.033
	-4.21	-.183	.0253	.043
	.07	.003	.0121	-.001
	.34	.014	.0122	-.004
	.87	.037	.0127	-.010
	1.92	.082	.0148	-.020
	2.96	.126	.0183	-.031
	3.99	.169	.0234	-.041
	6.06	.250	.0371	-.060
	8.13	.332	.0562	-.079
	10.21	.410	.0802	-.096
	12.27	.479	.1080	-.111
	14.34	.549	.1415	-.123
	16.41	.614	.1789	-.130
	17.45	.649	.2008	-.134

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TABLE III.- AERODYNAMIC CHARACTERISTICS OF WING WITH TAPER RATIO OF 0.4 - Concluded

(b) R = 4.0 million per foot

M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m
0.70	-0.39	-0.022	0.0075	-0.001	0.60	-1.25	-0.065	0.0084	0.001	0.80	0.08	0.006	0.0066	-0.001
	-.68	-.039	.0076	0		-2.34	-.128	.0114	.004		.36	.022	.0070	-.001
	-1.24	-.069	.0082	.001		-3.34	-.188	.0158	.008		.93	.055	.0078	-.003
	-2.25	-.131	.0112	.005		-4.43	-.258	.0231	.014		2.03	.117	.0100	-.008
	-3.35	-.196	.0160	.009		.04	.004	.0069	-.001		3.14	.188	.0150	-.013
	-4.45	-.267	.0238	.017		.35	.020	.0074	-.001		4.26	.262	.0228	-.023
	.07	.005	.0069	-.001		.88	.051	.0082	-.002		6.49	.416	.0474	-.044
	.36	.020	.0072	-.001		1.97	.112	.0107	-.006		8.73	.563	.0845	-.052
	.92	.053	.0082	-.003		3.06	.175	.0151	-.010		10.92	.659	.1252	-.041
	2.01	.115	.0105	-.007		4.14	.238	.0215	-.015		13.11	.785	.1803	-.050
	3.12	.179	.0154	-.011		6.35	.394	.0446	-.036					
	4.22	.248	.0225	-.017		8.52	.533	.0786	-.050	0.90	-.40	-.024	.0070	-.001
	6.44	.400	.0448	-.038		10.71	.645	.1178	-.038		-.69	-.041	.0075	0
	8.67	.551	.0817	-.053		12.87	.757	.1657	-.032		-1.26	-.076	.0081	.003
	10.83	.651	.1204	-.037		15.02	.852	.2182	-.023		-2.30	-.147	.0118	.009
	13.01	.760	.1691	-.033		17.17	.945	.2793	-.017		-3.43	-.222	.0180	.018
	15.19	.858	.2229	-.028		18.31	.979	.3101	-.013		-4.38	-.308	.0276	.031
											2.06	.131	.0097	-.010
0.60	-.42	-.022	.0075	-.001	0.80	-3.37	-.206	.0159	.012		3.18	.206	.0160	-.018
	-.69	-.036	.0080	0		-4.49	-.277	.0240	.020		4.32	.286	.0245	-.032
											6.60	.462	.0535	-.062

(c) R = 6.0 million per foot

M	α	C_L	C_D	C_m	M	α	C_L	C_D	C_m
0.80	-0.48	-0.028	0.0081	0	0.90	-0.47	-0.030	0.0078	0
	-.75	-.045	.0080	.001		-.77	-.046	.0079	.001
	-1.32	-.075	.0087	.002		-1.34	-.080	.0090	.003
	-2.39	-.140	.0113	.005		-2.44	-.154	.0120	.009
	-3.51	-.201	.0160	.009		-3.61	-.231	.0182	.017
	-4.68	-.281	.0246	.019		-4.78	-.311	.0277	.030
	.05	.008	.0076	-.001		.07	.010	.0075	-.002
	.35	.026	.0078	-.002		.37	.028	.0078	-.002
	.94	.059	.0083	-.003		.95	.063	.0086	-.005
	2.08	.122	.0105	-.007		2.09	.129	.0108	-.009
	3.22	.190	.0152	-.011		3.27	.206	.0157	-.016
	4.36	.258	.0221	-.017		4.46	.285	.0243	-.028
	6.67	.407	.0473	-.041		6.78	.435	.0498	-.051
	8.48	.535	.0743	-.051					

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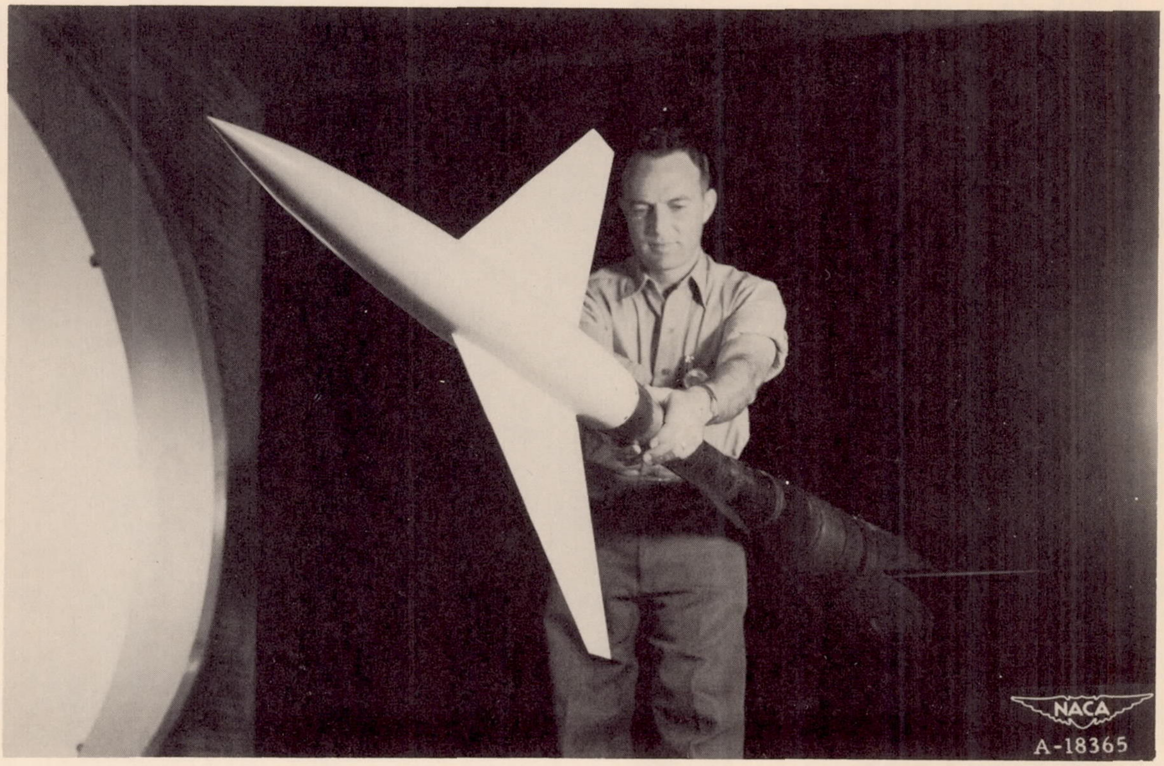

Figure 1.- Model with wing of taper ratio of 0.2 installed in Ames 6- by 6-foot supersonic wind tunnel.

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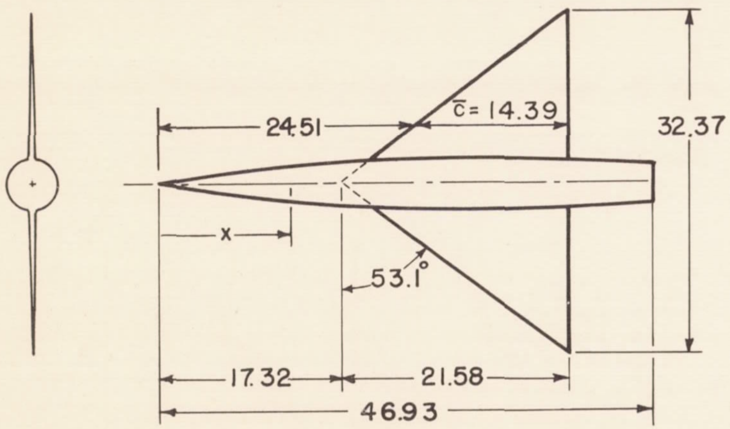
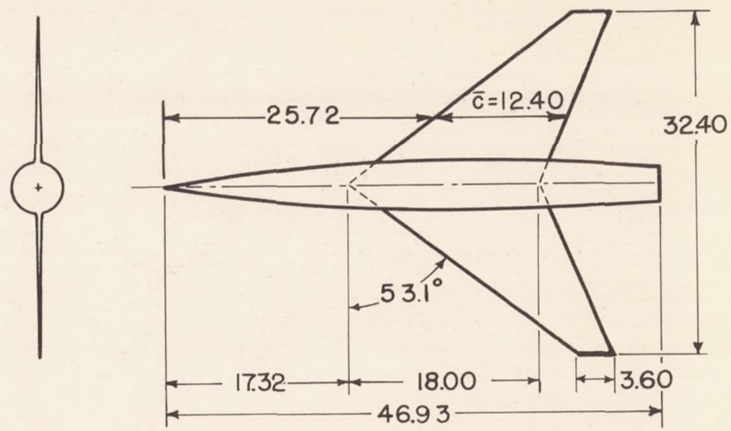
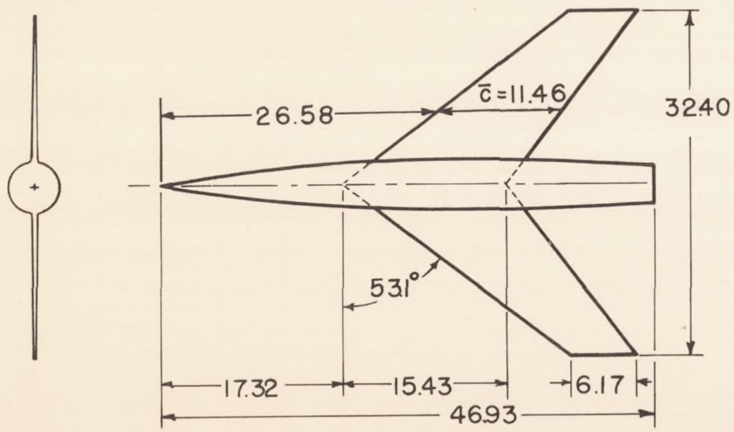


(a) Taper ratio = 0.



(b) Taper ratio = 0.2.



(c) Taper ratio = 0.4.

Equation for body radius:

$$r = r_o \left[1 - \left(1 - \frac{2x}{\ell}\right)^2\right]^{3/4}$$

Maximum radius, $r_o = 2.38$

Length for closure, $\ell = 59.50$

All dimensions in inches unless otherwise noted

Figure 2.- Dimensional sketches of models.

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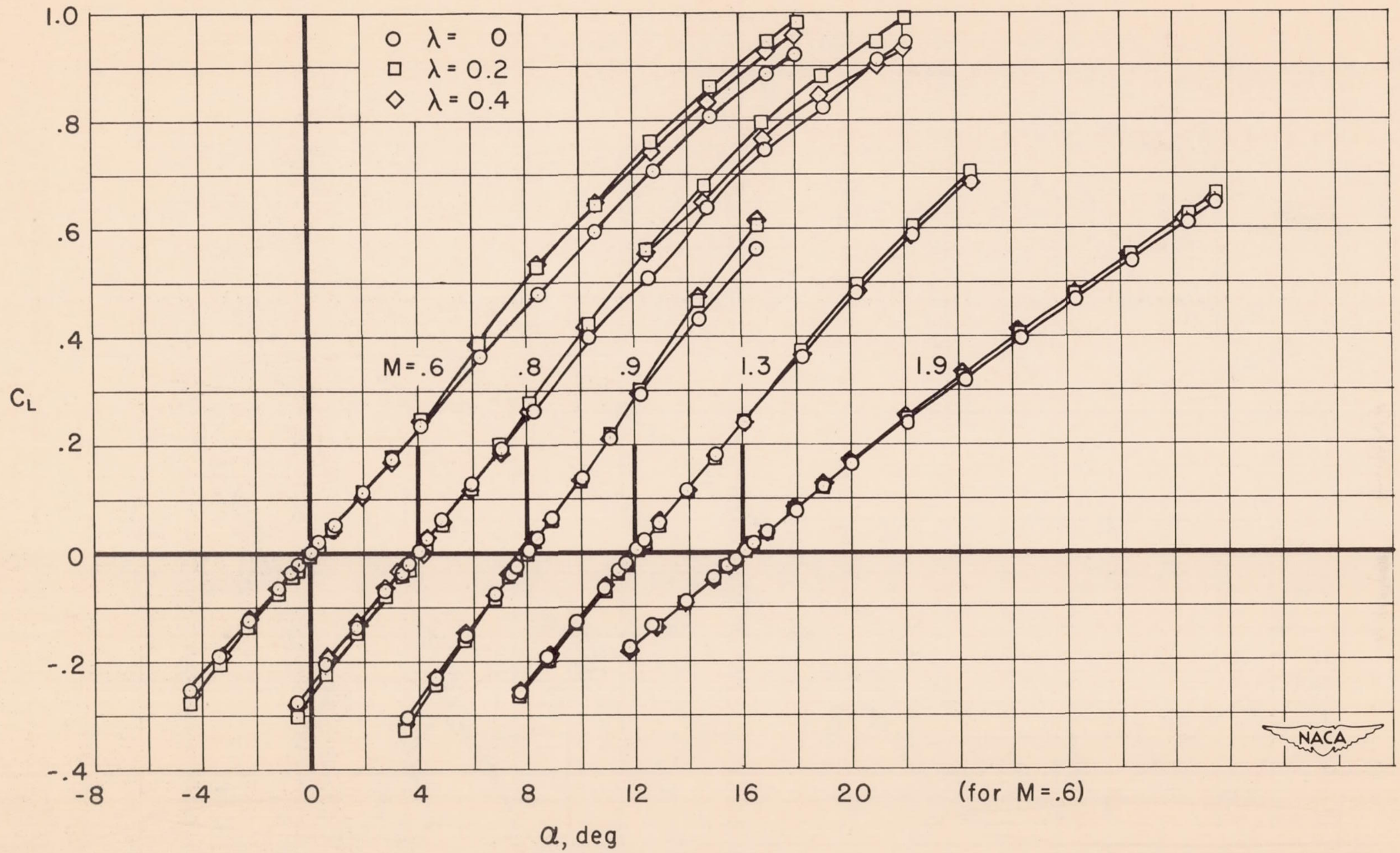

Figure 3.- Effect of taper ratio on the variation of lift coefficient with angle of attack; R = 3.0 million per foot.

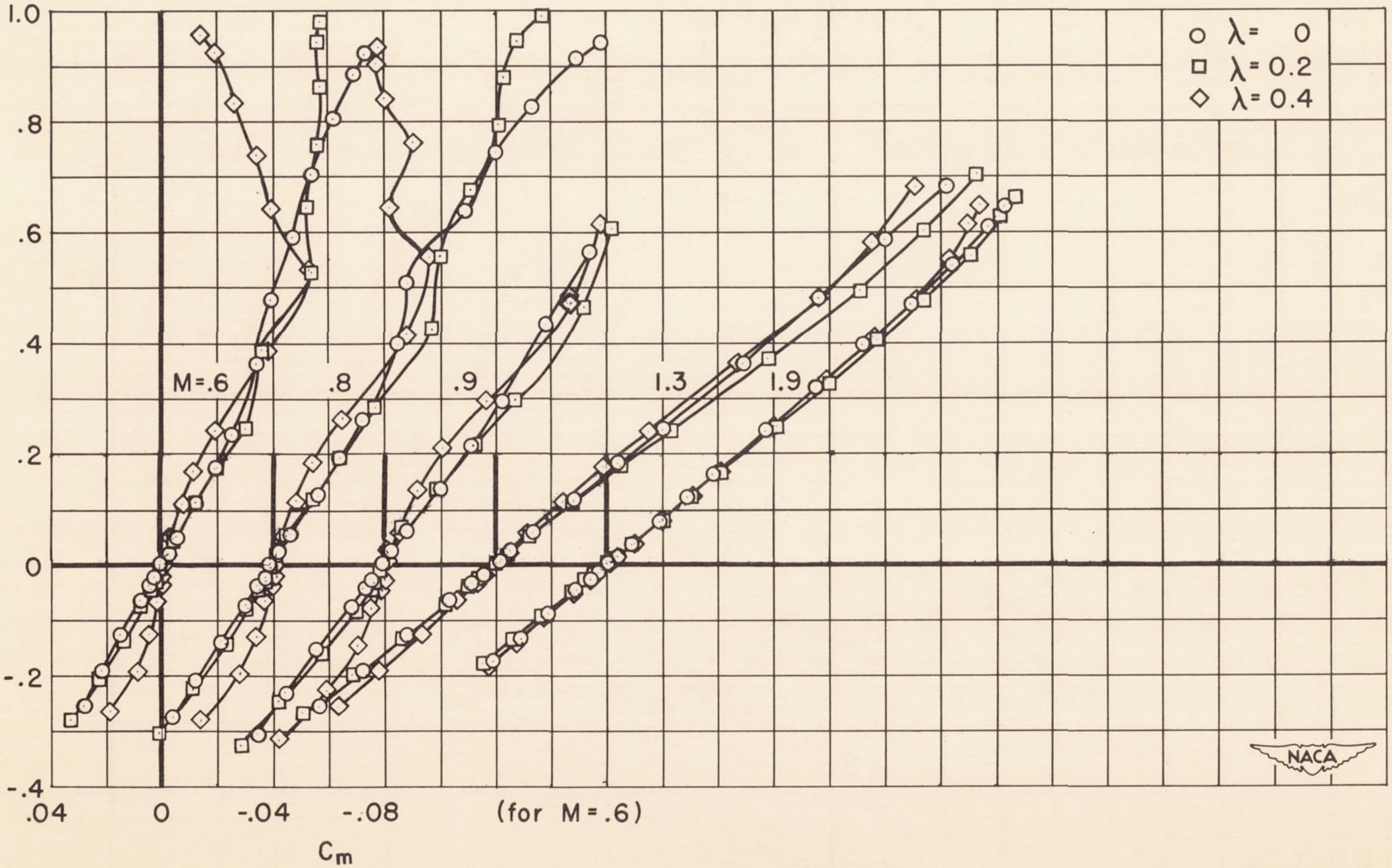

Figure 4.- Effect of taper ratio on the variation of pitching-moment coefficient with lift coefficient; R = 3.0 million per foot.

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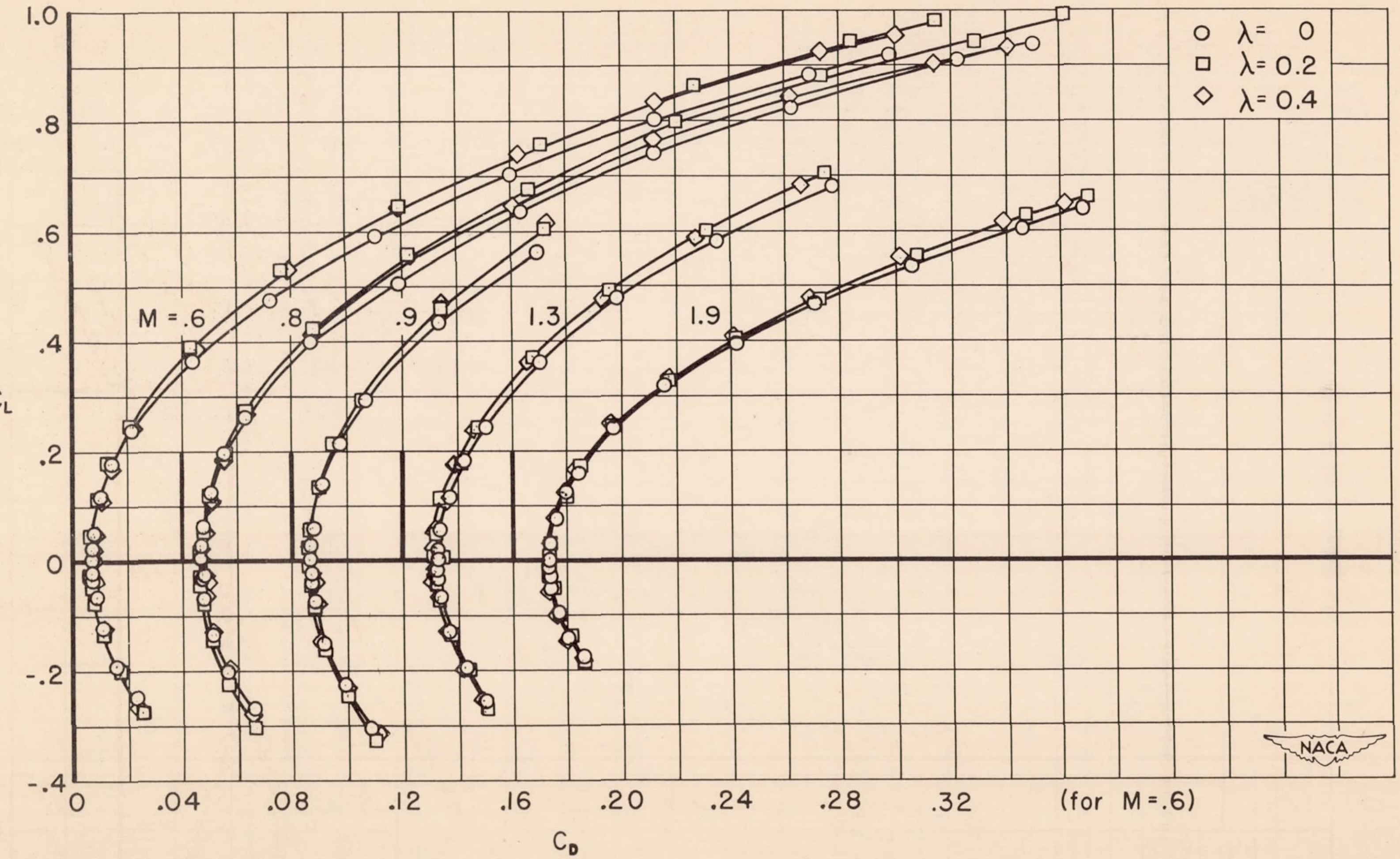

Figure 5.- Effect of taper ratio on the variation of drag coefficient with lift coefficient; R = 3.0 million per foot.

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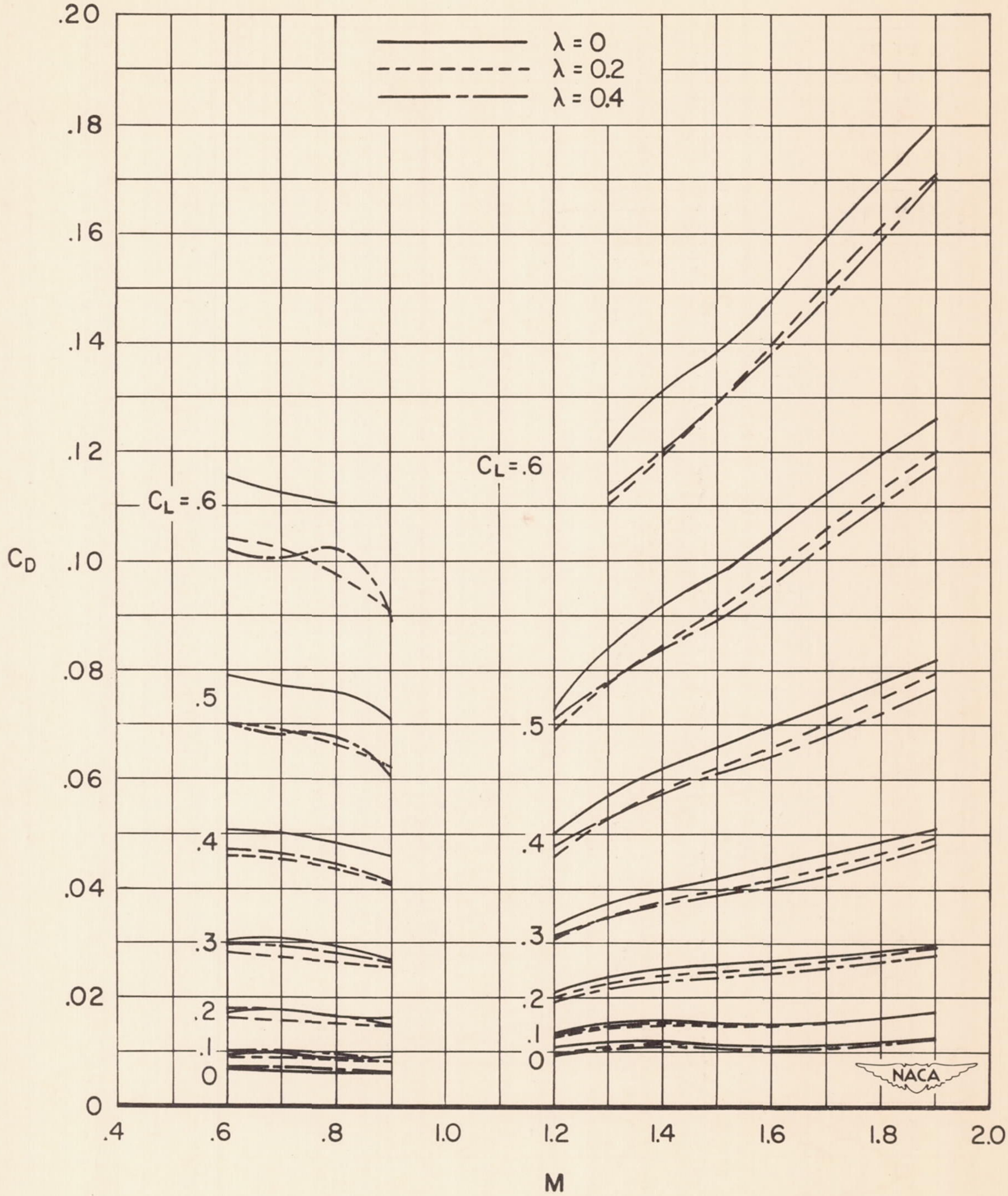

Figure 6.- Effect of taper ratio on the variation with Mach number of the drag coefficients at various lift coefficients; R = 3.0 million per foot.

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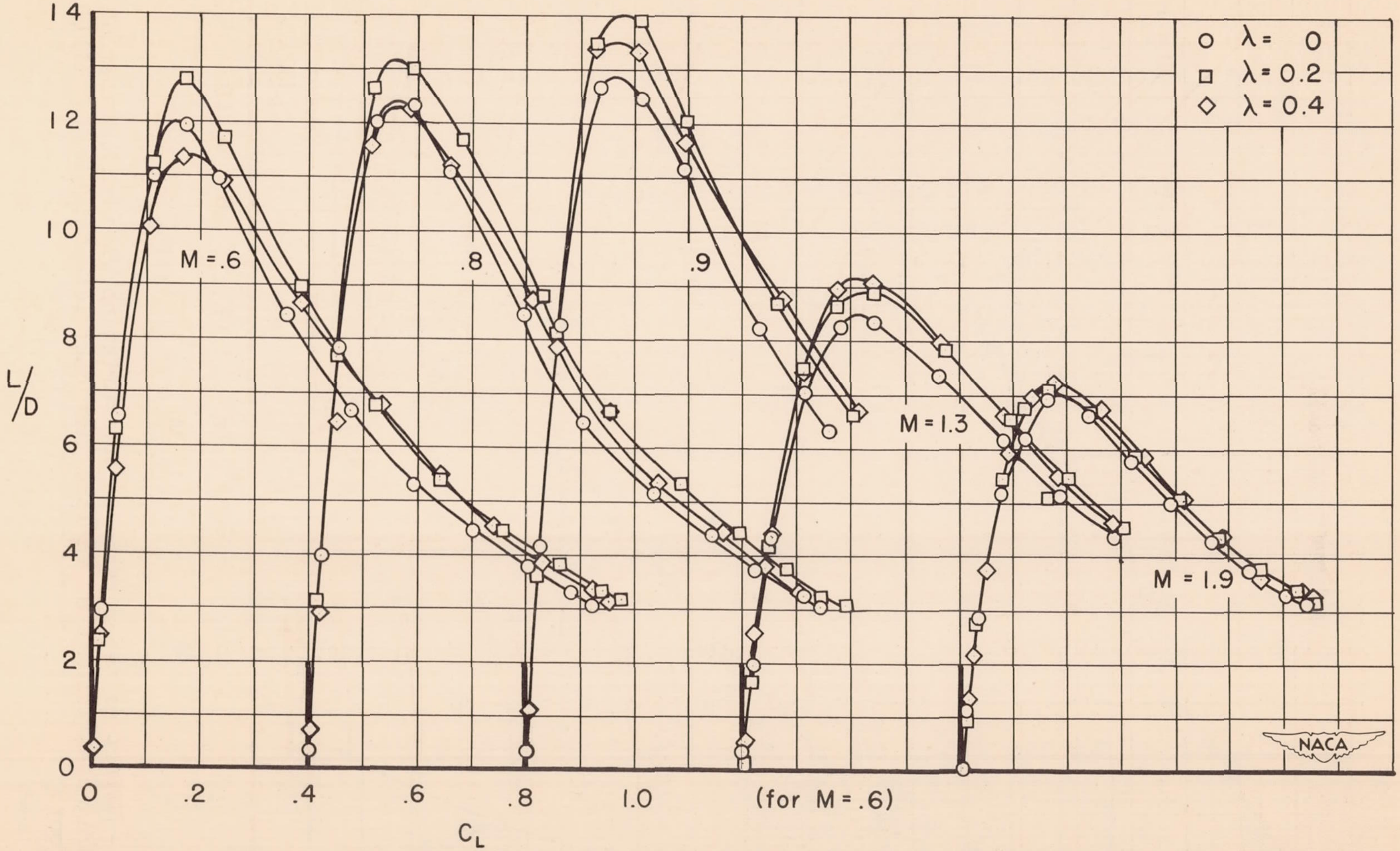

Figure 7.- Effect of taper ratio on the variation of lift-drag ratio with lift coefficient; R = 3.0 million per foot.

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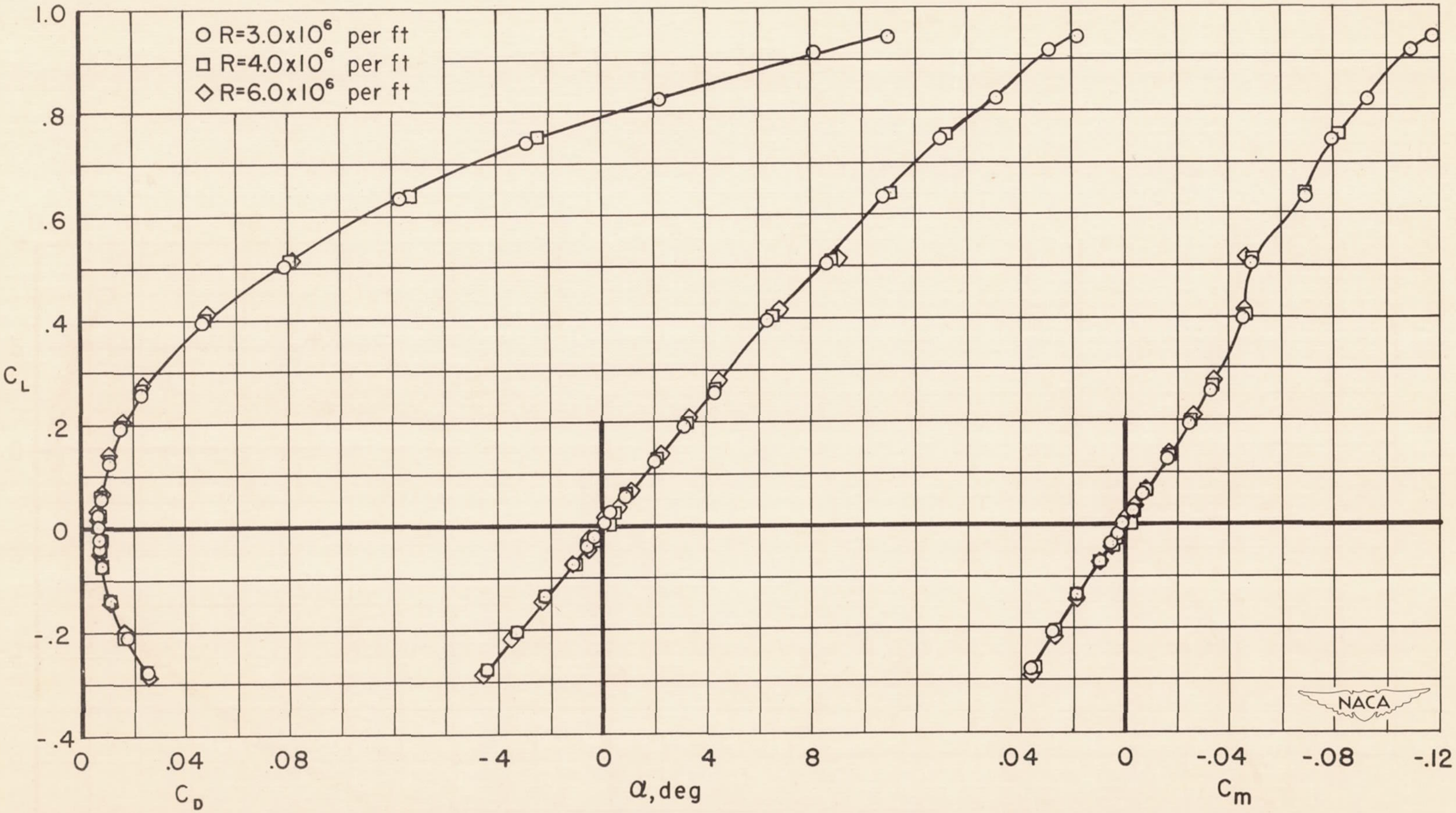

(a) $\lambda = 0$

Figure 8.- Effect of Reynolds number on aerodynamic characteristics of the three models at a Mach number of 0.8.

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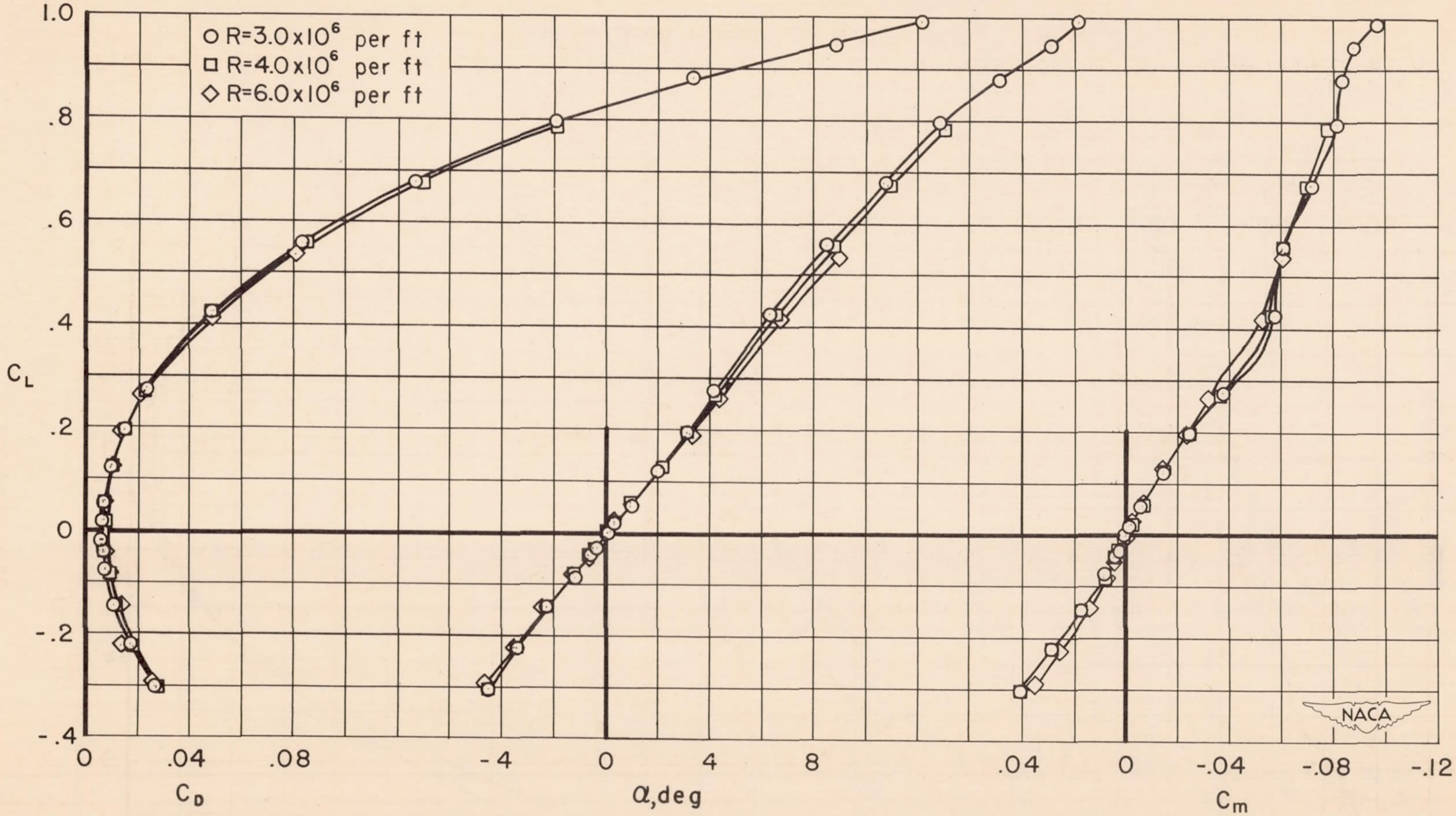

(b) $\lambda = 0.2$

Figure 8.- Continued.

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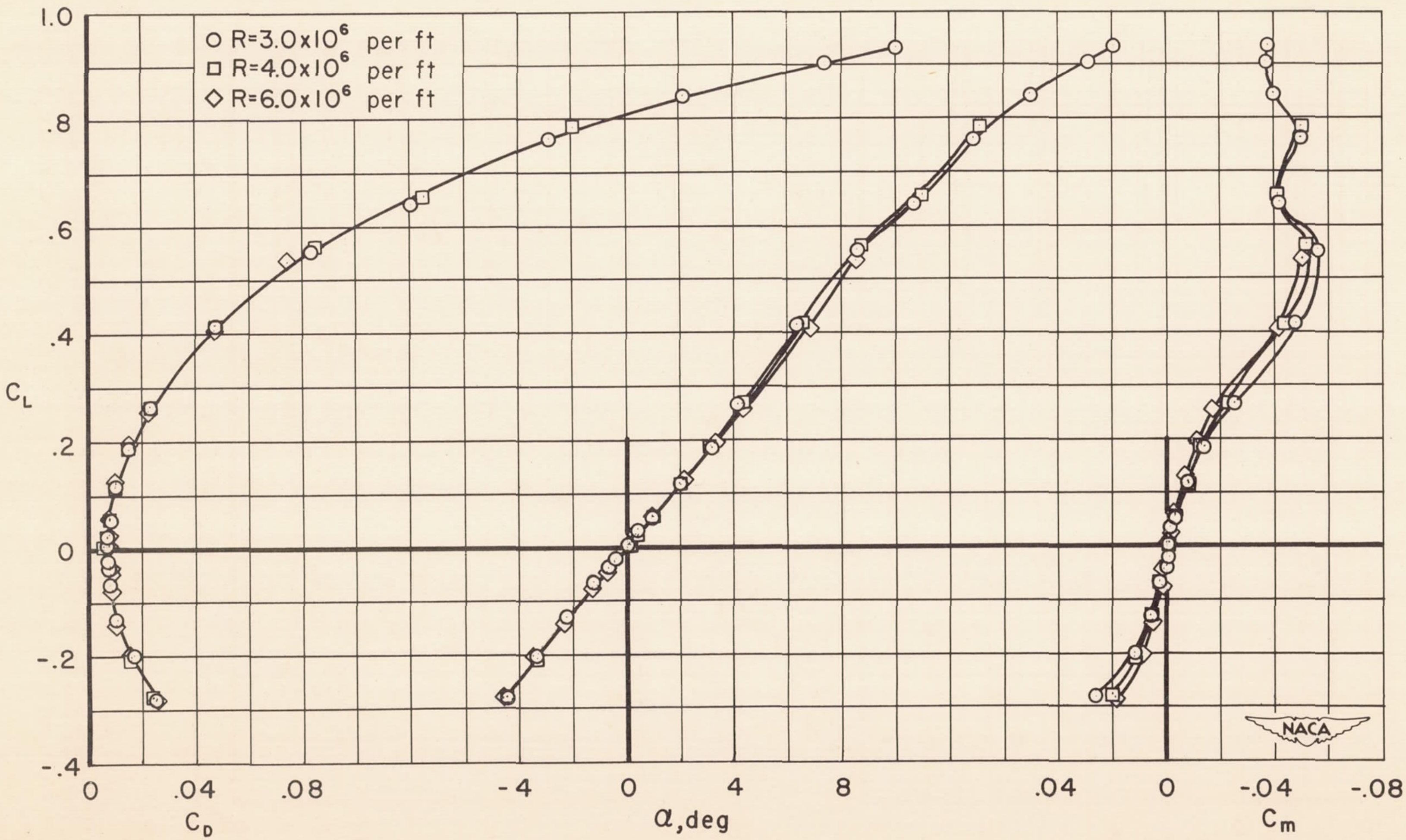

(c) $\lambda = 0.4$

Figure 8.- Concluded.

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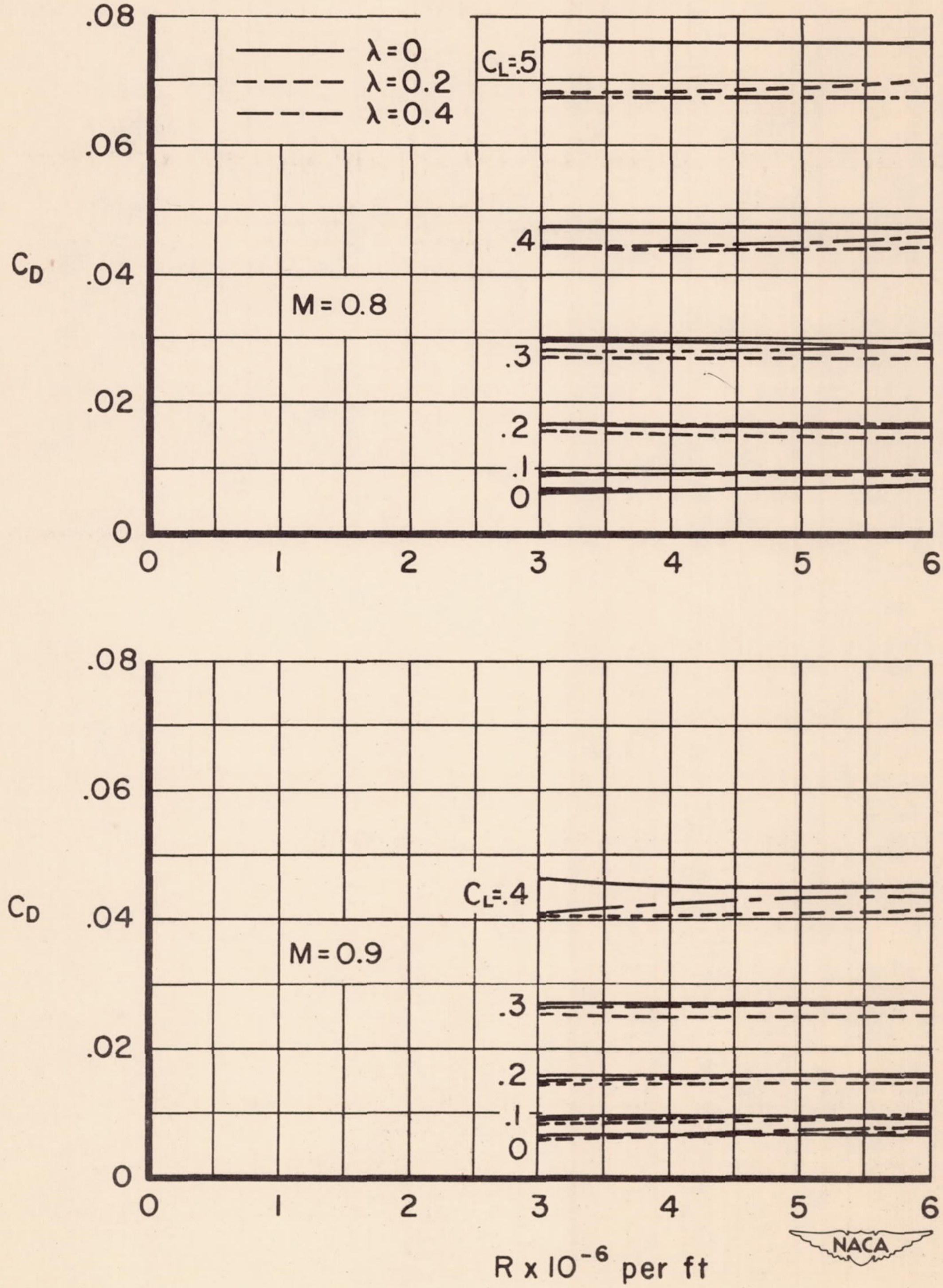

Figure 9.- Variation with Reynolds number of the drag coefficients at various lift coefficients for the three models at subsonic speeds.

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