NASA TM-72851

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March 1978

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National Aeronautics and Space Administration
Washington, D.C. 20546

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INTRODUCTION

Because of the continuing interest in flight simulation and handling qualities, reliable estimates of the stability and control derivatives of most types of aircraft are required. In response to these requirements, the NASA Dryden Flight Research Center perfected a technique for determining the stability and control derivatives of aircraft from flight data (ref. 1) and developed a set of FORTRAN computer programs to implement the technique (ref. 2). These programs use a modified maximum likelihood method with a Newton-Balakrishnan algorithm to perform the required minimization.

These computer programs are currently being used at the Dryden Flight Research Center to obtain stability and control derivatives for a wide variety of aircraft. Among the aircraft being studied is the F-111A fighter bomber airplane. This report presents the estimates of the derivatives for the F-111A airplane determined from flight data by the modified maximum likelihood estimation technique. The F-111A airplane of this report is the baseline vehicle for the transonic aircraft technology (TACT) program. The data are therefore of particular interest for assessing the effect of the TACT modifications on the stability and control characteristics of the baseline vehicle.

The flight data were selected from maneuvers performed in the course of a multiple purpose flight test program. As a result, the entire flight envelope was not studied in the flight test program. In some instances, the incremental effect of a configuration was studied instead of all possible configurations.

SYMBOLS

Parenthetical symbols are computer identifiers.

a_n normal acceleration

C_l (CL)	rolling-moment coefficient
C_m (CM)	pitching-moment coefficient
C_N (CN)	normal-force coefficient
C_n (CN*)	yawing-moment coefficient
C_Y (CY)	side-force coefficient
CG	center of gravity
IX	roll moment of inertia
IXZ	cross product of inertia between roll and yaw axes
IY	pitch moment of inertia
IZ	yaw moment of inertia
M (MACH)	Mach number
p (P)	roll rate
q (Q)	pitch rate
r (R)	yaw rate
α (ALPHA)	angle of attack
β	angle of sideslip
δ_a (DA)	aileron deflection
δ_c (DC)	blend of aileron and spoiler deflection
δ_e (DE)	elevator deflection
δ_r (DR)	rudder deflection

Subscripts:

p (P), q (Q), r (R), α, β, δ_a (DA), δ_c (DC), δ_e (DE), δ_r (DR)	partial derivative with respect to the indicated quantity

DESCRIPTION OF AIRPLANE AND INSTRUMENTATION

The F-111A airplane (fig. 1) is a two-place (side-by-side), long-range fighter bomber aircraft designed for all-weather supersonic operation at both low and high altitudes. Power is provided by two TF30-P-3 axial flow, dual compressor turbofan engines equipped with afterburners. The wings are equipped with leading edge slots and trailing edge flaps and may be varied in sweep angle between 16° and 71.5° (fig. 2). The empennage consists of a fixed vertical stabilizer with rudder for directional control and a horizontal stabilizer (rolling tail) that is moved symmetrically for pitch control and asymmetrically for roll control. At wing-sweep angles of less that 47°, wing spoilers augment roll-control power; at high wing-sweep angles, the spoilers are disengaged. The aircraft has an adaptive gain-scheduled stability augmentation system that was not engaged during these maneuvers. Physical characteristics of the airplane are given in table 1. A more complete description of the aircraft and its control system is given in reference 3.

Airspeed, altitude, and the pertinent stability and control quantities were among the data recorded. Angles of attack and sideslip were measured by vanes on a nose boom. Data were acquired by means of a pulse code modulation (PCM) system. Standard passive analog filters with break frequencies at 10 hertz were applied to all the data signals. The digital data were recorded at 20 samples per second on magnetic tape and telemetered to a ground station for real-time monitoring and recording. The data were corrected for all known time and phase shifts due to sampling skew and filtering.

TEST PROCEDURE AND FLIGHT CONDITIONS

Standard stability and control pulses were performed at wing-sweep angles of 26°, 35°, and 58°. Elevator and rudder pulses were obtained at all wing-sweep angles. Aileron (rolling tail) pulses were obtained at a wing-sweep angle of 58°; however, at wing-sweep angles of 26° and 35°, the roll-control pulses resulted in combined aileron-spoiler motion, δ_c, as mentioned previously. The flight conditions analyzed covered a Mach number range of 0.63 to 1.43, an angle of attack range of 2° to 15°, and an altitude range of 3000 to 11,000 meters. The stability augmentation system was off for all these maneuvers.

The flight program consisted of 25 flights, of which flights 5 to 8, 16, and 17 contained usable stability and control maneuvers. For correlation with other data, these flight numbers are retained in this report.

The initial data were gathered from flights 5 to 8 in level flight at 1g conditions. To investigate aeroelastic effects, elevated g data were taken during flights 16 and 17. These maneuvers were performed during steady turns, and normal acceleration ranged from 0.9g to 3.8g. It was anticipated that the wing deformation under load would affect the aerodynamic derivatives. No δ_c pulses were obtained at the elevated g conditions.

METHOD OF ANALYSIS

A modified maximum likelihood estimator program was used to determine a complete set of linear stability and control derivatives from the maneuvers performed in flight. The program, sometimes called the Newton-Raphson program, minimizes the difference between the measured aircraft response and the computed aircraft response by adjusting the stability and control derivative values used in calculating the computed response. A Newton-Balakrishnan iterative algorithm was used to perform the minimization. The method can be modified to include *a priori* information from previous calculations, flight tests, or wind tunnel tests. This modification is made by including a penalty for adjusting the unknown stability and control derivatives away from the *a priori* values. If new information is contained in a flight maneuver, the estimate of the derivative is not affected significantly by the *a priori* feature. If no new information is contained in a maneuver, however, the *a priori* value results. A low *a priori* weighting was used on these data. A complete description of the computer program used for the derivative extraction and the FORTRAN listings is given in reference 2.

In addition to giving estimates of the derivatives, this method of analysis provides uncertainty levels for each derivative. The uncertainty levels are proportional to the Cramèr-Rao bounds described in reference 1 and are analogous to the standard deviations of the estimated derivatives. The larger the uncertainty level, the more uncertainty there is in the estimated value. The uncertainty levels obtained for a derivative from different maneuvers at the same flight condition can be compared to determine the best estimate. Therefore, the uncertainty levels provide additional information about the validity of the estimate of the derivative.

Since rolling tail and spoiler surfaces move together for wing-sweep angles of 26° and 35°, it is not possible to estimate their effectiveness separately. Thus, an equivalent combined effectiveness was obtained as suggested in reference 4, by using the spoiler position only. The spoiler signal was used for the equivalent control because the moments produced by the spoiler deflection were larger than the moments produced by the rolling tail. The spoiler position was not measured directly but was computed from the differential tail movements and the known characteristics of the control system. This equivalent combined control is referred to as δ_c. For a wing-sweep angle of 58°, the rolling tail moves alone and the usual δ_a derivatives are obtained.

RESULTS AND DISCUSSION

The results are presented in figures summarizing the stability and control coefficients as functions of angle of attack. The data in these figures are corrected to the wind tunnel reference center of gravity. The center of each symbol indicates the maximum likelihood estimate of the coefficient, and the vertical line indicates the uncertainty level of the estimate. Those estimates with smaller uncertainty levels are more reliable estimates and should be considered more strongly in fairing the estimated coefficients. A further explanation of uncertainty levels is given in reference 4. The figures summarizing the coefficients are divided into groups of longitudinal and lateral-directional coefficients and then further divided as a function of increasing wing sweep.

Analysis of Data Obtained at 1g Conditions

Estimates of the vehicle's stability and control characteristics at 1g conditions were obtained from 71 maneuvers performed during flights 5 to 8. Thirty of these maneuvers were longitudinal. Based on the quality of the fits obtained and the uncertainty levels, 27 (that is, 90 percent) of the longitudinal maneuvers were considered acceptable. Similarly, 36 of the 41 lateral-directional maneuvers were used, which constituted 88-percent utilization. Several of the lateral-directional maneuvers used were analyzed in pairs, obtaining one set of derivatives for each pair of maneuvers as discussed in reference 4.

Table 2 summarizes the flight conditions, weights, and inertias for all the maneuvers (both longitudinal and lateral-directional) for flights 5 to 8. The inertias are based on the best available calculated values. The estimated derivative values are presented in table 3 for the longitudinal maneuvers and in table 4 for the lateral-directional maneuvers. All these data are referenced to the wind tunnel center of gravity locations. The maneuver numbers used in tables 3 and 4 are defined in table 2.

Longitudinal data.—Figures 3 to 5 summarize the longitudinal stability and control data from flights 5 to 8 for wing-sweep angles of 26°, 35°, and 58°. These data are corrected to the 0.45-chord wind tunnel reference center of gravity. The longitudinal wind tunnel data were obtained from reference 5.

The flight-determined estimates generally show consistent trends in reasonable agreement with the wind tunnel estimates. C_{m_α} for a wing-sweep angle of 26° is the obvious exception. Figure 6 shows C_{m_α} as a function of Mach number, with symbol shape denoting the approximate angle of attack. C_{m_α} shows a significant change near Mach 0.85 and then returns to the same value as at the lower Mach numbers. Thus, the apparent scatter in C_{m_α} (fig. 3) is due to the particular Mach breakpoints used (Mach 0.7, 0.8, and 0.9); the estimates from the Mach 0.85 transition region were divided between the Mach 0.8 and 0.9 breakpoints, giving the appearance of large scatter. If the three flagged data points from the transition region are grouped, there is a well defined trend, on which the fairings are based.

Lateral-directional data.—Figures 7 to 9 summarize the lateral-directional stability and control data from flights 5 to 8. The format is the same as for the longitudinal data. The lateral-directional wind tunnel data are the same as those used in the Air Force Flight Test Center's F-111A simulator. All the lateral-directional data are corrected to the 0.305-chord reference center of gravity of the wind tunnel data. Well defined trends were obtained for all the derivatives except C_{l_r}.

The maneuvers analyzed did not contain enough information to accurately estimate C_{l_r}; thus, the *a priori* weighting held it close to the *a priori* values. The wind tunnel data were used for *a priori* values in this analysis. This is evidenced by the fact that the C_{l_r} estimates are all very close to the *a priori* values and have large uncertainty levels. A more complete discussion of this conclusion is given in reference 4.

The C_{Y_β} and C_{n_β} estimates were generally smaller in magnitude than the wind tunnel estimates for all wing sweeps. The flight estimates ranged from 40 to 80 percent of the wind tunnel values. The C_{l_β} estimates for a wing-sweep angle of 58° agree well with the wind tunnel estimates, but those for wing-sweep angles of 26° and 35° show some significant differences, particularly a strong Mach effect between Mach 0.8 and 0.9. The two flagged data points in figures 7 and 8 are for a Mach number of 0.82. Nonetheless, they agree quite well with the Mach 0.9 estimates rather than those for Mach 0.8 and below. This indicates a significant and abrupt Mach effect at a Mach number of approximately 0.82. Some of the discrepancies between the flight and wind tunnel estimates of the angle of sideslip derivatives may be attributable to the nonlinearities observed in the wind tunnel data near 0° sideslip. As a result of these nonlinearities, the wind tunnel derivative estimates depend on the angle of sideslip increment used.

The flight and wind tunnel estimates for C_{l_p} and C_{n_r} agree fairly well, the flight estimates being slightly more negative in some areas. Although the wind tunnel C_{n_p} estimates are much closer to zero than the flight estimates, all the values are relatively small.

The flight estimates of $C_{Y_{\delta_r}}$ and $C_{n_{\delta_r}}$ were significantly lower in magnitude than the wind tunnel estimates, although $C_{l_{\delta_r}}$ showed reasonable agreement.

The flight estimates of the roll control derivatives generally agreed well with the wind tunnel estimates.

Analysis of Data Obtained at Elevated g Conditions

Estimates of the vehicle stability and control characteristics at elevated g conditions were obtained from data collected from flights 16 and 17. A total of 109 maneuvers were obtained from these flights. Of these, 86 maneuvers were successfully analyzed. This resulted in 79-percent utilization of the maneuvers. This is lower than the 89-percent utilization achieved for the 1g maneuvers. The reason for the lower utilization is that the elevated g maneuvers were obtained in steady turns, which are more difficult to adequately stabilize than the 1g maneuvers.

Table 5 summarizes the flight conditions, weights, and inertias for all the flight 16 and 17 maneuvers. The inertias are based on the best available calculated values. The estimated derivative values are presented in table 6 for the longitudinal maneuvers and in table 7 for the lateral-directional maneuvers. All these data are referenced to the wind tunnel center of gravity locations. The maneuver numbers used in tables 6 and 7 are defined in table 5.

Figures 10 to 15 summarize the stability and control data obtained from flights 16 and 17. The 1g points from flights 5 to 8 are repeated on these figures for comparison. The data are presented in a manner similar to that used for the data from flights 5 to 8, but the shape of the symbol indicates the g level at which the maneuver was obtained, and the fairing is from the data for flights 5 to 8. Deviation from this fairing may indicate aeroelastic effects.

Longitudinal data.—Figures 10 to 12 summarize the results of the longitudinal stability and control analysis, corrected to the 0.450 chord, obtained from flights 16 and 17. Where the data obtained from flights 16 and 17 overlap the data from flights 5 to 8, no discrepancies are evident. In some instances, the trend established by the 1g data (which were only available at lower angles of attack) changes at the high angle of attack where data were obtained only at elevated g conditions. No effect is evident that can be attributed conclusively to aeroelasticity.

Lateral-directional data.—Figures 13 to 15 summarize the results of the lateral-directional stability and control analysis, corrected to the 0.305 chord, obtained from flights 16 and 17. At a wing-sweep angle of 26° and high angles of attack, C_{l_β}, C_{l_p}, and C_{n_p} were somewhat closer to zero than an extrapolation of the 1g fairing would indicate. At wing-sweep angles of 35° and 58° and high angles of attack, C_{n_p} remains more negative than the 1g data would indicate. The values of C_{l_r} and C_{n_r} are not well determined in the analysis of the elevated g data, as is indicated by the large uncertainty levels obtained and the small deviation from the extrapolated 1g data. As mentioned previously, little information was available in the 1g flight data for C_{l_r}. Since the aircraft was in a banked attitude at a high angle of attack for the elevated g maneuvers, it is not surprising that little information was obtained from these maneuvers for C_{n_r} or C_{l_r}. There is no conclusive indication that aeroelasticity has a marked effect on the lateral-directional stability and control characteristics.

In extracting stability and control coefficients from flight data, it is sometimes apparent that different values are indicated for the same coefficient at the same flight condition. The uncertainty levels and the quality of the fits can be used to substantiate the differences. The phenomenon is usually difficult to show conclusively, because the time history is a complex, simultaneous interaction of many of the coefficients. However, the phenomenon is illustrated by the estimates obtained for $C_{l_{\delta_r}}$ at a wing-sweep angle of 35°. Figure 16, which is repeated from figure 14(e), shows the data points for maneuvers 74 and 75, which were performed within 50 seconds of each other at essentially the same flight condition. The value of $C_{l_{\delta_r}}$ from maneuver 75 is several times greater than the value of $C_{l_{\delta_r}}$ from maneuver 74. This difference is shown convincingly in figures 17 and 18. Figure 17 is a time history of maneuver 74, and figure 18 is a time history of maneuver 75. The significant parameters are the rudder input, δ_r, and the roll response, p. As shown in the figures, the rudder pulse for maneuver 75 is somewhat stronger than that for maneuver 74. The two pulses have roughly the same amplitude, but the pulse for maneuver 75 occurs over a longer time period. Very little, if any, immediate roll response to the pulse is apparent for maneuver 74, while a significant immediate roll motion results from the rudder pulse for maneuver 75. As would be expected, the value of $C_{l_{\delta_r}}$ for maneuver 74 is smaller than that for maneuver 75. The variation in the aircraft's response to two similar pulses is probably due to some effect that has not been accounted for.

CONCLUDING REMARKS

A complete set of linear stability and control derivatives of the F-111A airplane was determined with a modified maximum likelihood estimator. The derivatives were determined at wing-sweep angles of 26°, 35°, and 58°. The flight conditions included a Mach number range of 0.63 to 1.43 and an angle of attack range of 2° to 15°. Maneuvers were performed at normal accelerations from 0.9g to 3.8g during steady turns to assess the aeroelastic effects on the stability and control characteristics.

The derivatives generally showed consistent trends and reasonable agreement with the wind tunnel estimates. Significant Mach effects were observed for Mach numbers as low as 0.82, particularly for static longitudinal stability. At high angles of attack, rolling moment due to rudder deflection showed two significantly different values at the same flight condition. This is presumably due to some effect that was not accounted for. No large effects attributable to aeroelasticity were noted.

Dryden Flight Research Center
National Aeronautics and Space Administration
Edwards, Calif., August 18, 1977

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TABLE 1.—PHYSICAL CHARACTERISTICS OF F-111A AIRPLANE

Wing—	
Airfoil section, at pivot	NACA 64A210.7 (modified)*
Airfoil section, tip	NACA 64A209.8 (modified)*
Sweep, deg (leading edge)	16 to 71.5
Incidence, deg	1
Dihedral, deg	1
Reference span, m	18.1
Reference area, m^2	48.8
Reference chord, m	2.76
Leading-edge slats—	
Area (planform projected), m^2	4.38
Span, percent of exposed wing-panel span	96.5
Deflection, maximum, deg	45
Trailing-edge flaps—	
Type	Multisection Fowler
Area (aft of hinge line), m^2	9.75
Span, percent of exposed wing-panel span	100
Deflection, maximum, deg	35
Spoilers—	
Area (planform projected), m^2	2.74
Span, m	3.6
Deflection, maximum, deg	43
Wing pivot—	
Distance from airplane nose, m	11.83
Distance from airplane centerline, m	1.79
Horizontal tail (all movable)—	
Airfoil section	Biconvex
Incidence, deg	1
Dihedral, deg	-1
Sweep at leading edge, deg	57.5
Span, m	9.11
Area (exposed), m^2	15.74
Area (movable), m^2	13.92
Aspect ratio	1.54
Mean aerodynamic chord (exposed), cm	349.3
As elevators:	
Trailing edge up	≈25
Trailing edge down	≈10
As ailerons (total)	±15
Surface stops:	
Trailing edge up	≈31
Trailing edge down	≈16

*Unswept wing.

TABLE 1.—Concluded

Vertical tail—	
Airfoil section	Biconvex
Sweep at leading edge, deg	55
Span, m	2.71
Area, m^2	10.09
Aspect ratio	1.42
Mean aerodynamic chord, cm	404.6
Rudder—	
Span, m	2.38
Area, m^2	2.65
Deflection, maximum, deg	±30
Speed brake—	
Area, m^2	2.39
Deflection, maximum, deg	77
Ventrals—	
Area (total), m^2	2.26
Power plants—	
TF30-P-3 engines	2

TABLE 2.—FLIGHT STATISTICS FOR FLIGHTS 5 TO 8

(a) Maneuver type, wing-sweep angle, Mach number, angle of attack, and center of gravity. SWEEP, deg; ALPHA, deg; CG, fraction of reference chord.

NO.	FLT	TYPE	SWEEP	MACH	ALPHA	CG
1	5	ELEVATOR	58.0	.970	8.50	.360
2	5	ELEVATOR	26.0	.909	5.50	.350
3	5	AILERON RUDDER	26.0	.920	5.00	.350
4	5	ELEVATOR	35.0	.910	5.00	.370
5	5	RUDDER	35.0	.910	5.00	.360
6	6	ELEVATOR	26.0	.700	8.50	.320
7	5	AILERON RUDDER	26.0	.710	8.00	.320
8	6	ELEVATOR	26.0	.710	8.00	.330
9	6	ELEVATOR	35.0	.700	10.00	.330
10	6	AILERON RUDDER	35.0	.710	9.50	.330
11	6	ELEVATOR	35.0	.700	10.00	.330
12	6	RUDDER	58.0	1.220	3.50	.410
13	6	ELEVATOR	58.0	1.210	2.20	.430
14	6	AILERON RUDDER	58.0	1.210	2.00	.440
15	7	ELEVATOR	26.0	.820	6.50	.320
16	7	RUDDER	26.0	.820	6.00	.330
17	7	AILERON	35.0	.800	7.00	.330
18	7	RUDDER	35.0	.820	6.50	.330
19	7	ELEVATOR	58.0	.920	10.80	.370
20	7	RUDDER	58.0	.900	11.50	.370
21	7	RUDDER	58.0	.890	12.00	.370
22	7	ELEVATOR	58.0	.870	8.50	.370
23	7	AILERON RUDDER	58.0	.890	8.06	.370
24	7	ELEVATOR	26.0	.860	4.70	.330
25	7	ELEVATOR	26.0	.860	4.50	.340
26	7	AILERON	26.0	.880	5.00	.350
27	7	ELEVATOR	58.0	1.230	5.50	.410
28	7	RUDDER	58.0	1.240	5.50	.410
29	7	ELEVATOR	58.0	1.430	4.50	.430
30	7	RUDDER	58.0	1.430	4.25	.430

TABLE 2.—Continued

(a) Concluded

NO.	FLT	TYPE	SWEEP	MACH	ALPHA	CG
31	8	AILERON RUDDER	26.0	.810	4.25	.350
32	8	ELEVATOR	26.0	.810	4.40	.350
33	8	AILERON	35.0	.820	5.00	.360
34	8	ELEVATOR	35.0	.820	5.50	.360
35	8	AILERON RUDDER	26.0	.700	5.00	.350
36	8	ELEVATOR	26.0	.710	5.00	.350
37	8	AILERON RUDDER	35.0	.710	5.50	.370
38	8	ELEVATOR	35.0	.850	5.50	.370
39	8	RUDDER	58.0	.710	9.00	.400
40	8	ELEVATOR	26.[illegible]	.510	4.00	.370
41	8	AILERON RUDDER	35.0	.910	3.00	.380
42	8	AILERON RUDDER	58.0	.900	5.00	.430
43	8	ELEVATOR	58.0	.900	5.00	.430
44	8	AILERON RUDDER	26.0	.810	2.00	.390
45	8	ELEVATOR	26.0	.810	2.00	.390
46	8	AILERON RUDDER	35.0	.800	2.70	.410
47	8	ELEVATOR	35.0	.800	2.50	.410
48	8	AILERON RUDDER	58.0	.700	5.50	.450
49	8	ELEVATOR	58.0	.700	5.20	.460
50	8	AILERON RUDDER	35.0	.690	3.00	.430
51	8	ELEVATOR	35.0	.700	3.00	.430
52	8	AILERON RUDDER	26.0	.690	2.50	.420
53	8	ELEVATOR	26.0	.700	2.20	.430
54	8	RUDDER	58.0	.920	3.00	.490
55	8	ELEVATOR	58.0	.920	3.00	.490

TABLE 2.—Continued

(b) Mass characteristics, dynamic pressure, and velocity

NO.	I, $SLUG\text{-}FT^2$	IY, $SLUG\text{-}FT^2$	IZ, $SLUG\text{-}FT^2$	IXZ, $SLUG\text{-}FT^2$	WEIGHT, POUNDS	DYNAMIC PRESSURE, LB/FT^2	VELOCITY, FT/SEC
1		378000.			67400.	315.0	938.0
2		351000.			63100.	307.0	899.0
3	68500.		407000.	3240.0	62500.	302.0	900.0
4		342000.			59800.	299.0	892.0
5	62500.		393000.	5670.0	59800.	292.0	886.0
6		427000.			75300.	178.0	682.0
7	69900.		478000.	4490.0	75100.	184.0	694.0
8		427000.			75000.	183.0	696.0
9		421000.			74400.	190.0	686.0
10	64700.		469000.	5230.0	73800.	188.0	696.0
11		421000.			73700.	186.0	692.0
12	46400.		381000.	6770.0	58400.	599.0	1214.0
13		342000.			56600.	1119.0	1267.0
14	46400.		377000.	7210.0	56600.	1119.0	1265.0
15		419000.			73590.	244.0	800.5
16	69300.		456000.	5250.0	73000.	246.0	804.0
17	64600.		453000.	5630.0	71900.	236.0	784.0
18	64600.		453000.	[illegible]630.0	71700.	248.0	804.0
19		384000.			69400.	225.0	883.0
20	47800.		428000.	5300.0	69000.	214.0	867.0
21	47800.		428000.	5300.0	68800.	209.0	853.0
22		379500.			67100.	311.0	860.0
23	47800.		415000.	5220.0	67400.	317.0	871.0
24		362000.			67000.	303.0	850.0
25		362000.			66500.	298.5	850.0
26	68500.		418000.	3900.0	66300.	305.0	863.0
27		351000.			60300.	415.0	1191.0
28	47100.		386000.	5700.0	60000.	428.0	1207.0
29		342000.			57100.	556.0	1385.0
30	46300.		378000.	7060.0	56900.	552.0	1378.0

TABLE 2.—Concluded

(b) Concluded

NO.	IX, SLUG-FT²	IY, SLUG-FT²	IZ, SLUG-FT²	IXZ, SLUG-FT²	WEIGHT, POUNDS	DYNAMIC PRESSURE, LB/FT²	VELOCITY, FT/SEC
31	69000.		495000.	3980.0	66300.	301.0	810.0
32		351000.			66100.	296.5	800.0
33	63500.		423003.	4430.0	65600.	306.0	81[illegible].0
34		366000.			65700.	305.0	813.0
35	68500.		415000.	3680.0	65200.	289.0	713.0
36		358000.			65200.	296.0	722.0
37	63700.		412000.	4040.0	64800.	304.0	726.0
38		342000.			64700.	436.0	869.0
39	47300.		465000.	4340.0	64100.	305.0	725.0
40		353030.			58900.	455.0	925.0
41	62500.		389500.	5770.0	58000.	490.0	929.0
42	46400.		432500.	7260.0	56600.	465.0	919.0
43		330006.			56500.	474.0	919.0
44	67000.		391000.	6565.0	56000.	499.0	846.0
45		324900.			55800.	501.0	858.0
46	62400.		383500.	6850.0	55500.	493.0	840.0
47		333002.			55300.	511.0	853.0
48	42540.		361500.	8540.0	54900.	497.0	758.0
49		335000.			54800.	490.0	755.0
50	65500.		357600.	9450.0	54400.	491.0	745.0
51		335000.			54300.	499.0	758.0
52	67400.		386000.	6250.0	54000.	472.0	742.0
53		329000.			53800.	486.0	748.0
54	45300.		371000.	8110.0	53300.	830.0	987.7
55		327000.			53000.	820.0	984.0

TABLE 3.—LONGITUDINAL DERIVATIVES FOR FLIGHTS 5 TO 8

[All derivatives are per degree, except CM_Q, which is per radian]

NO.	CN_α	CM_α	CM_Q	CN_{DE}	CM_{DE}
1	.0653	-.0345	-34.13	.0033	-.0356
2	.0970	-.0184	-42.96	.0015	-.0405
4	.0880	-.0098	-44.43	.0007	-.0374
6	.0603	.0014	-17.60	-.0034	-.0193
8	.1085	-.0032	-45.97	-.0111	-.0334
9	.0787	-.0033	-52.68	-.0024	-.0405
11	.0760	-.0035	-38.19	-.0076	-.0265
13	.0456	-.0462	-23.25	-.0048	-.0293
15	.0838	.0033	-38.83	.0033	-.0363
19	.0570	-.0219	-39.60	.0136	-.0331
22	.0600	-.0220	-36.03	.0046	-.0345
24	.1005	.0019	-53.72	.0073	-.0395
25	.0905	.0052	-38.47	.0077	-.0362
27	.0594	-.0580	-29.34	.0004	-.0331
29	.0515	-.0500	-26.06	.0005	-.0284
32	.1092	-.0130	-39.65	-.0030	-.0351
34	.0922	-.0189	-42.92	.0077	-.0271
36	.0916	-.0106	-31.30	.0116	-.0297
38	.0576	-.0123	-27.71	.0029	-.0203
40	.0870	-.0145	-40.80	.0085	-.0397
43	.0594	-.0248	-35.59	.0096	-.0354
45	.1083	-.0105	-35.41	.0097	-.0332
47	.0883	-.0183	-37.53	.0136	-.0345
49	.0552	-.0239	-29.16	.0097	-.0313
51	.0843	-.0194	-29.66	.0114	-.0319
53	.1009	-.0098	-32.82	.0094	-.0342
55	.0581	-.0264	-37.71	.0119	-.0360

TABLE 4.—LATERAL-DIRECTIONAL DERIVATIVES FOR FLIGHTS 5 TO 8

[All derivatives are per degree, except CL_P, CL_R, CN^*_P, and CN^*_R, which are per radian]

(a) Combined lateral controls

NO.	CY_β	CL_β	CL_P	CL_R	CN^*_β	CN^*_P	CN^*_R	CY_{DR}	CL_{DR}	CN^*_{DR}	CY_{DC}	CL_{DC}	CN^*_{DC}
3	-.0111	.0007	-.5371	.0920	.0016	-.0619	-.2601	.0011	.0002	-.0013	.0002	-.0004	-.0001
5	-.0114	.0006	-.1823	.0803	.0015	-.0146	-.25	.0010	.0003	-.0014			
7	-.0099	-.0030	-.4313	.1355	.0007	-.0976	-.57 1	.0015	.0002	-.0015	.0018	-.0021	-.0005
10	-.0080	-.0027	-.2044	.0566	.0008	-.0168	-.5300	.0015	.0002	-.0015	.0015	-.0014	-.0003
16	-.0116	.0002	-.4399	.1267	.0015	.0275	-.3217	.0010	.0003	-.0014			
17	-.0069	-.0021	-.3076	.1265	.0010	-.0183	-.4642				.0011	-.0016	-.0003
18	-.0109	-.0010	-.3818	.0827	.0014	-.0678	-.3338	.0013	.0003	-.0015			
26	-.0129	.0001	-.3969	.1533	.0017	-.0504	-.2477				.0005	-.0005	-.0001
31	-.0101	-.0018	-.5683	.1428	.0013	-.1347	-.3759	.0027	.0003	-.0015	.0031	-.0028	-.0005
33	-.0123	-.0021	-.3884	.0463	.0009	-.0557	-.2432				.0024	-.0020	-.0003
35	-.0093	-.0022	-.5046	.1629	.0009	-.1021	-.2998	.0030	.0003	-.0015	.0019	-.0021	-.0004
37	-.0099	-.0023	-.4134	.0503	.0009	-.0837	-.2747	.0027	.0003	-.0014	.0019	-.0019	-.0004
41	-.0108	.0003	-.3988	.0546	.0015	-.0318	-.2342	.0012	.0002	-.0014	.0011	-.0014	-.0002
44	-.0103	-.0021	-.5623	.1080	.0012	-.0415	-.2173	.0016	.0003	-.0014	.0011	-.0028	-.0004
46	-.0106	-.0022	-.4668	.0589	.0009	-.0603	-.2345	.0021	.0002	-.0014	.0015	-.0023	-.0004
50	-.0099	-.0018	-.3950	.0455	.0010	-.0304	-.2080	.0015	.0002	-.0013	.0009	-.0021	-.0003
52	-.0107	-.0019	-.4880	.1117	.0011	-.0425	-.2529	.0011	.0002	-.0015	.0010	-.0024	-.0004

TABLE 4.—Concluded

(b) Aileron controls

NO.	CY_{β}	CL_{β}	CL_P	CL_R	CN^*_{β}	CN^*_P	CN^*_R	CY_{DR}	CL_{DR}	CN^*_{DR}	CY_{DA}	CL_{DA}	CN^*_{DA}
12	-.0108	-.0018	-.1627	.0823	.0014	-.0286	-.1771	.0003	.0003	-.0009			
14	-.0122	-.0018	-.1649	.0642	.0014	-.0245	-.2267	.0002	.0002	-.0008	.0013	-.0020	-.0004
20	-.0092	-.0023	-.1295	.1871	.0009	.0058	-.1285	.0010	.0002	-.0014			
21	-.0100	-.0022	-.1647	.0659	.0008	-.0287	-.3395	.0010	.0003	-.0013			
23	-.0091	-.0024	-.1870	.0751	.0006	-.0517	-.3086	.0009	.0003	-.0014	.0018	-.0017	-.0006
28	-.0106	-.0020	-.1823	.0962	.0017	-.0080	-.2558	.0002	.0002	-.0011			
30	-.0127	-.0018	-.1706	.0607	.0015	-.0330	-.2801	.0002	.0002	-.0009			
39	-.0094	-.0019	-.1477	.0559	.0010	-.0219	-.2507	.0026	.0002	-.0017			
42	-.0101	-.0022	-.1758	.0540	.0008	-.0592	-.3081	.0023	.0001	-.0015	.0027	-.0017	-.0005
48	-.0104	-.0020	-.1600	.0422	.0010	-.0331	-.2392	.0017	.0003	-.0012	.0031	-.0015	-.0004
54	-.0106	-.0017	-.1735	.0441	.0010	-.0072	-.2313	.0007	.0002	-.0012			

TABLE 5.—FLIGHT STATISTICS FOR FLIGHTS 16 AND 17

(a) Maneuver type, wing-sweep angle, Mach number, angle of attack, center of gravity, normal acceleration, and altitude. SWEEP, deg; ALPHA, deg; CG, fraction of reference chord; NORMAL ACC., g; ALT, ft.

NO.	FLT	TYPE	SWEEP	MACH	ALPHA	CG	NORMAL ACC.	ALT
1	16	ELEVATOR	26.0	.700	3.35	.318	1.0	3243
2	16	ELEVATOR	26.0	.700	4.90	.322	1.5	3255
3	16	ELEVATOR	26.0	.700	7.80	.318	2.4	2940
4	16	ELEVATOR	35.0	.700	4.30	.335	1.0	3210
5	16	ELEVATOR	35.0	.700	5.50	.324	1.4	3094
6	16	ELEVATOR	35.0	.700	10.00	.320	2.6	2966
7	16	ELEVATOR	35.0	.700	8.00	.329	2.2	2950
8	16	ELEVATOR	26.0	.700	10.00	.302	2.9	3150
9	16	ELEVATOR	35.0	.700	10.60	.316	2.7	3074
10	16	ELEVATOR	35.0	.720	10.75	.320	2.9	3056
11	16	ELEVATOR	35.0	.700	11.50	.323	2.7	3056
12	16	ELEVATOR	35.0	.700	13.50	.315	3.1	2953
13	16	ELEVATOR	35.0	.740	10.75	.328	3.1	3252
14	16	ELEVATOR	58.0	.920	4.55	.376	1.4	3191
15	16	ELEVATOR	58.0	.930	6.25	.373	2.0	3172
16	16	ELEVATOR	58.0	.900	9.90	.380	3.3	3090
17	16	ELEVATOR	26.0	.720	4.70	.333	1.8	3099
18	16	ELEVATOR	35.0	.720	5.30	.352	1.8	3025
19	16	ELEVATOR	26.0	.700	10.20	.352	3.6	3335
20	16	ELEVATOR	26.0	.690	11.30	.356	3.7	3286
21	16	ELEVATOR	58.0	.920	4.80	.406	1.7	3071
22	16	ELEVATOR	26.0	.880	4.00	.352	1.7	9489
23	16	ELEVATOR	26.0	.870	5.90	.354	1.5	9339
24	16	ELEVATOR	58.0	.890	5.60	.474	.9	9310
25	16	ELEVATOR	58.0	.880	9.20	.472	1.5	9229
26	16	ELEVATOR	58.0	.860	12.30	.486	2.1	9359
27	17	ELEVATOR	26.0	.710	5.19	.307	1.1	7154
28	17	ELEVATOR	35.0	.720	5.80	.317	1.0	7024
29	17	ELEVATOR	26.0	.730	8.50	.307	1.8	7224
30	17	ELEVATOR	26.0	.730	10.00	.307	1.8	7224

TABLE 5.—Continued

(a) Continued

NO.	FLT	TYPE	SWEEP	MACH	ALPHA	CG	NORMAL ACC.	ALT
31	17	ELEVATOR	26.0	.700	11.50	.307	1.9	6779
32	17	ELEVATOR	35.0	.710	10.00	.322	1.8	7367
33	17	ELEVATOR	35.0	.710	11.09	.320	1.8	6830
34	17	ELEVATOR	35.0	.710	13.92	.327	2.1	7047
35	17	ELEVATOR	58.0	.920	5.49	.365	1.1	7056
36	17	ELEVATOR	58.0	.910	10.00	.362	2.0	7123
37	17	ELEVATOR	58.0	.910	10.77	.357	2.3	7049
38	17	ELEVATOR	26.0	.700	6.55	.349	1.1	10012
39	17	ELEVATOR	26.0	.700	9.09	.349	1.3	9937
40	17	ELEVATOR	26.0	.700	12.22	.347	1.5	9844
41	17	ELEVATOR	35.0	.710	7.54	.370	1.2	10218
42	17	ELEVATOR	35.0	.690	13.07	.370	1.5	10217
43	17	ELEVATOR	35.0	.710	14.45	.370	1.7	10309
44	17	ELEVATOR	58.0	.920	7.29	.411	1.1	10690
45	17	ELEVATOR	58.0	.920	11.85	.414	1.7	10556
46	16	RUDDER	26.0	.700	7.30	.325	2.4	2860
47	16	RUDDER	35.0	.700	3.80	.320	1.0	3083
48	16	RUDDER	35.0	.700	7.00	.323	2.0	2938
49	16	RUDDER	35.0	.700	9.00	.319	2.3	2996
50	16	RUDDER	35.0	.650	13.25	.323	3.0	3230
51	16	RUDDER	58.0	.930	4.25	.371	1.3	3412
52	16	RUDDER	58.0	.920	6.30	.374	2.0	3224
53	16	RUDDER	58.0	.920	10.65	.380	3.7	3236
54	16	RUDDER	35.0	.730	5.00	.344	1.6	3270
55	16	RUDDER	26.0	.720	4.60	.330	1.8	2955
56	16	RUDDER	35.0	.710	6.30	.341	2.0	2974
57	16	RUDDER	35.0	.730	6.40	.348	2.1	2962
58	16	RUDDER	35.0	.670	15.10	.364	3.8	2938
59	16	RUDDER	26.0	.680	11.50	.348	3.7	2844
60	16	RUDDER	26.0	.630	13.10	.349	3.5	2785

TABLE 5.—Continued

(a) Concluded

NO.	FLT	TYPE	SWEEP	MACH	ALPHA	CG	NORMAL ACC.	ALT
61	16	RUDDER	58.0	.920	6.80	.408	2.4	3123
62	16	RUDDER	58.0	.920	4.10	.409	1.5	3328
63	16	RUDDER	26.0	.880	3.90	.358	1.1	9489
64	16	RUDDER	26.0	.860	4.00	.374	1.0	9438
65	16	AILERON	58.0	.890	6.30	.495	1.1	9384
66	16	AILERON	58.0	.863	9.50	.499	1.5	9444
67	16	RUDDER	58.0	.860	9.06	.500	1.5	9444
68	16	RUDDER	58.0	.870	11.50	.506	2.0	9240
69	16	AILERON	58.0	.850	12.04	.538	2.2	9093
70	17	RUDDER	26.0	.710	4.96	.318	1.0	7129
71	17	RUDDER	35.0	.710	6.03	.317	1.0	7043
72	17	RUDDER	26.0	.710	10.35	.306	1.9	6850
73	17	RUDDER	26.0	.730	11.17	.306	2.1	6699
74	17	RUDDER	35.0	.700	14.00	.319	1.9	7209
75	17	RUDDER	35.0	.700	13.00	.323	1.6	7377
76	17	RUDDER	58.0	.920	4.00	.361	.7	7102
77	17	RUDDER	58.0	.940	9.60	.356	2.1	7039
78	17	RUDDER	58.0	.930	11.32	.363	2.2	7193
79	17	RUDDER	26.0	.890	6.50	.327	1.6	9356
80	17	RUDDER	26.0	.710	7.01	.354	1.0	10400
81	17	RUDDER	35.0	.700	7.66	.361	1.0	10401
82	17	RUDDER	35.0	.700	14.00	.357	1.5	10025
83	17	RUDDER	58.0	.920	6.50	.396	1.2	10365
84	17	RUDDER	58.0	.920	11.88	.398	1.7	10303
85	17	RUDDER	58.0	.890	14.26	.411	1.9	10284
86	17	RUDDER	58.0	.920	14.17	.424	2.0	10592

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TABLE 5.—Continued

(b) Mass characteristics, dynamic pressure, and velocity

NO.	IX ($SLUG-FT^2$)	IY ($SLUG-FT^2$)	IZ ($SLUG-FT^2$)	IXZ ($SLUG-FT^2$)	WEIGHT (POUNDS)	DYNAMIC PRESSURE (LB/FT^2)	VELOCITY (FT/SEC)
1		443851.			78237.	490.8	754.1
2		443684.			78013.	488.0	750.8
3		443349.			77563.	499.7	747.5
4		443528.			76888.	506.0	763.9
5		441680.			76664.	498.7	754.1
6		439831.			76439.	491.4	744.3
7		439831.			76439.	491.4	744.3
8		426088.			75090.	489.3	747.5
9		415779.			73516.	517.5	763.9
10		412102.			73066.	524.8	770.5
11		410253.			72842.	470.5	731.1
12		404707.			72167.	449.6	704.9
13		397765.			71043.	538.4	790.2
14		391083.			68570.	950.0	986.9
15		389813.			68345.	973.0	1000.0
16		377111.			66097.	831.2	970.5
17		365516.			65647.	523.4	773.8
18		365221.			65198.	518.6	767.2
19		346660.			61601.	485.1	754.1
20		344782.			60926.	468.4	734.4
21		349859.			59577.	865.7	990.2
22		337837.			58453.	322.0	865.6
23		337897.			58453.	324.1	859.0
24		339935.			55306.	340.0	882.0
25		339451.			55081.	337.1	872.1
26		338482.			54631.	311.6	852.5
27		430995.			75697.	300.3	729.5
28		433730.			75697.	309.7	735.1
29		412640.			73426.	307.0	740.3
30		412640.			73426.	307.0	740.3

TABLE 5.—Continued

(b) Continued

NO.	IX SLUG-FT^2	IY SLUG-FT^2	IZ SLUG-FT^2	IXZ SLUG-FT^2	WEIGHT POUNDS	DYNAMIC PRESSURE LB/FT^2	VELOCITY FT/SEC
31		410096.			73111.	307.8	723.0
32		395888.			70706.	288.1	723.3
33		395137.			70571.	307.2	723.9
34		395137.			70571.	297.3	721.3
35		389178.			68233.	506.2	941.6
36		389178.			68233.	491.6	931.5
37		387527.			67941.	496.6	932.1
38		353249.			63444.	199.4	686.6
39		353249.			63444.	192.8	689.2
40		351497.			63129.	196.1	691.1
41		349932.			61983.	190.1	696.4
42		349557.			61848.	180.9	674.3
43		347554.			61129.	184.4	689.5
44		344776.			57554.	296.9	896.4
45		344485.			57419.	302.8	897.7
46	56920.		499841.	3487.4	77113.	512.3	754.1
47	64769.		489638.	4361.2	76214.	512.3	770.5
48	64769.		487821.	4433.2	75989.	522.7	763.9
49	64768.		487821.	4433.2	75989.	528.0	767.2
50	64405.		441967.	5214.7	69694.	423.4	698.4
51	47104.		420983.	5284.1	67671.	852.1	1000.0
52	47104.		419695.	5232.6	67446.	825.9	977.0
53	47104.		417118.	5129.5	66996.	841.6	983.0
54	63742.		418442.	4253.8	65647.	522.7	777.0
55	68894.		421675.	3885.8	65647.	533.2	773.8
56	63706.		417135.	4200.4	65423.	543.7	773.8
57	63669.		415828.	4147.0	65198.	564.6	793.4
58	63558.		411907.	3986.9	64523.	449.6	718.0
59	58416.		405694.	3347.0	62725.	470.5	724.6
60	68305.		403705.	3723.3	62050.	407.7	672.1

TABLE 5.—Concluded

(b) Concluded

NO.	IX, SLUG-FT^2	IY, SLUG-FT^2	IZ, SLUG-FT^2	IXZ, SLUG-FT^2	WEIGHT, POUNDS	DYNAMIC PRESSURE, LB/FT^2	VELOCITY, FT/SEC
61	46630.		385229.	5854.1	60027.	838.5	980.3
62	46593.		385660.	5983.0	5[illegible]02.	836.4	986.9
63	67694.		392650.	5783.6	58[illegible]8.	319.9	868.9
64	67634.		391379.	5928.8	57554.	319.5	859.0
65	46368.		372132.	7723.5	54182.	330.6	875.4
66	46368.		372132.	7723.5	54182.	314.9	852.5
67	46368.		371688.	7773.9	53957.	304.2	842.6
68	46368.		371244.	7824.3	53732.	328.7	859.0
69	46368.		370801.	7874.8	53507.	326.2	845.9
70	69920.		490598.	3894.7	75989.	296.5	723.6
71	64768.		485459.	4526.9	75697.	303.2	728.2
72	69920.		480800.	4326.5	74798.	310.9	729.5
73	69920.		475809.	4546.4	74191.	330.2	745.2
74	64762.		454644.	5732.5	71875.	283.3	710.8
75	64689.		452030.	5625.7	71425.	278.5	711.5
76	47104.		431163.	5691.3	69447.	506.6	944.6
77	47104.		429230.	5614.0	69110.	524.6	957.4
78	47104.		425890.	5480.0	68525.	503.5	946.6
79	69101.		428798.	4184.7	66906.	335.0	877.4
80	68615.		412022.	3480.1	63939.	184.0	693.1
81	63282.		402359.	3653.1	63837.	179.2	683.9
82	63238.		401608.	3803.3	62567.	187.6	683.6
83	46461.		382180.	6446.9	58993.	309.3	896.4
84	46368.		379942.	6835.9	58135.	313.2	698.7
85	46368.		379632.	6871.2	57981.	300.7	875.1
86	46368.		376303.	7249.4	56295.	302.6	899.3

TABLE 6.—LONGITUDINAL DERIVATIVES FOR FLIGHTS 16 AND 17

[All derivatives are per de [illegible] cept CM_Q, which is per radian]

NO.	CN_α	CM_α	CM_Q	CN_{DE}	CM_{DE}
1	.0932	-.0078	-34.76	.0102	-.0323
2	.0943	-.0090	-33.59	.0095	-.0330
3	.0932	-.0058	-38.87	.0011	-.0348
4	.0821	-.0199	-32.52	.0072	-.0332
5	.0802	-.0186	-31.85	.0083	-.0307
6	.0741	-.0067	-42.18	.0059	-.0324
7	.0860	-.0128	-37.70	.0055	-.0321
8	.0759	-.0044	-34.99	.0042	-.0336
9	.0727	-.0111	-45.22	.0054	-.0352
10	.0694	-.0048	-48.01	.0027	-.0327
11	.0671	-.0060	-37.00	.0008	-.0302
12	.0625	-.0059	-44.91	.0015	-.0337
13	.0641	-.0008	-47.11	-.0035	-.0333
14	.0579	-.0270	-33.35	.0053	-.0327
15	.0612	-.0252	-37.62	.0010	-.0331
16	.0605	-.0214	-37.40	.0018	-.0307
17	.0862	-.0080	-40.03	.0118	-.0315
18	.0804	-.0192	-33.19	.0078	-.0301
19	.0727	-.0075	-35.31	.0073	-.0322
20	.0583	-.0100	-26.77	-.0042	-.0291
21	.0582	-.0270	-34.20	.0052	-.0334
22	.0908	.0044	-41.58	.0053	-.0364
23	.0833	-.0013	-31.48	.0049	-.0324

TABLE 6.—Concluded

NO.	CN_α	CM_α	CM_Q	CN_{DE}	CM_{DE}
24	.0631	-.0232	-38.80	.0052	-.0361
25	.0658	-.0256	-35.99	.0076	-.0327
26	.0651	-.0188	-47.93	.0074	-.0379
27	.0958	-.0064	-32.55	.0085	-.0320
28	.0822	-.0151	-34.83	.0080	-.0311
29	.0716	.0003	-42.45	.0031	-.0319
30	.0670	-.0025	-34.05	.0051	-.0281
31	.0434	-.0110	-25.28	-.0004	-.0274
32	.0562	-.0064	-41.21	.0007	-.0258
33	.0661	-.0037	-42.99	.0024	-.0307
34	.0551	-.0032	-49.11	-.0029	-.0335
35	.0593	-.0244	-37.21	.0052	-.0334
36	.0640	-.0203	-38.72	.0034	-.0316
37	.0657	-.0193	-36.71	-.0021	-.0278
38	.1034	-.0069	-35.80	.0043	-.0330
39	.086[illegible]	-.0024	-54.84	.0085	-.0409
40	.0547	-.0087	-28.57	-.0132	-.0320
41	.0837	-.0128	-33.72	.0094	-.0304
42	.0577	-.0039	-44.71	.0042	-.0355
43	.0645	-.0022	-37.4[illegible]	-.0080	-.0326
44	.0632	-.0233	-39.07	.0080	-.0333
45	.0654	-.0159	-49.21	.0000	-.0327

TABLE 7.—LATERAL-DIRECTIONAL DERIVATIVES FOR FLIGHTS 16 AND 17

[All derivatives are per degree, except CL_p, CL_R, CN^*_P, and CN^*_R, which are per radian]

NO.	CY_β	CL_β	CL_p	CL_r	CN_β	CN^*_p	CN^*_R	CY_{DR}	CL_{DR}	CN^*_{DR}	CY_{DA}	CL_{DA}	CN^*_{DA}
46	-.0109	-.0032	-.4514	.1771	.0005	-.1798	-.4662	.0023	.0002	-.0015			
47	-.0106	-.0022	-.4207	.0547	.0010	-.0492	-.2366	.0023	.0003	-.0014			
48	-.0101	-.0028	-.3277	.0693	.0007	-.1283	-.4468	.0024	.0002	-.0015			
49	-.0101	-.0031	-.2776	.0727	.0007	-.1007	-.5034	.0022	.0001	-.0015			
50	-.0079	-.0024	-.1439	.1002	.0015	-.0591	-.5607	.0015	.0001	-.0015			
51	-.0113	-.0018	-.1441	.0758	.0009	-.0269	-.2488	.0011	.0002	-.0013			
52	-.0115	-.0023	-.1494	.0825	.0009	-.0552	-.2815	.0016	.0002	-.0013			
53	-.0098	-.0024	-.1344	.0676	.0009	-.0431	-.2171	.0015	.0002	-.0013			
54	-.0106	-.0026	-.4048	.0653	.0009	-.0897	-.2704	.0022	.0003	-.0014			
55	-.0103	-.0025	-.5043	.1416	.0009	-.1123	-.3025	.0019	.0003	-.0014			
56	-.0108	-.0026	-.3506	.0659	.0008	-.1093	-.3294	.0018	.0003	-.0014			
57	-.0105	-.0027	-.3638	.0663	.0008	-.1168	-.3420	.0018	.0002	-.0014			
58	-.0070	-.0029	-.0387	.0399	.0003	-.0172	-.5565	.0008	.0003	-.0015			
59	-.0086	-.0024	-.2429	.1943	.0003	-.1115	-.7036	.0010	.0004	-.0014			
60	-.0104	-.0027	-.2390	.1989	.0004	-.0642	-.7118	.0016	.0003	-.0014			
61	-.0115	-.0023	-.1540	.0909	.0009	-.0573	-.2879	.0019	.0002	-.0013			
62	-.0112	-.0018	-.1488	.0758	.0009	-.0360	-.2430	.0014	.0002	-.0014			
63	-.0116	.0010	-.6295	.1176	.0015	.0029	-.2934	.0017	.0004	-.0014			
64	-.0120	.0005	-.3334	.1423	.0018	.0135	-.2753	.0013	.0003	-.0014			
65	-.0111	-.0022	-.1536	.0826	.0009	-.0369	-.2893				.0041	-.0016	-.0003
66	-.0095	-.0026	-.1421	.0875	.0008	-.0200	-.2699				.0020	-.0017	-.0003

TABLE 7.—Concluded

NO.	CY_{β}	CL_{β}	CL_{P}	CL_{R}	CN^{*}_{β}	CN^{*}_{P}	CN^{*}_{R}	CY_{DR}	CL_{DR}	CN^{*}_{DR}	CY_{DA}	CL_{DA}	CN^{*}_{DA}
67	-.0099	-.0025	-.1424	.0899	.0008	-.0417	-.2530	.0047	.0003	-.0014			
68	-.0104	-.0028	-.1263	.0575	.0005	-.0566	-.2235	.0014	.0003	-.0013			
69	-.0091	-.0024	-.1238	.0307	.0004	-.0505	-.1893				.0018	-.0018	-.0003
70	-.0098	-.0023	-.4979	.1495	.0008	-.1155	-.3271	.0025	.0002	-.0015			
71	-.0096	-.0023	-.3865	.0553	.0008	-.0877	-.3089	.0017	.0003	-.0014			
72	-.0082	-.0022	-.1206	.1822	.0009	-.0396	-.6585	.0013	.0001	-.0015			
73	-.0085	-.0024	-.2746	.1305	.0004	-.0926	-.6980	.0010	.0003	-.0015			
74	-.0083	-.0025	-.1415	.0995	.0005	.0052	-.5399	.0015	.0001	-.0014			
75	-.0108	-.0029	-.2390	.0944	.0008	-.0588	-.5581	.0024	.0003	-.0013			
76	-.0113	-.0018	-.1712	.0793	.0009	-.0099	-.2712	.0027	.0002	-.0014			
77	-.0099	-.0023	-.1674	.0736	.0005	-.0719	-.2509	.0016	.0004	-.0013			
78	-.0089	-.0023	-.1454	.0452	.0008	-.0666	-.2066	.0012	.0003	-.0013			
79	-.0107	.0001	-.4726	.1666	.0014	.0473	-.4547	.0009	.0003	-.0015			
80	-.0096	-.0028	-.5261	.1787	.0006	-.1649	-.4413	.0022	.0003	-.0015			
81	-.0099	-.0032	-.3669	.0681	.0008	-.0669	-.4649	.0018	.0001	-.0018			
82	-.0071	-.0021	-.1943	.0959	.0005	-.0164	-.5310	.0015	.0004	-.0015			
83	-.0104	-.0023	-.1928	.0880	.0007	-.0510	-.3044	.0021	.0001	-.0015			
84	-.0093	-.0024	-.1600	.0333	.0006	-.0820	-.1962	.0011	.0003	-.0012			
85	-.0073	-.0026	-.1735	.0325	.0004	-.0855	-.1929	.0012	.0003	-.0014			
86	-.0100	-.0029	-.2073	.0297	.0001	-.1189	-.1922	.0015	.0003	-.0014			

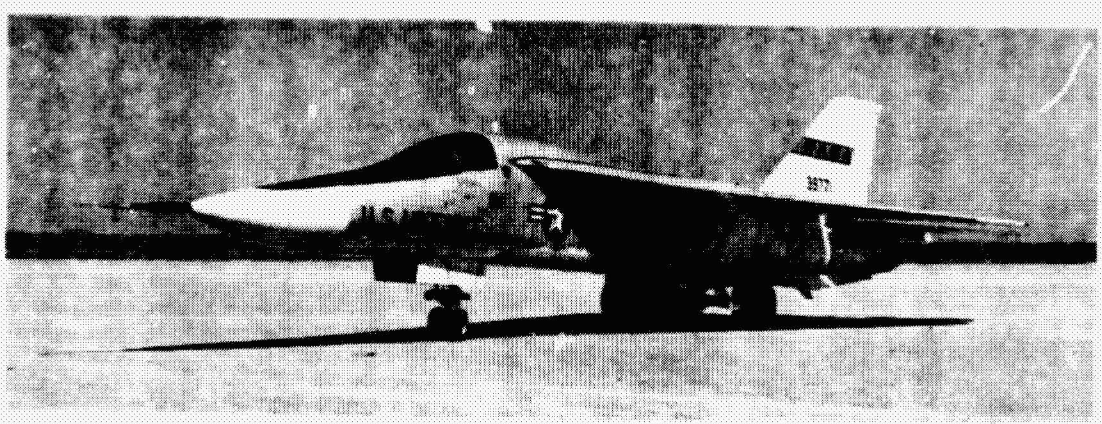

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Figure 1. F-111A airplane.

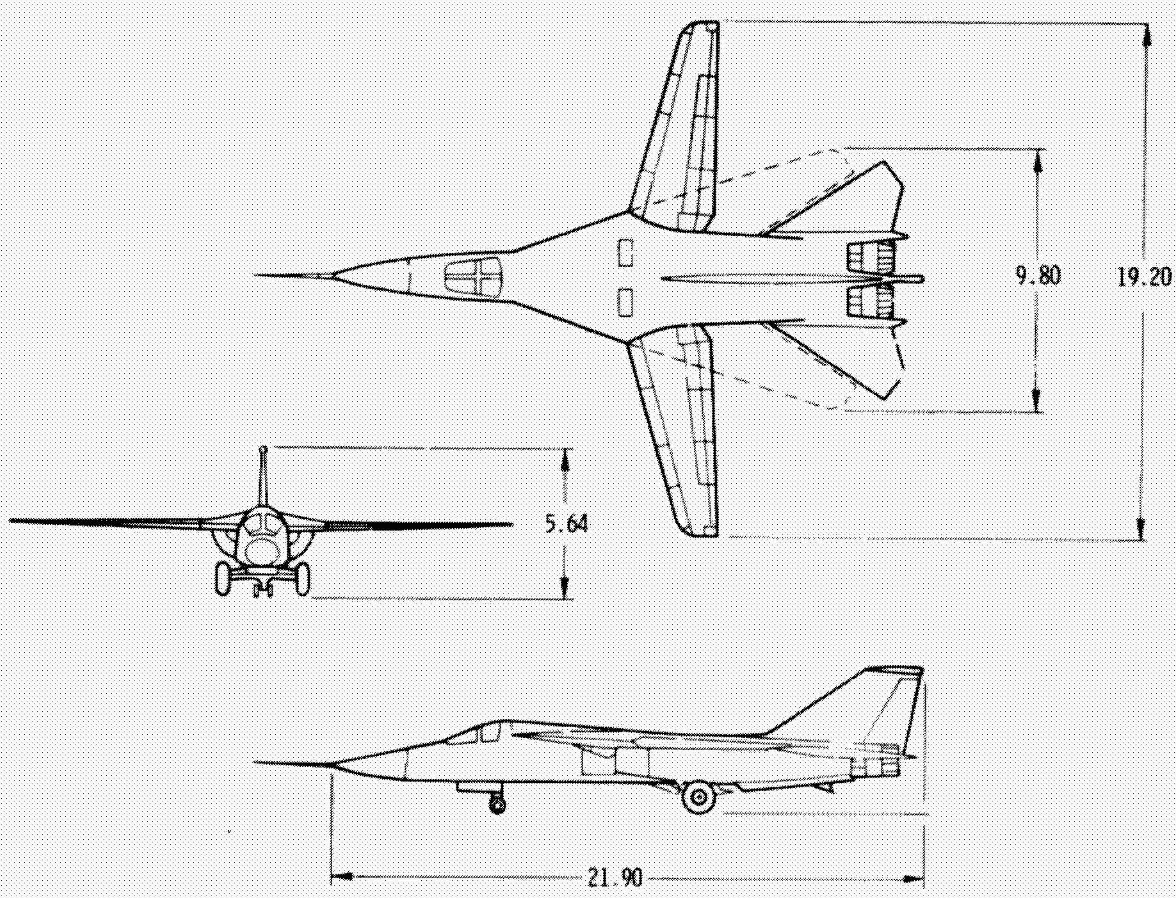
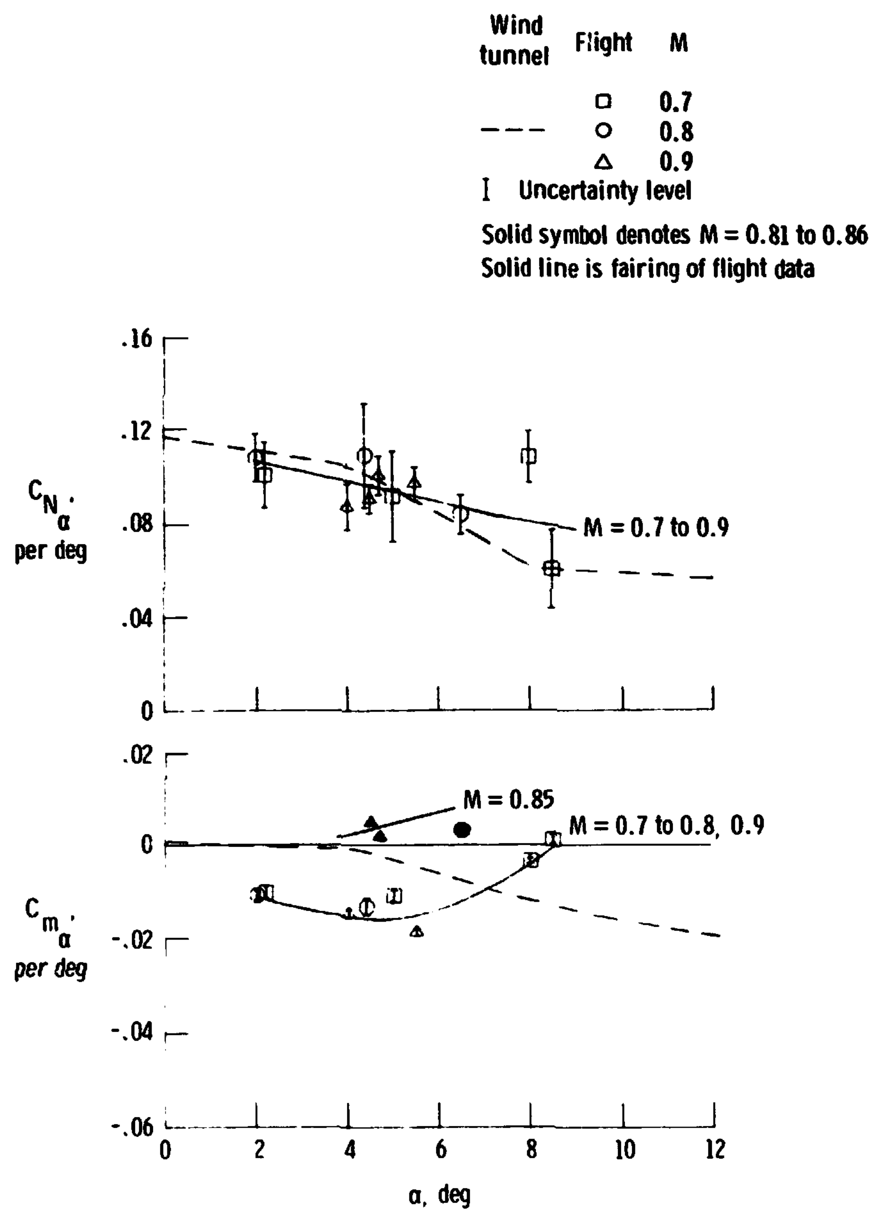
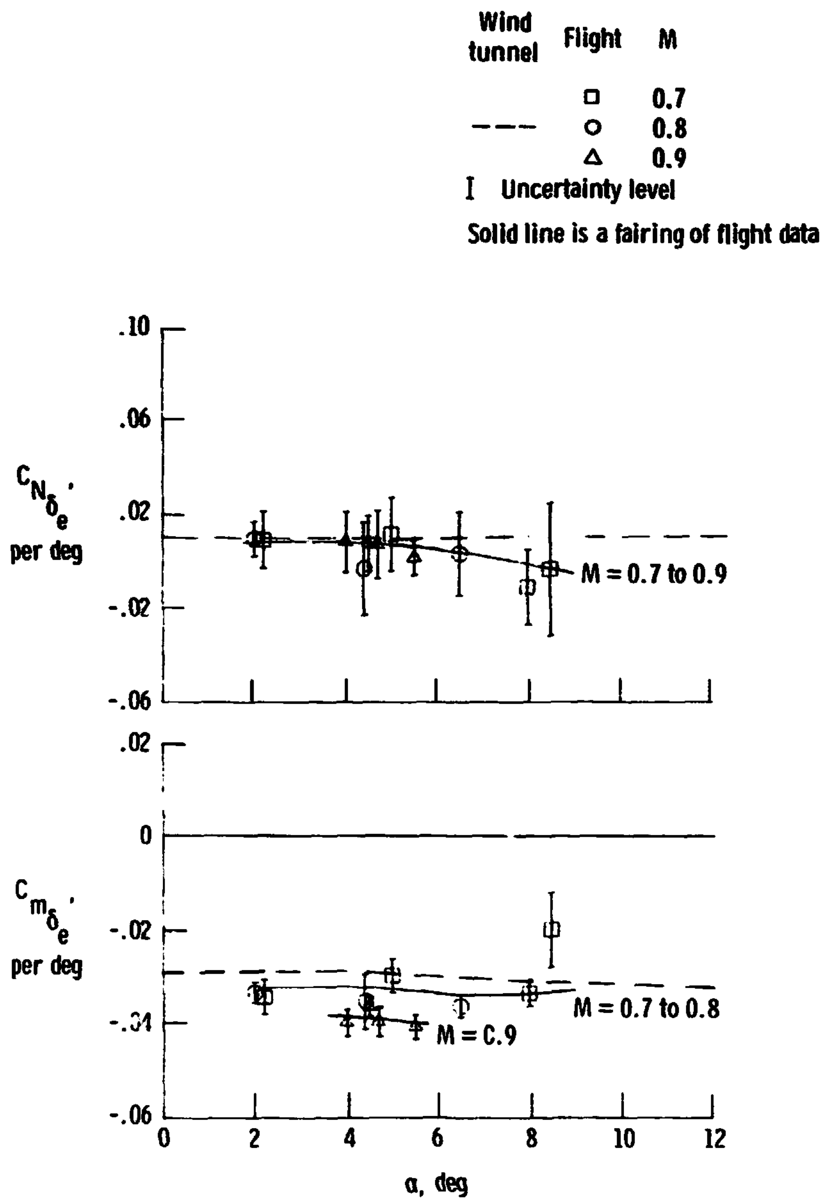


Figure 2. Three-view drawing of F-111A airplane. Dimensions are in meters.



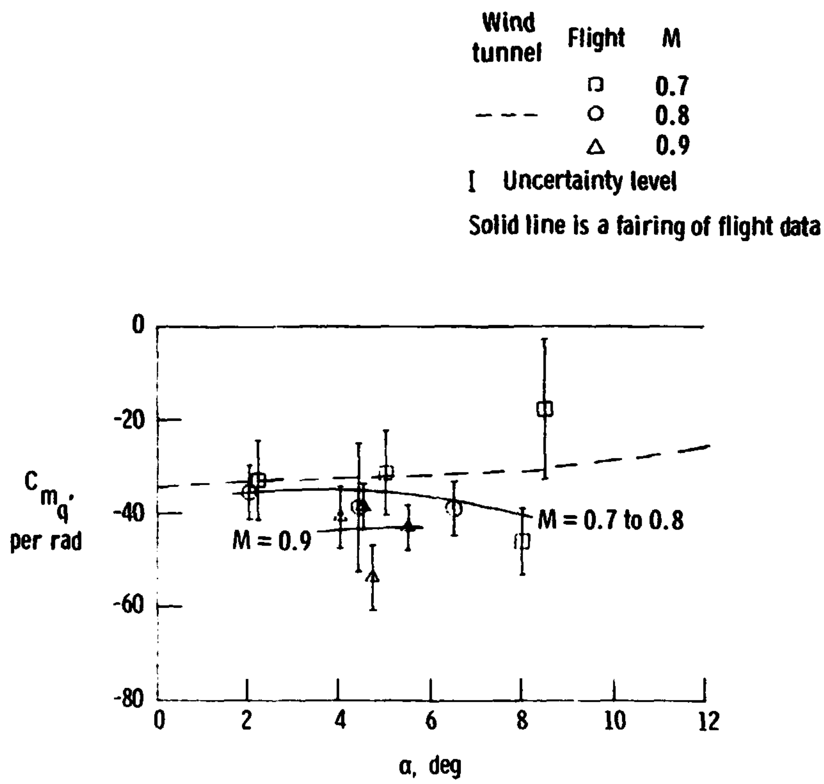
(a) C_{N_α} and C_{m_α}.

Figure 3. Longitudinal stability and control derivatives for 1g flight and 26° wing sweep.



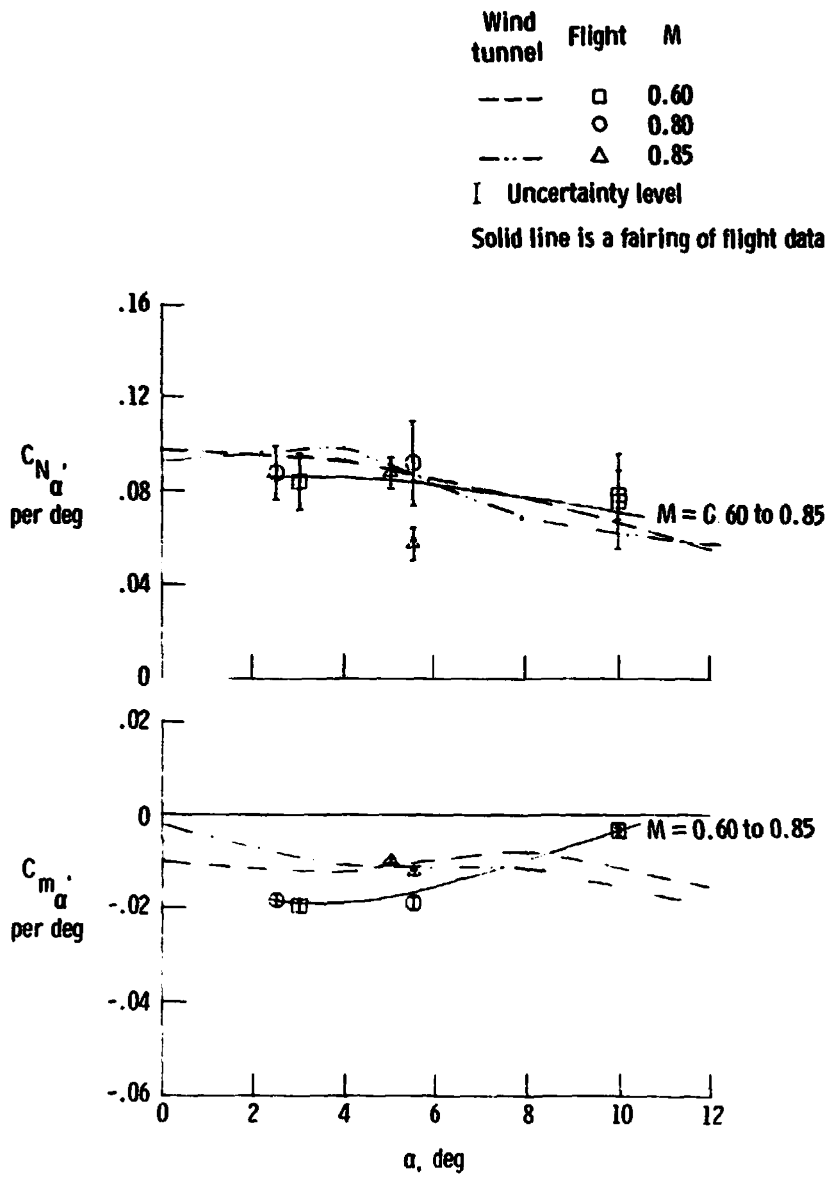
(b) $C_{N_{\delta_e}}$ and $C_{m_{\delta_e}}$.

Figure 3. Continued.



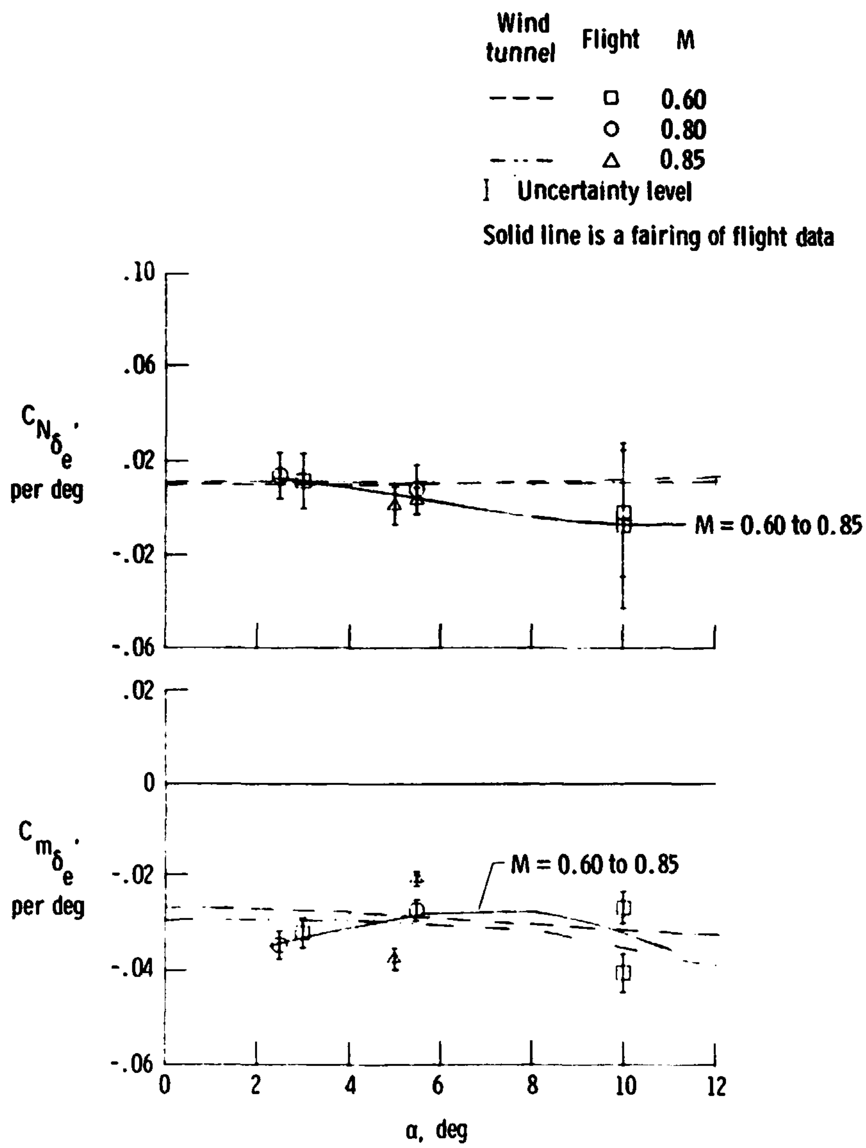
(c) C_{m_q}.

Figure 3. Concluded.



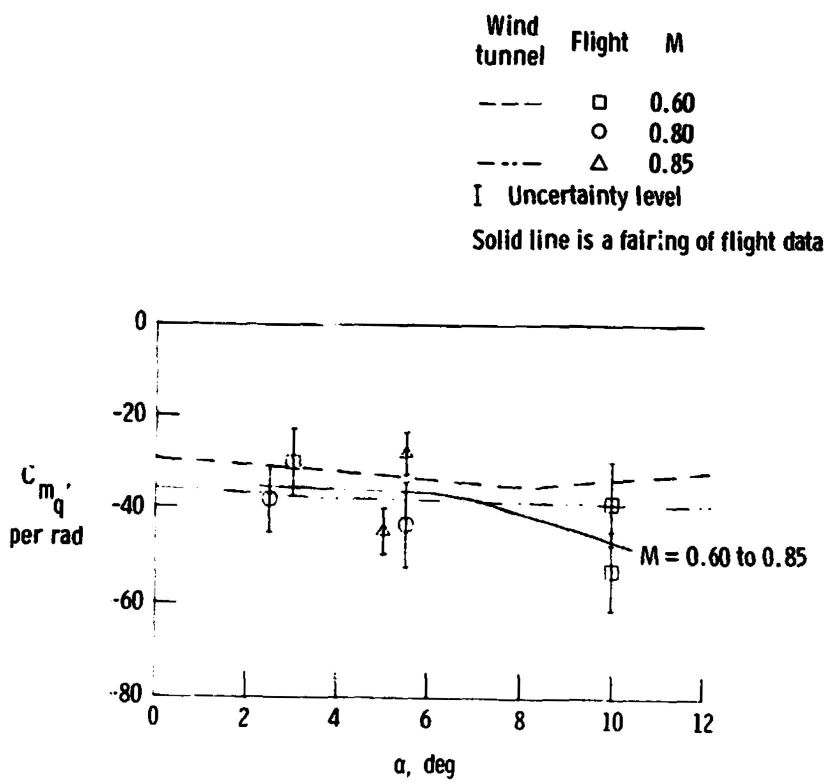
(a) C_{N_α} and C_{m_α}.

Figure 4. Longitudinal stability and control derivatives for 1g flight and 35° wing sweep.



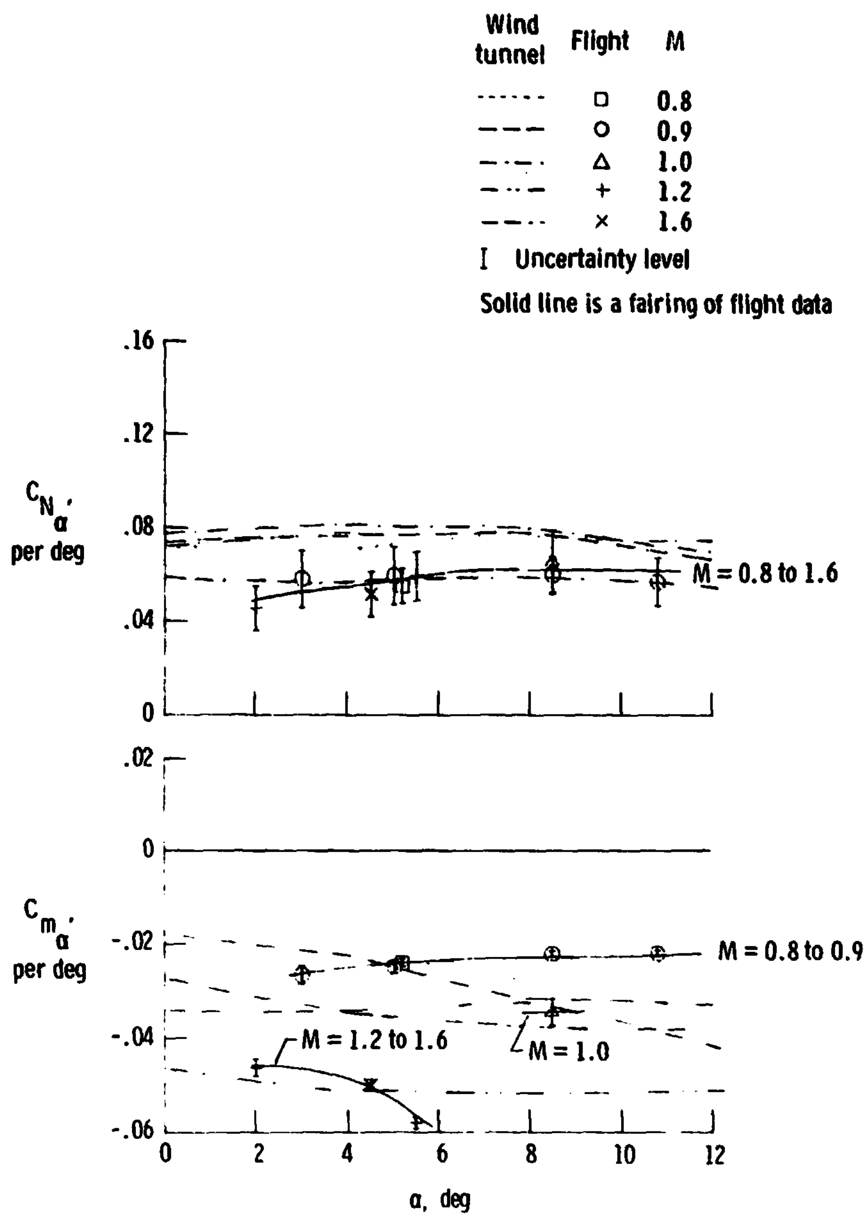
(b) $C_{N_{\delta_e}}$ *and* $C_{m_{\delta_e}}$.

Figure 4. Continued.



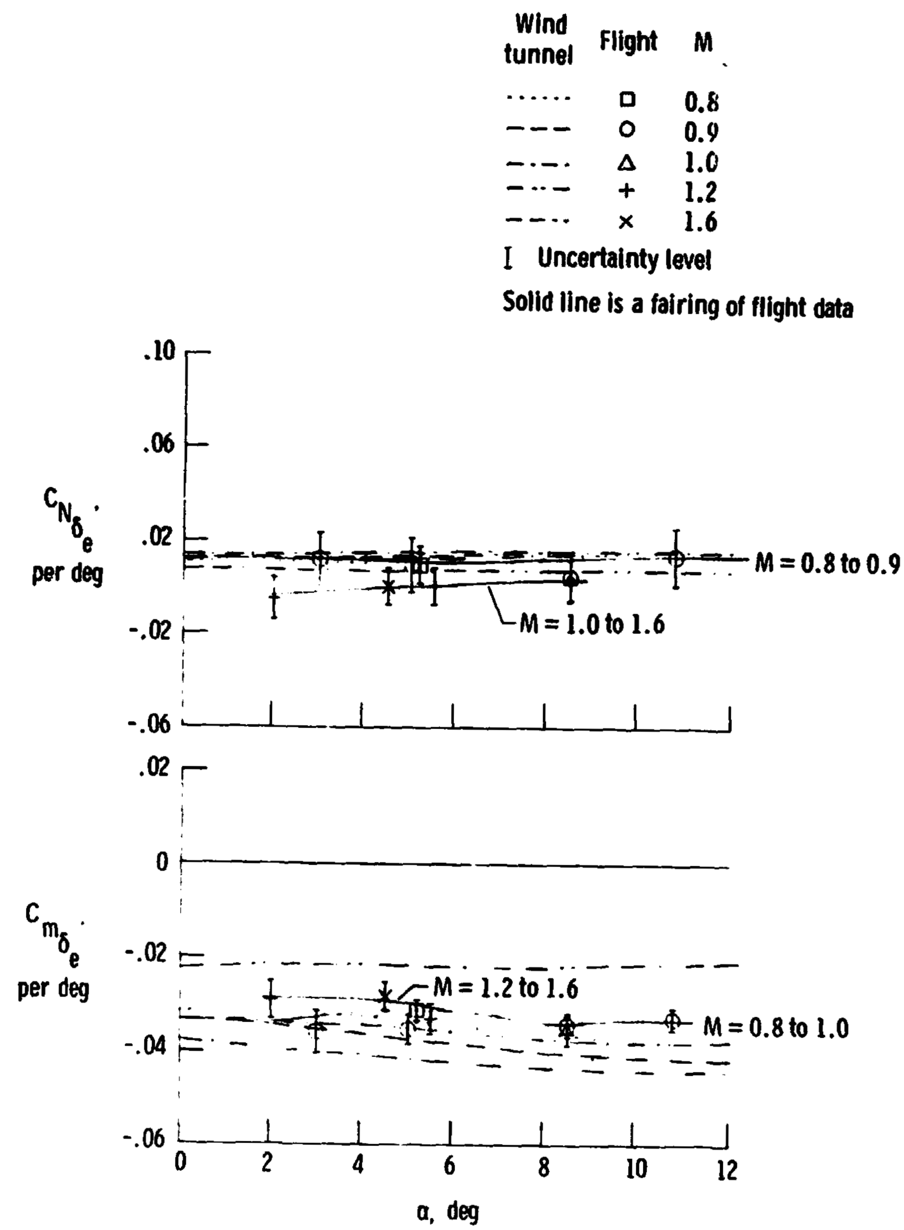
(c) C_{m_q}.

Figure 4. Concluded.



(a) C_{N_α} and C_{m_α}.

Figure 5. Longitudinal stability and control derivatives for 1g flight and 58° wing sweep.



(b) $C_{N_{\delta_e}}$ and $C_{m_{\delta_e}}$.

Figure 5. Continued.

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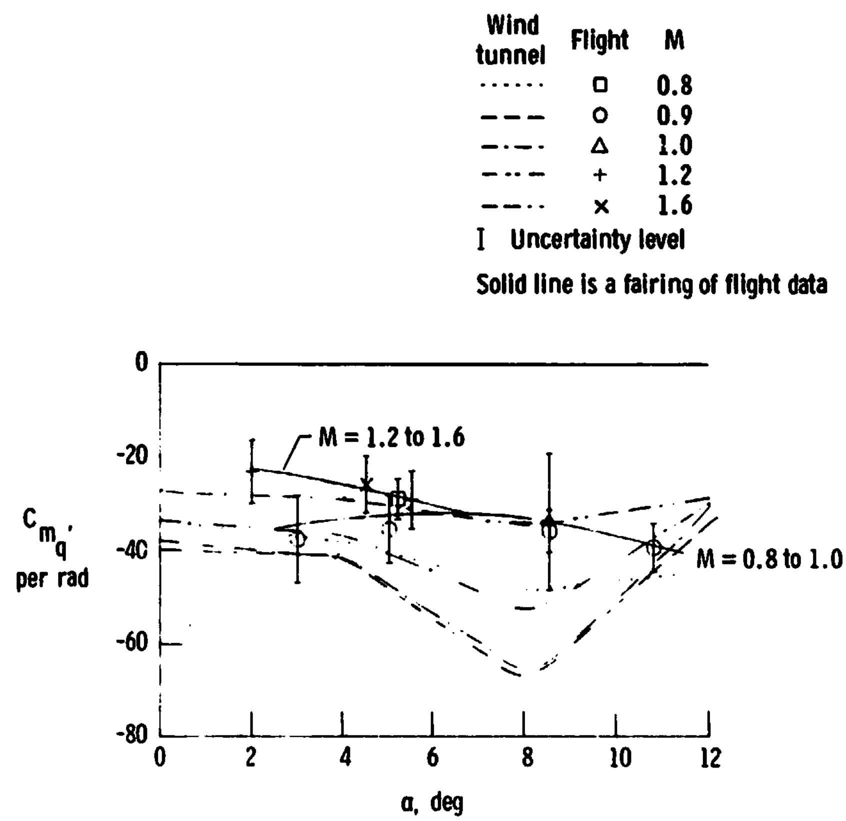


(c) C_{m_q}.

Figure 5. Concluded.

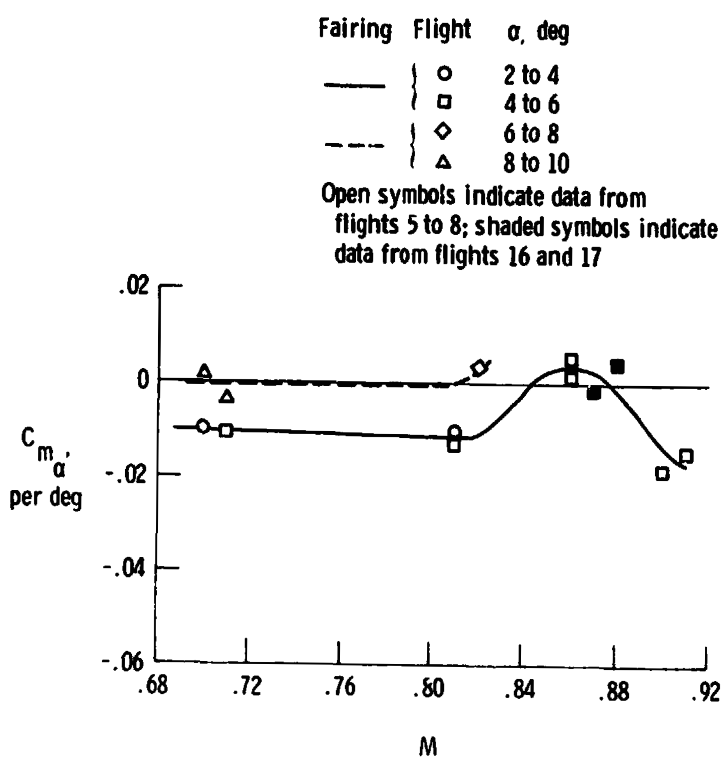
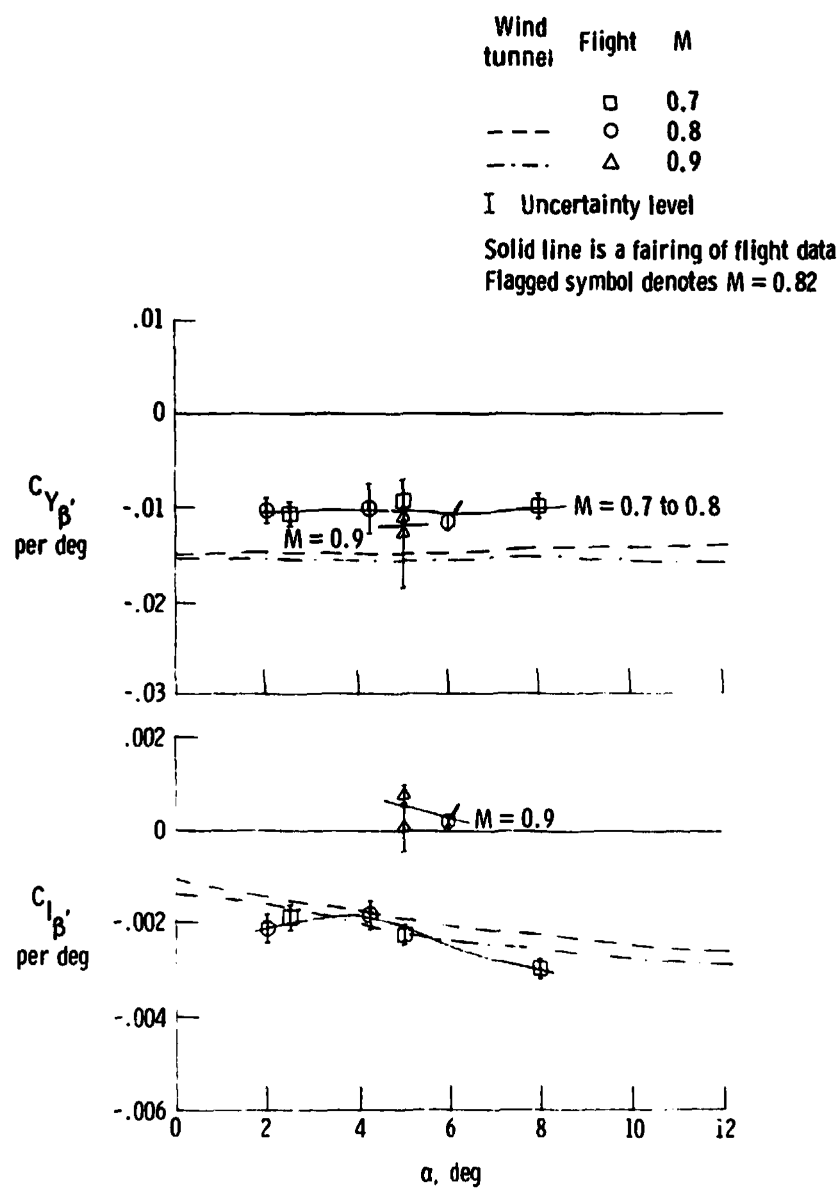
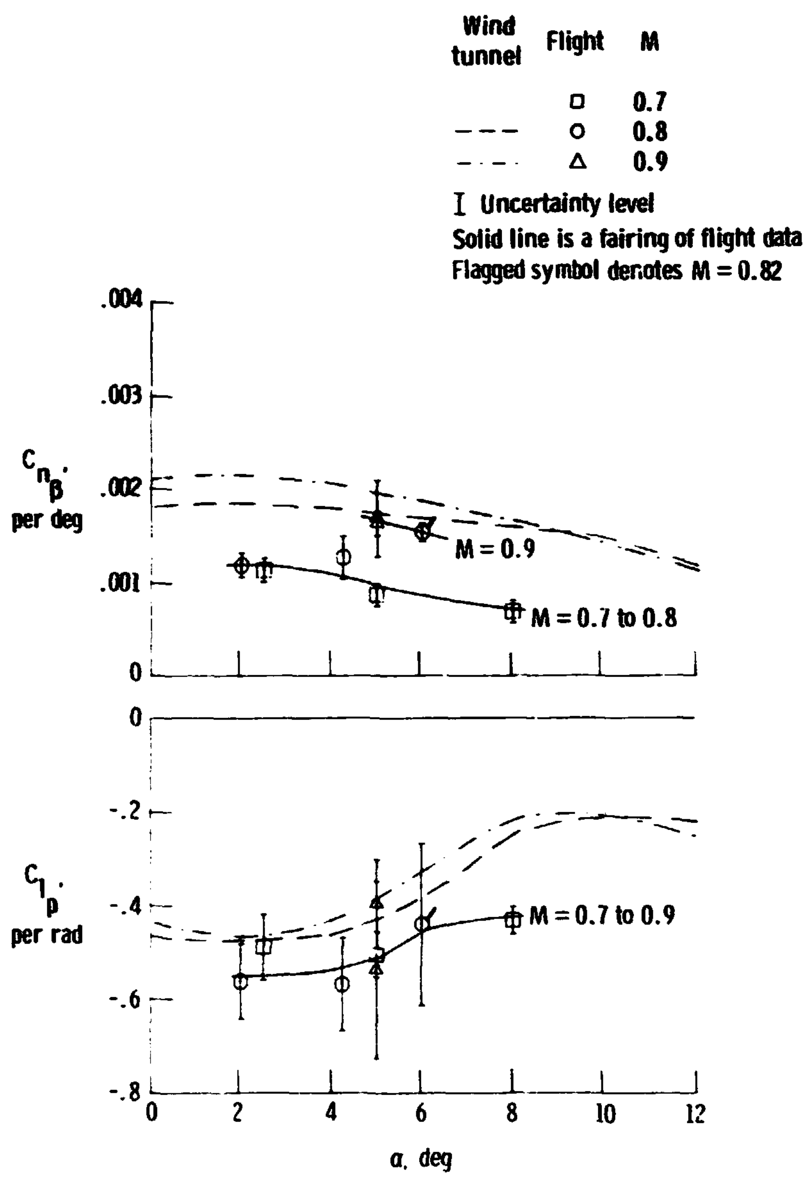


Figure 6. Static stability as a function of Mach number for 26° wing sweep.



(a) C_{Y_β} *and* C_{l_β}.

Figure 7. Lateral-directional stability and control derivatives for 1g flight and 26° wing sweep.



(b) C_{N_β} *and* C_{l_p}.

Figure 7. Continued.

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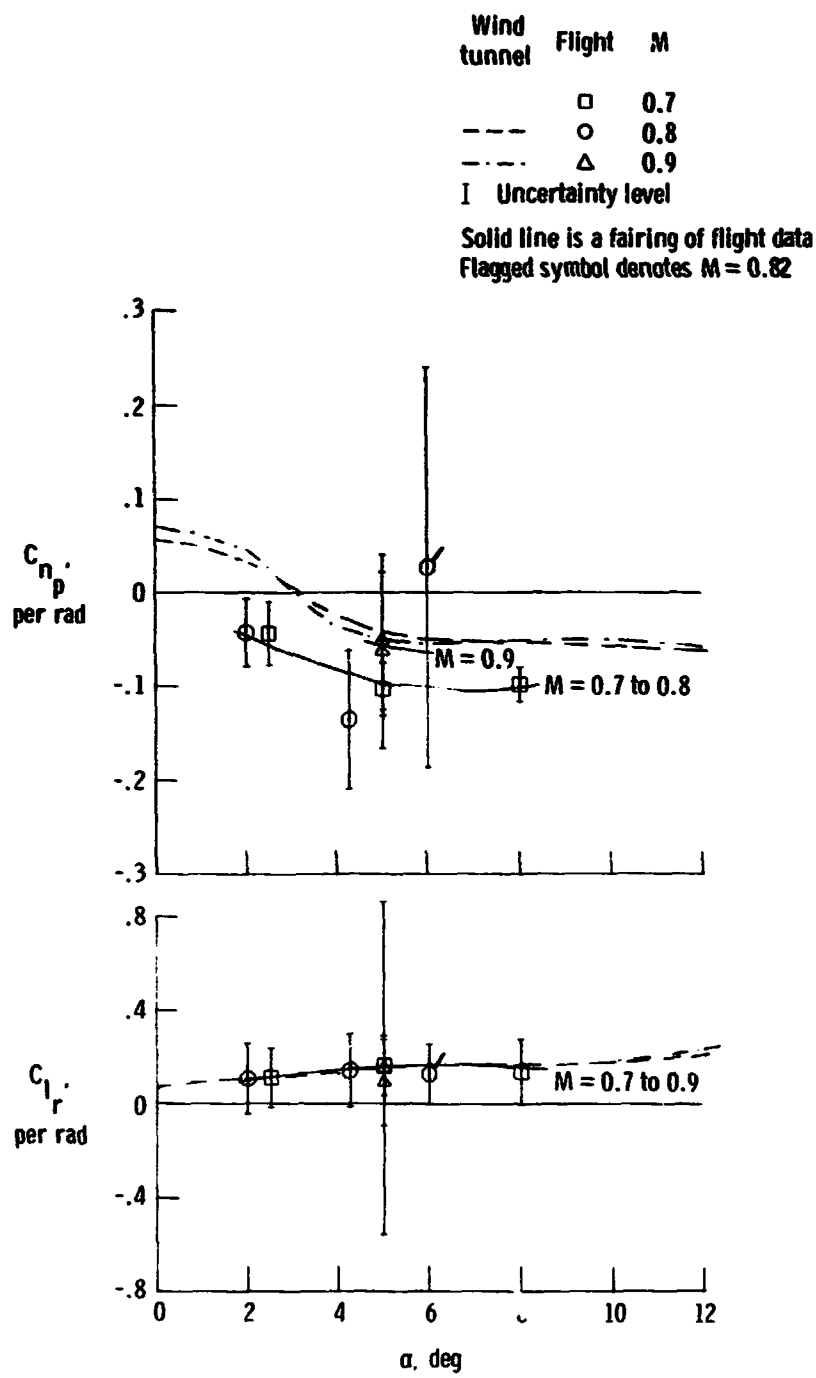
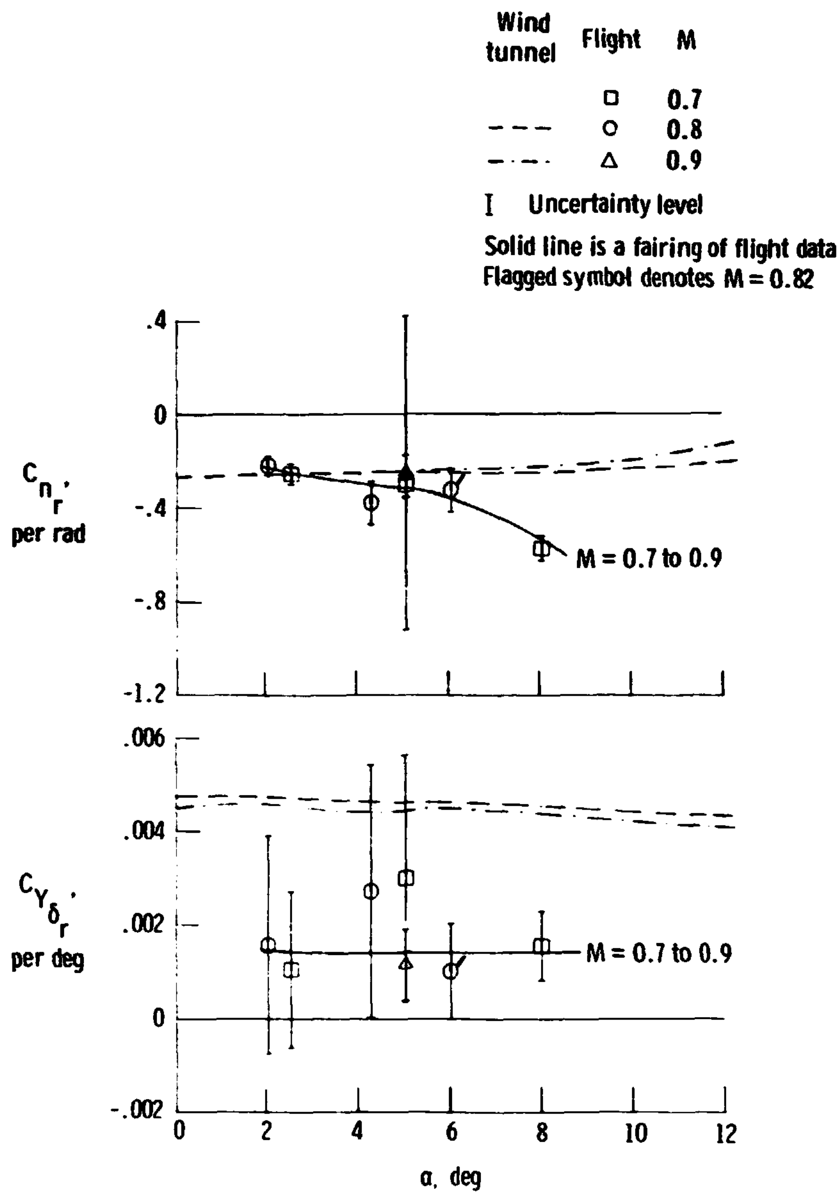


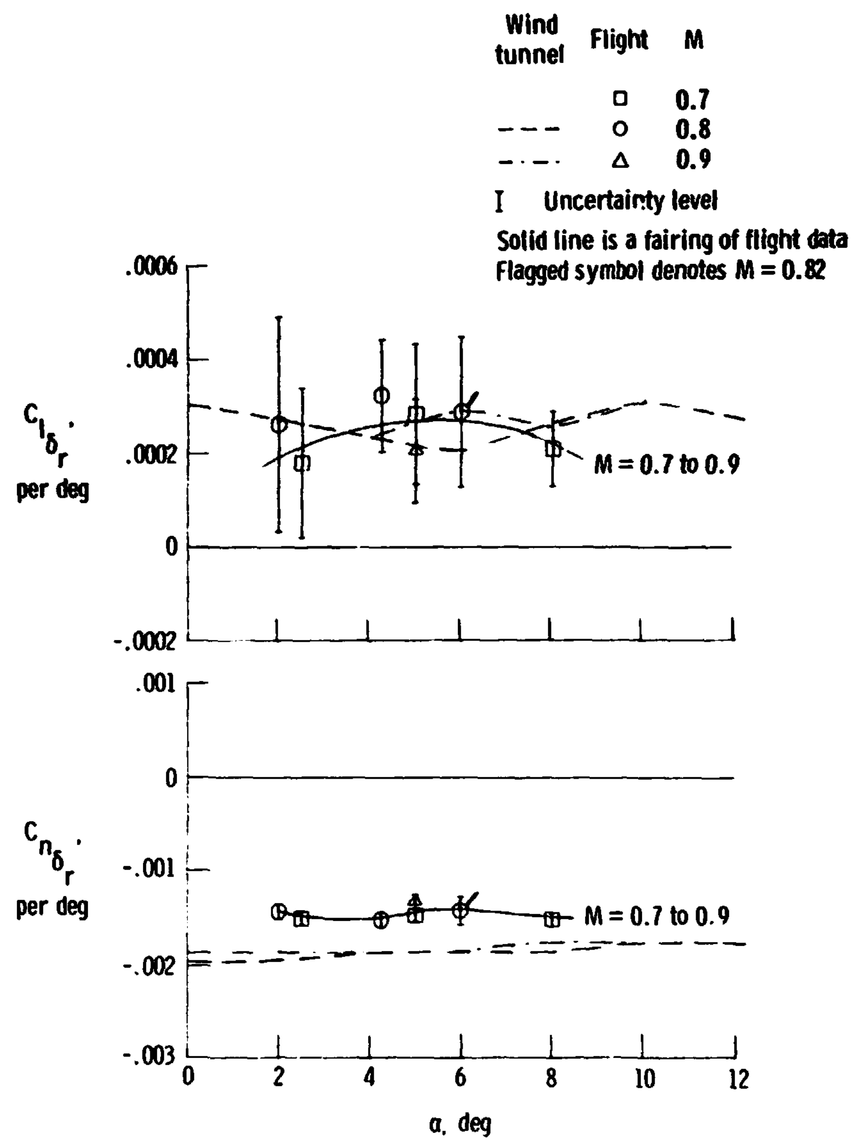
(c) C_{n_p} and C_{l_r}.

Figure 7. Continued.



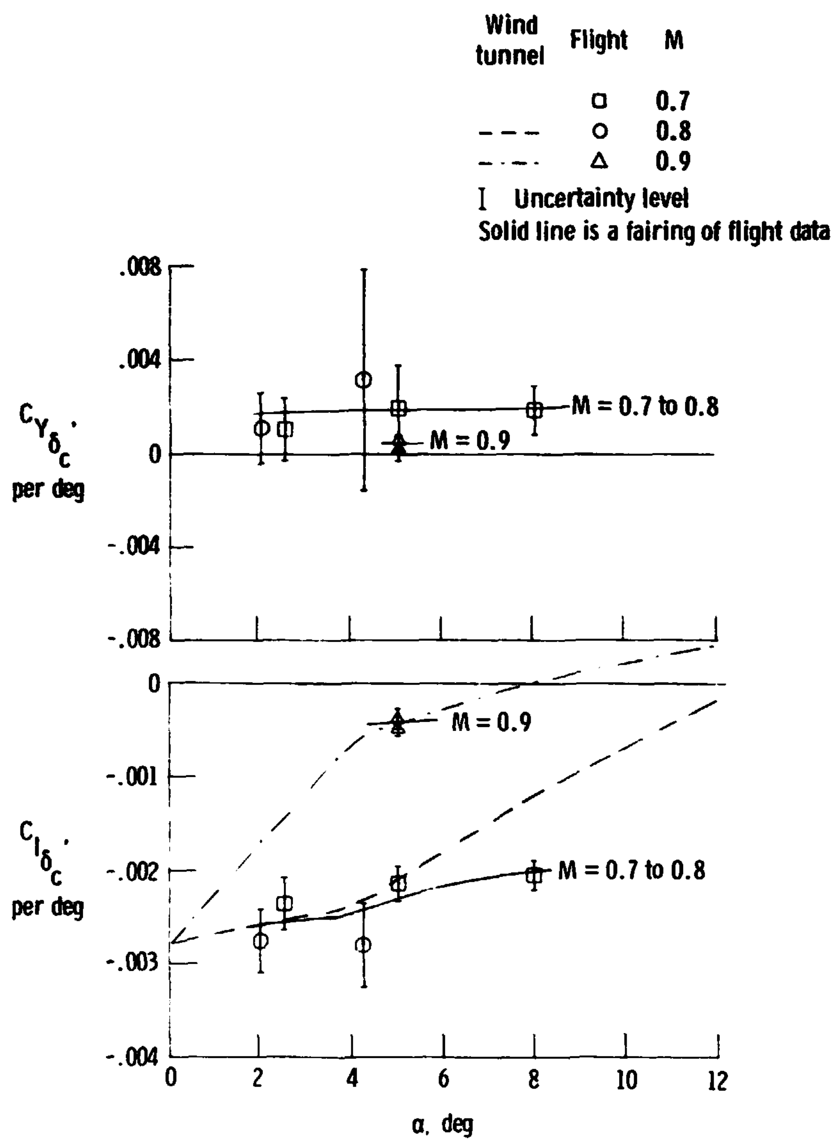
(d) C_{n_r} *and* $C_{Y_{\delta_r}}$.

Figure 7. Continued.



(e) $C_{l_{\delta_r}}$ *and* $C_{n_{\delta_r}}$.

Figure 7. Continued.



(f) $C_{Y_{\delta_c}}$ *and* $C_{l_{\delta_c}}$.

Figure 7. Continued.

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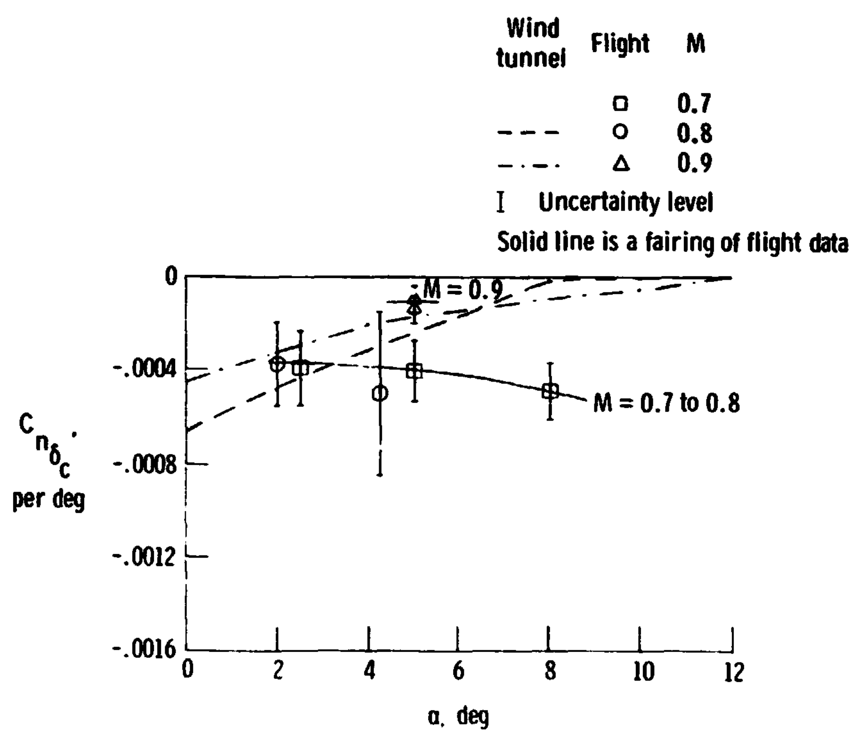
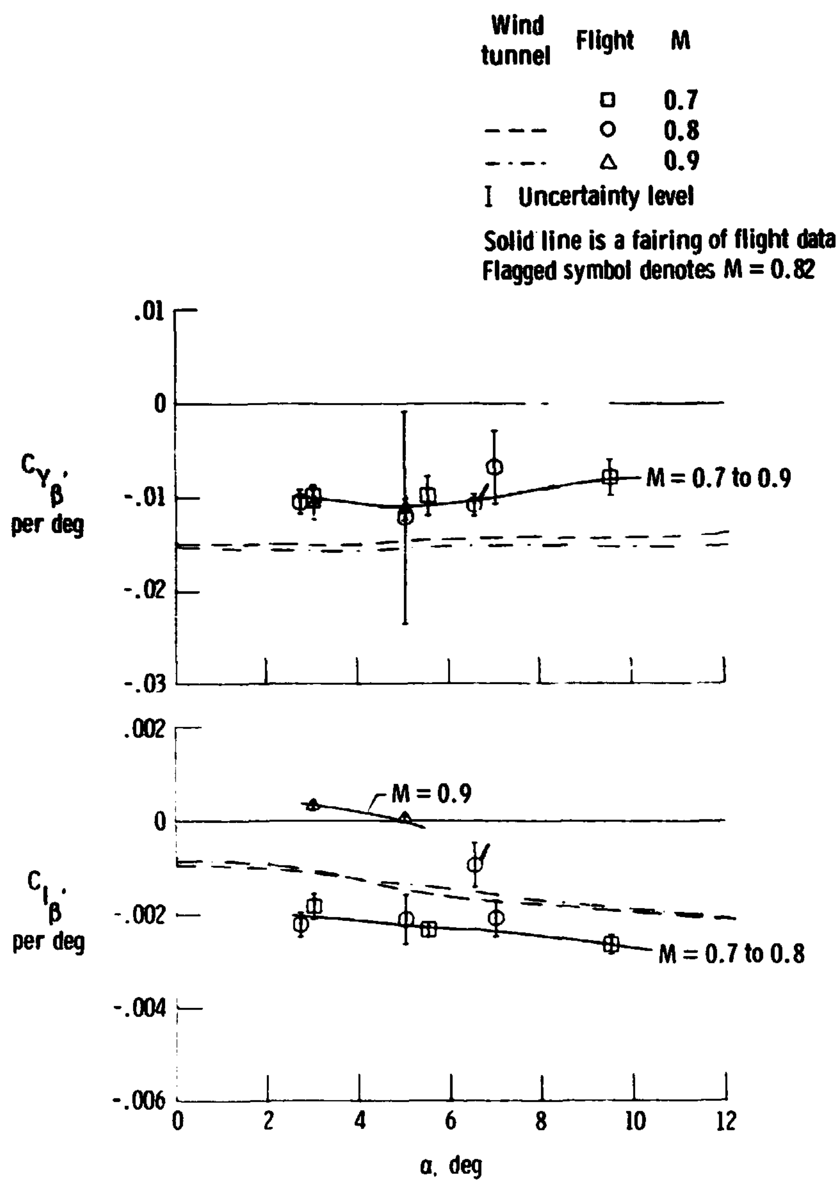


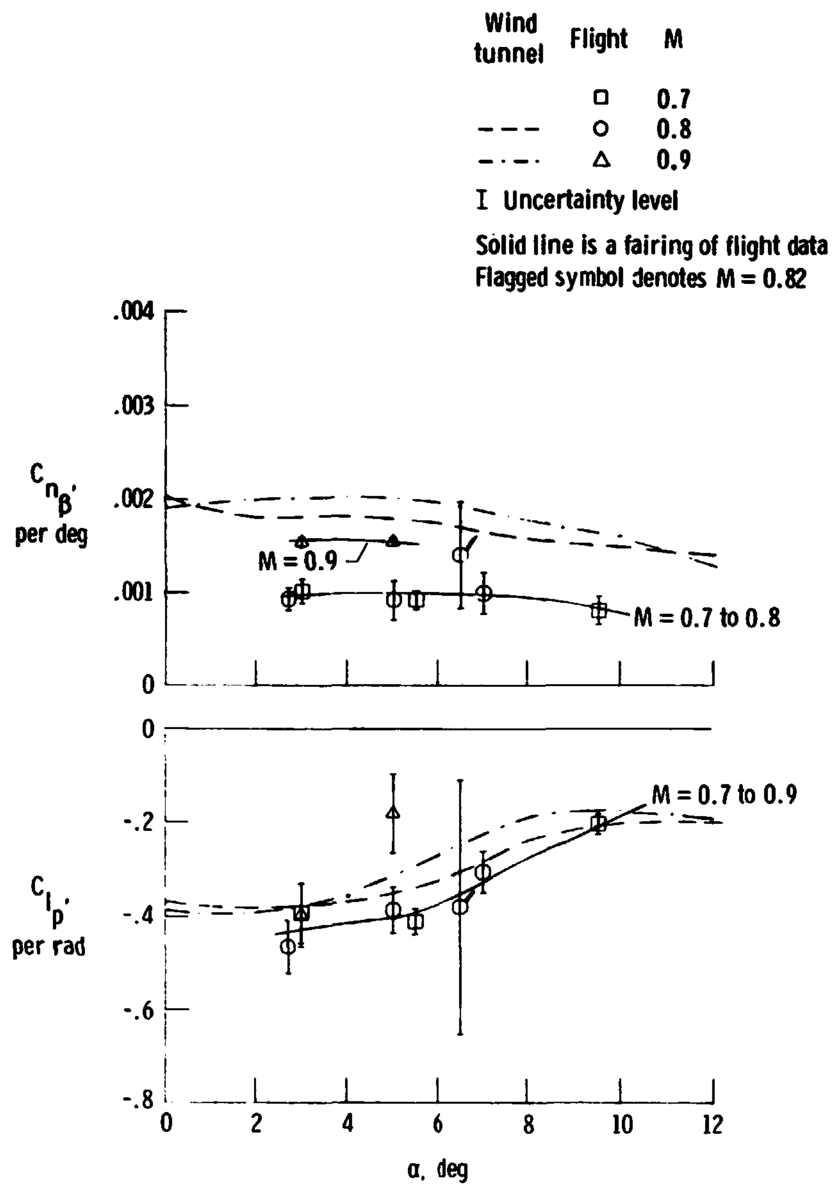
(g) $C_{n_{\delta_c}}$.

Figure 7. Concluded.



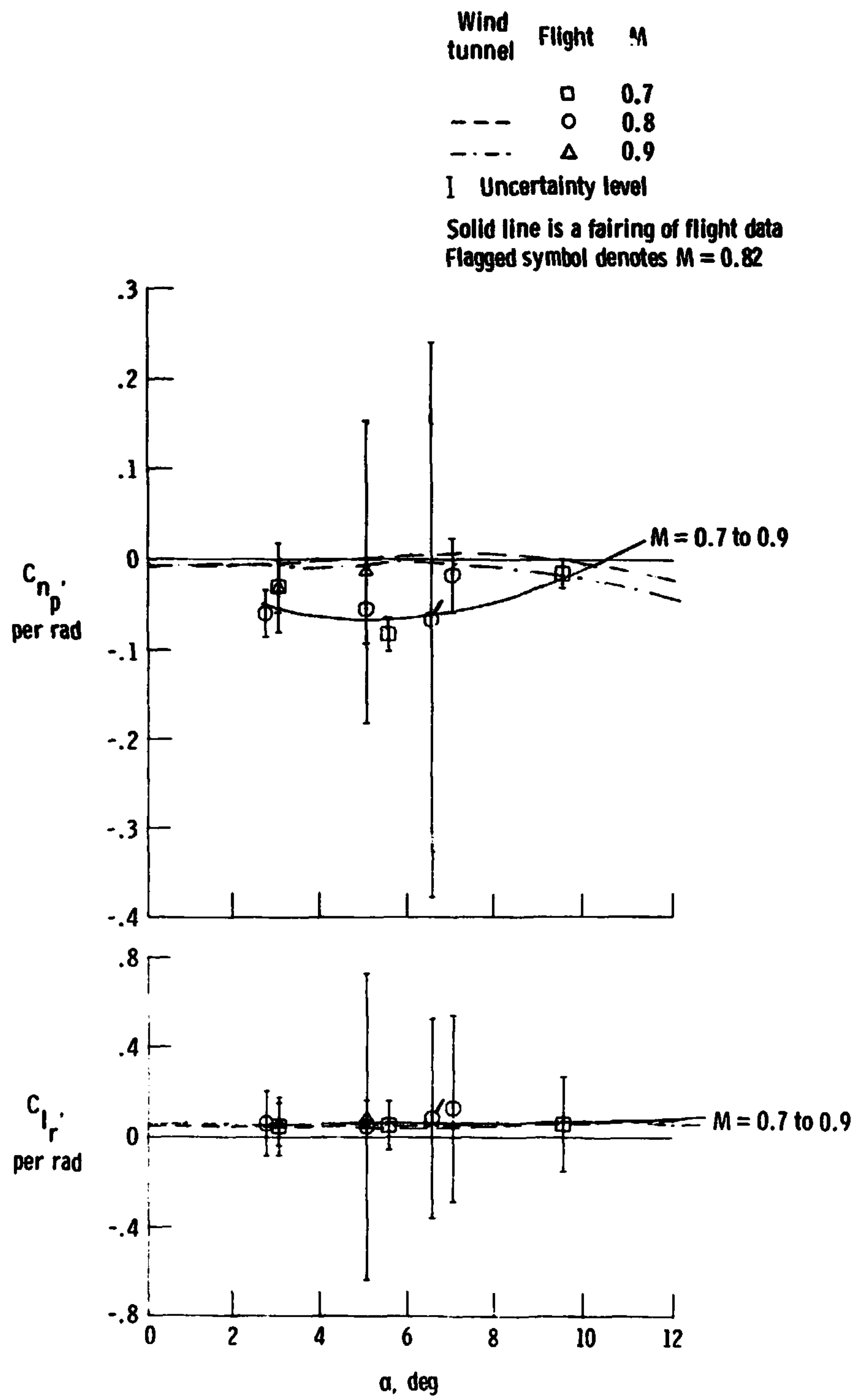
(a) C_{Y_β} and C_{l_β}.

Figure 8. Lateral-directional stability and control derivatives for 1g flight and 35° wing sweep.



(b) C_{n_β} *and* C_{l_p}.

Figure 8. Continued.



(c) C_{n_p} and C_{l_r}.

Figure 8. Continued.

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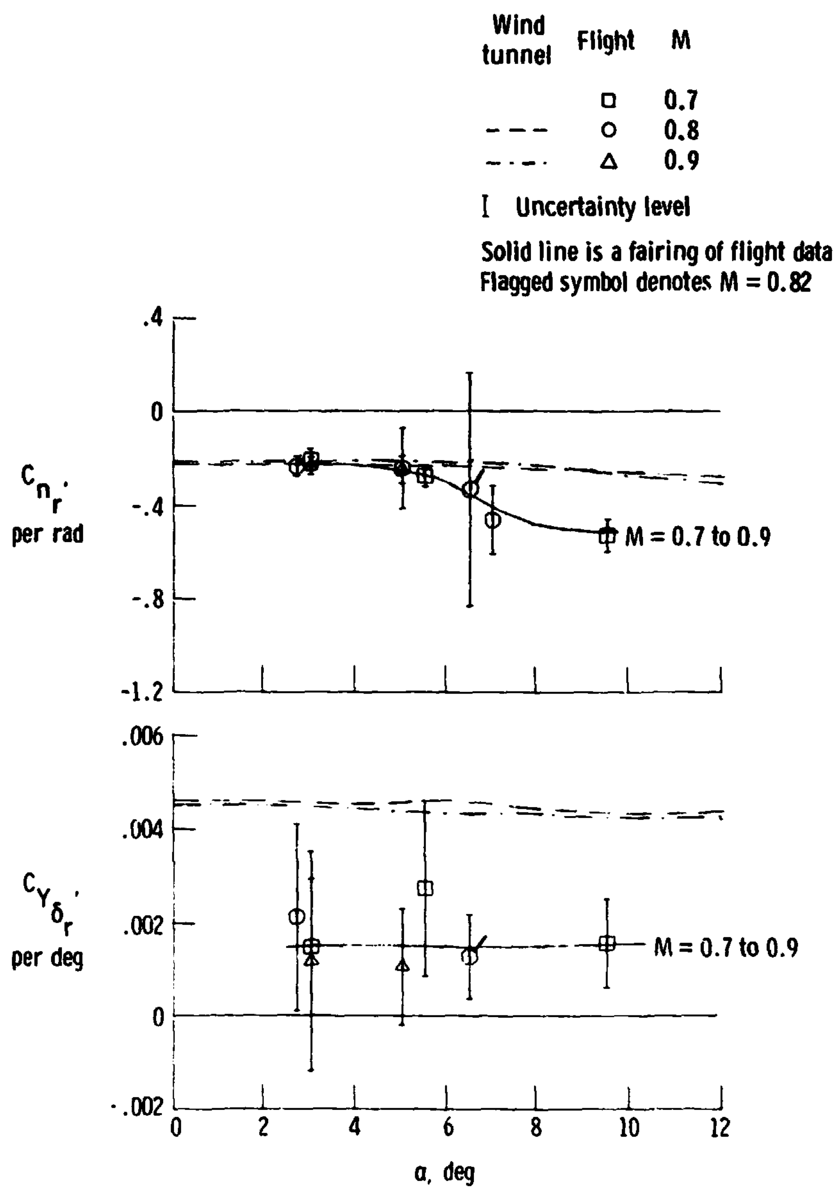
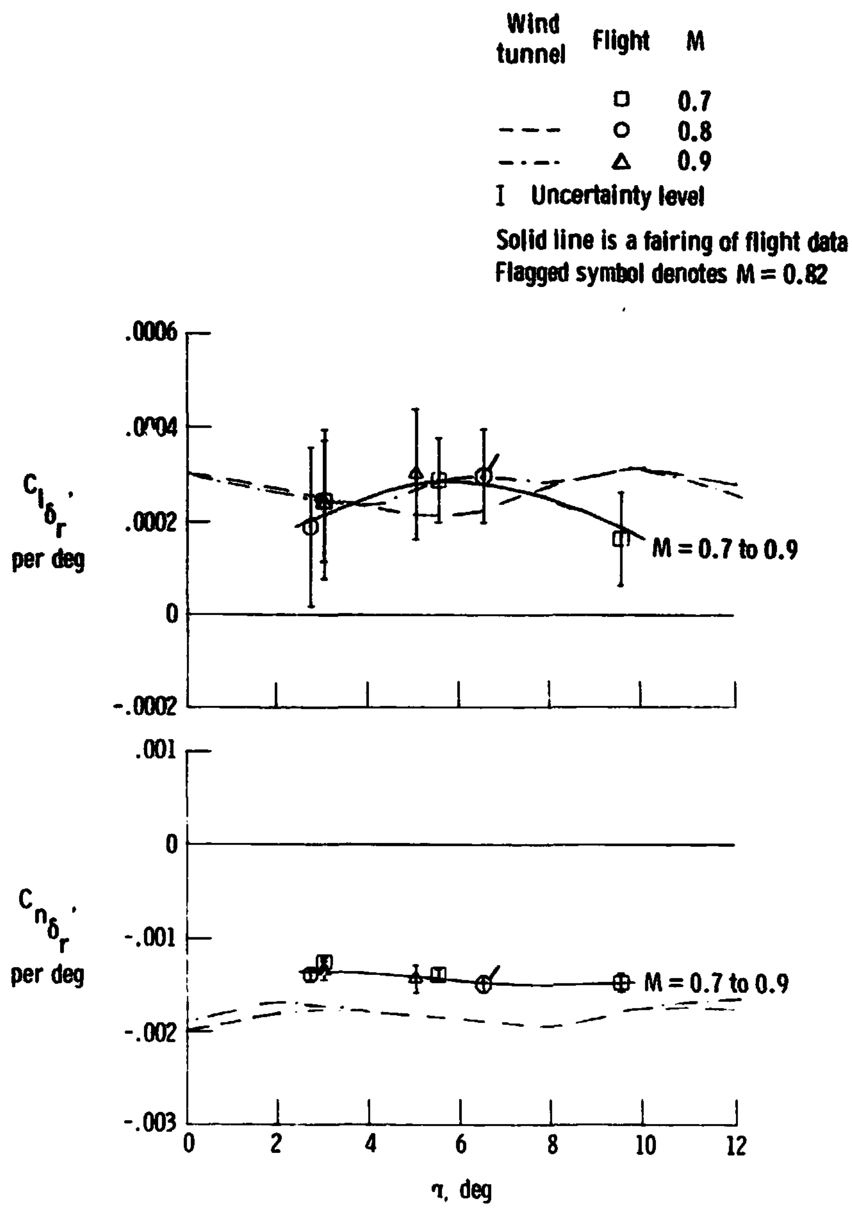


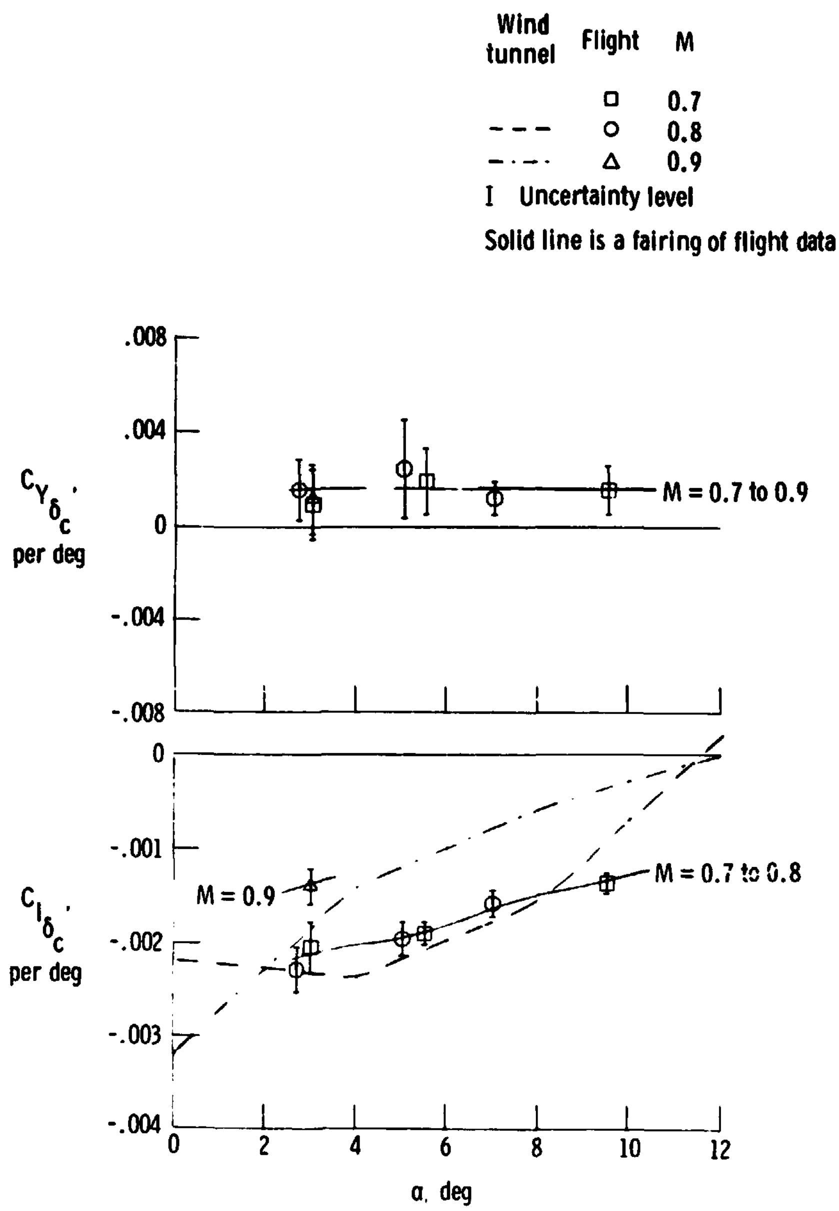
(d) C_{n_r} and $C_{Y_{\delta_r}}$.

Figure 8. Continued.



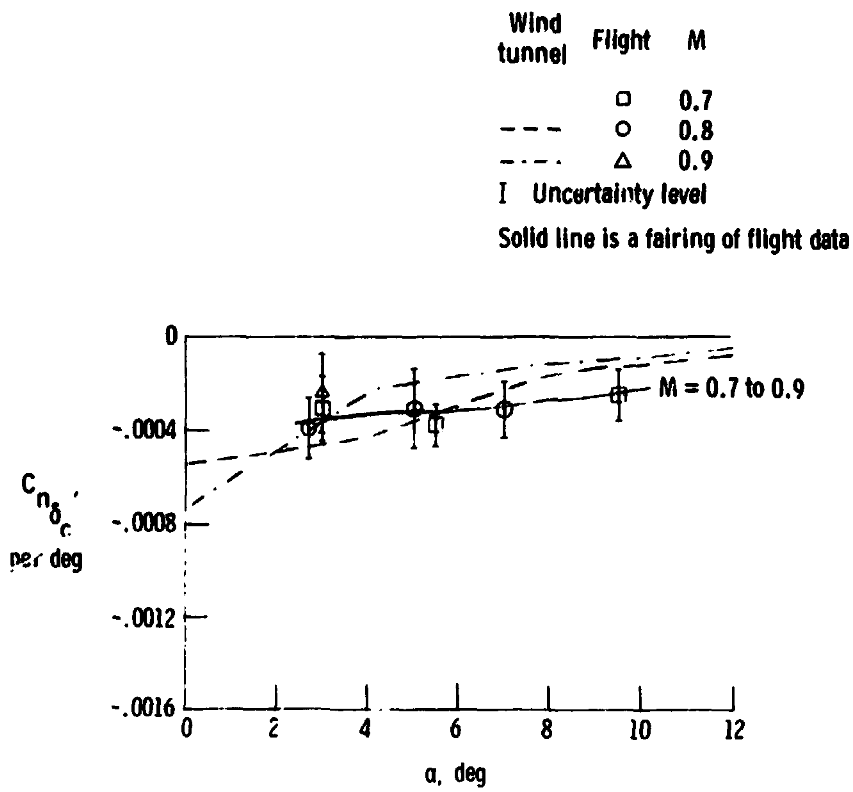
(e) $C_{l_{\delta_r}}$ *and* $C_{n_{\delta_r}}$.

Figure 8. Continued.



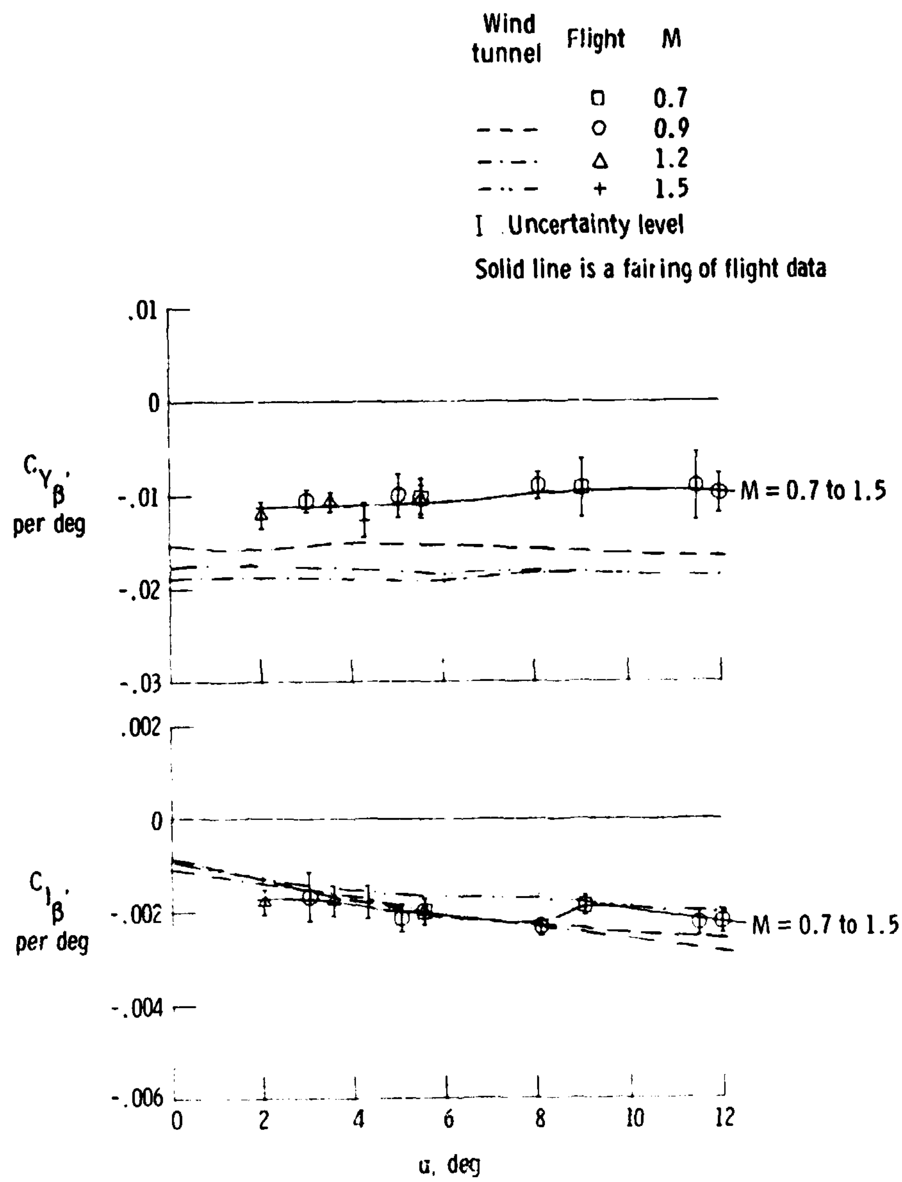
(f) $C_{Y_{\delta_c}}$ *and* $C_{l_{\delta_c}}$.

Figure 8. Continued.



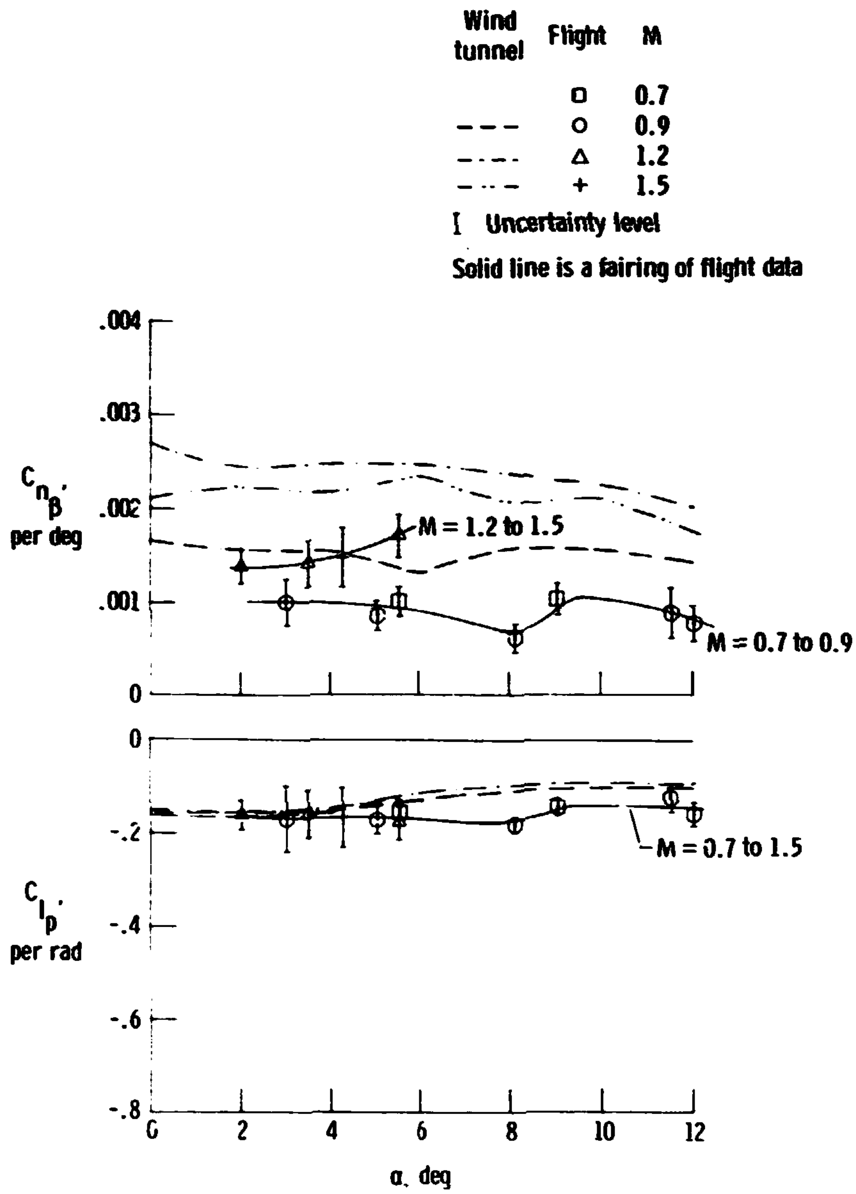
(g) $C_{n_{\delta_c}}$.

Figure 8. Concluded.



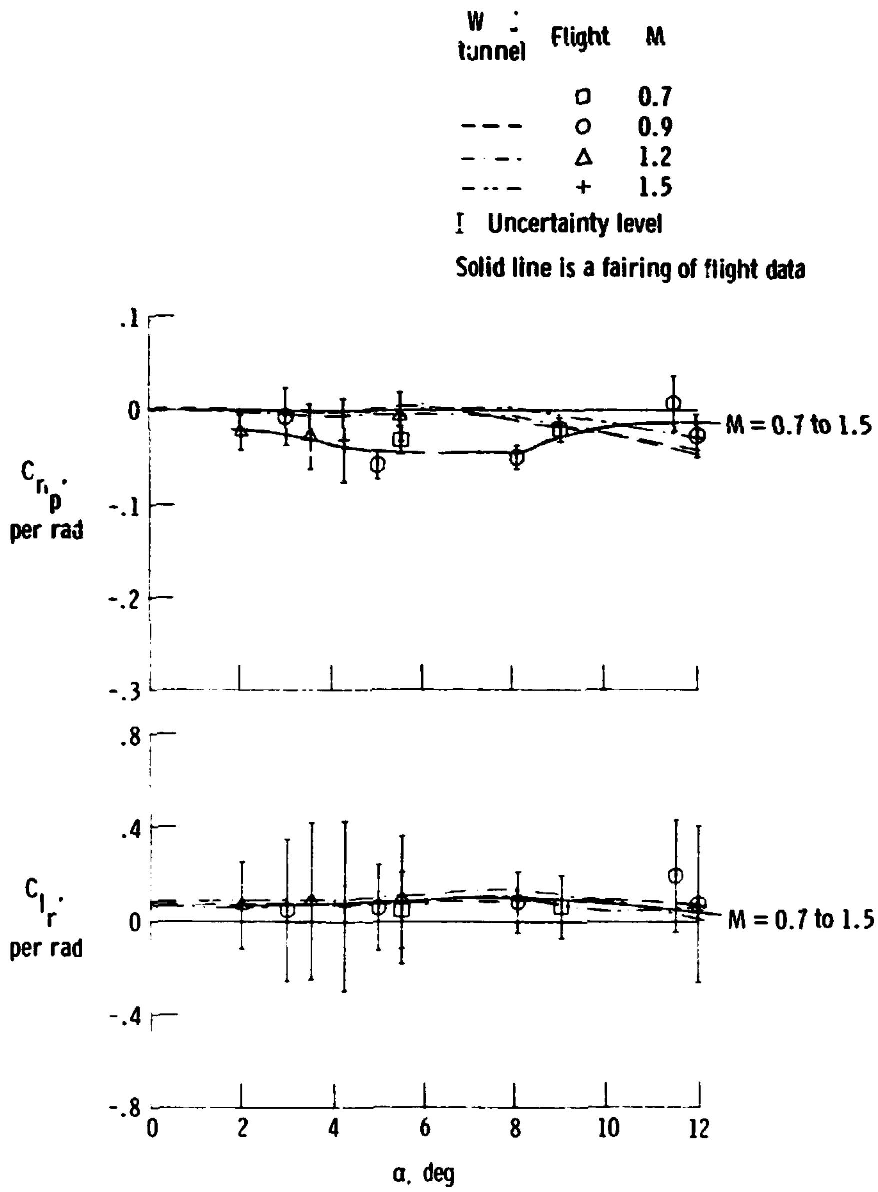
(a) C_{Y_β} *and* C_{l_β}.

Figure 9. Lateral-directional stability and control derivatives for 1g flight and 58° wing sweep.



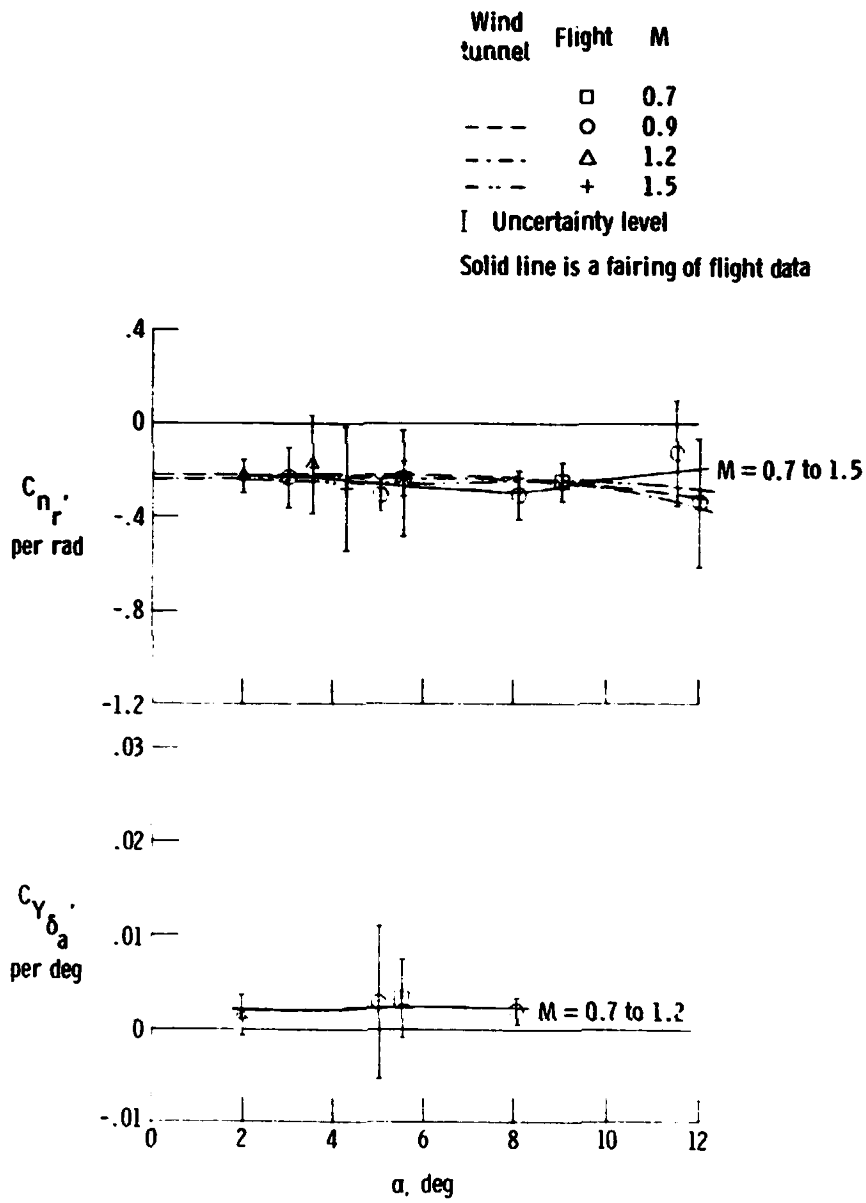
(b) C_{n_β} and C_{l_p}.

Figure 9. Continued.



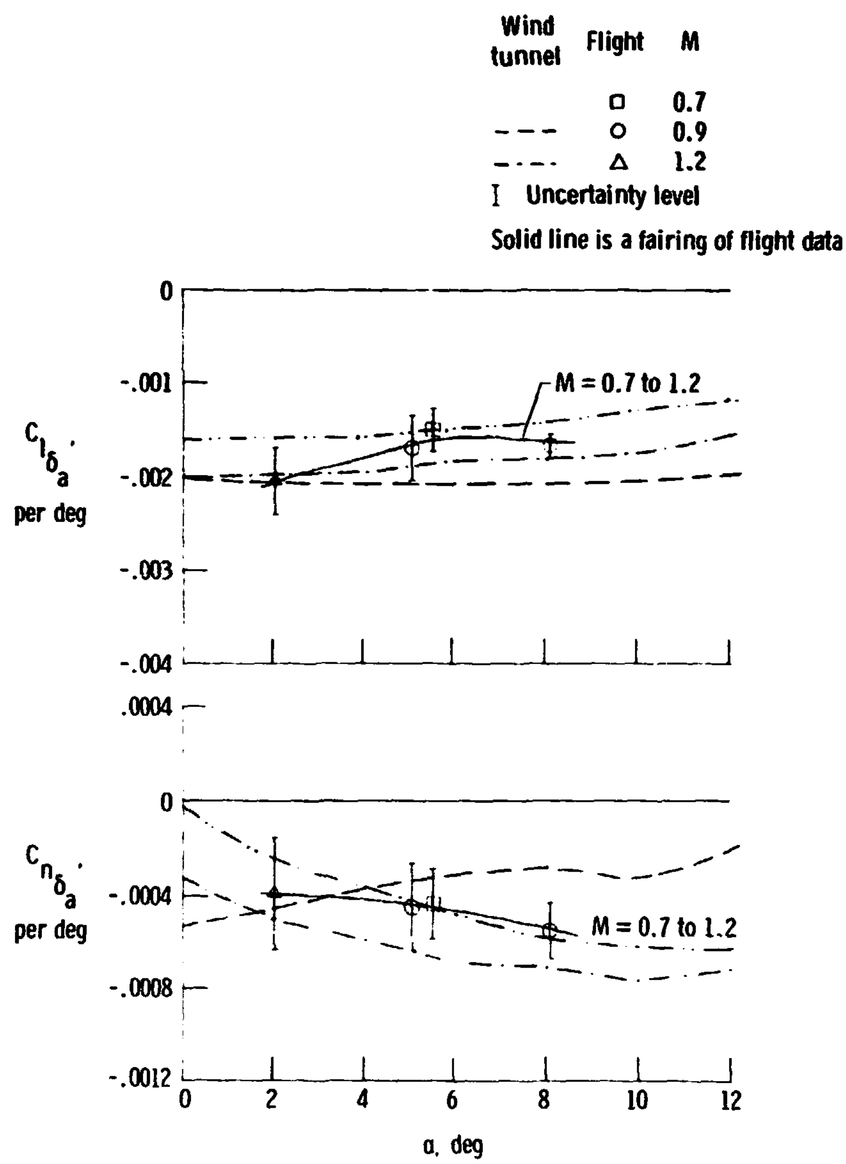
(c) C_{n_p} *and* C_{l_r}.

Figure 9. Continued.



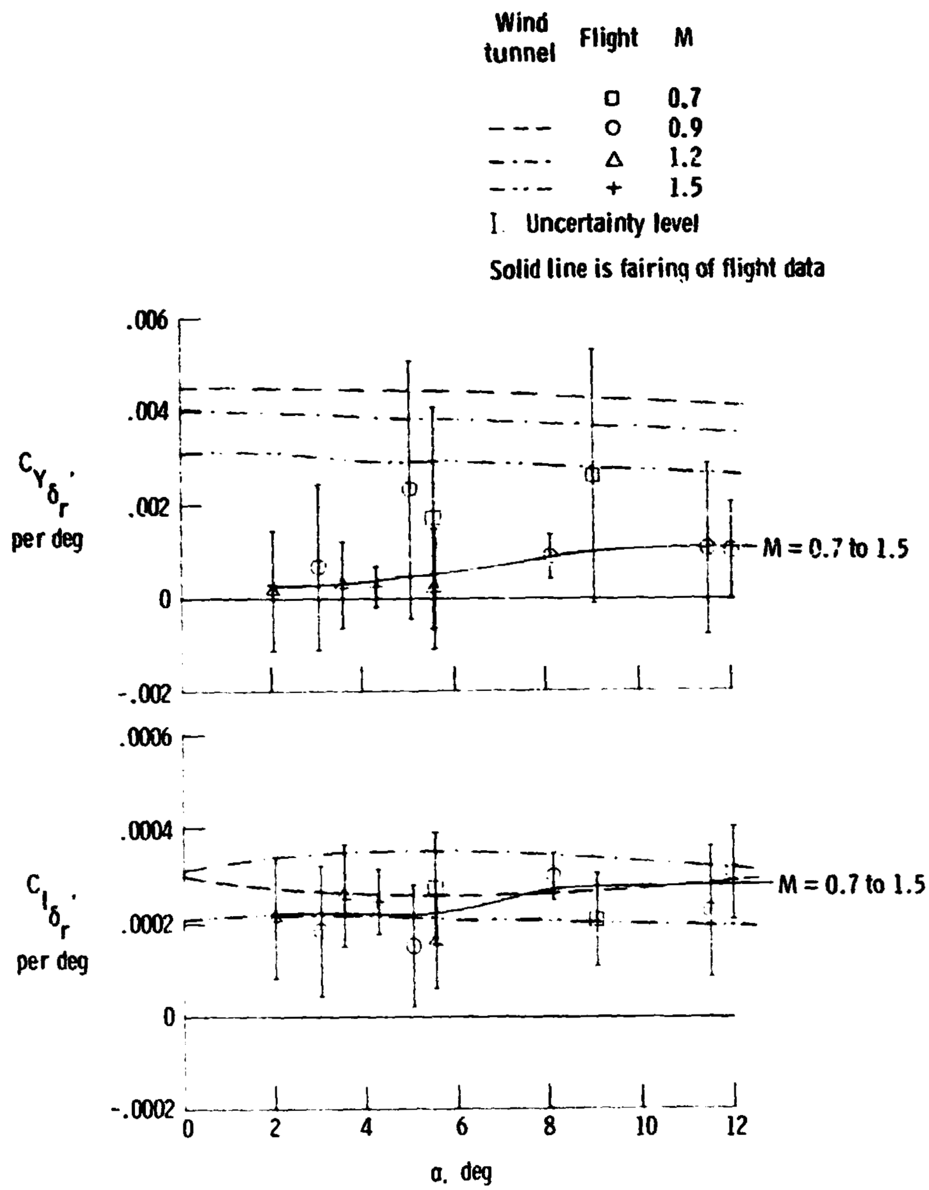
(d) C_{n_r} and $C_{Y_{\delta_a}}$.

Figure 9. Continued.



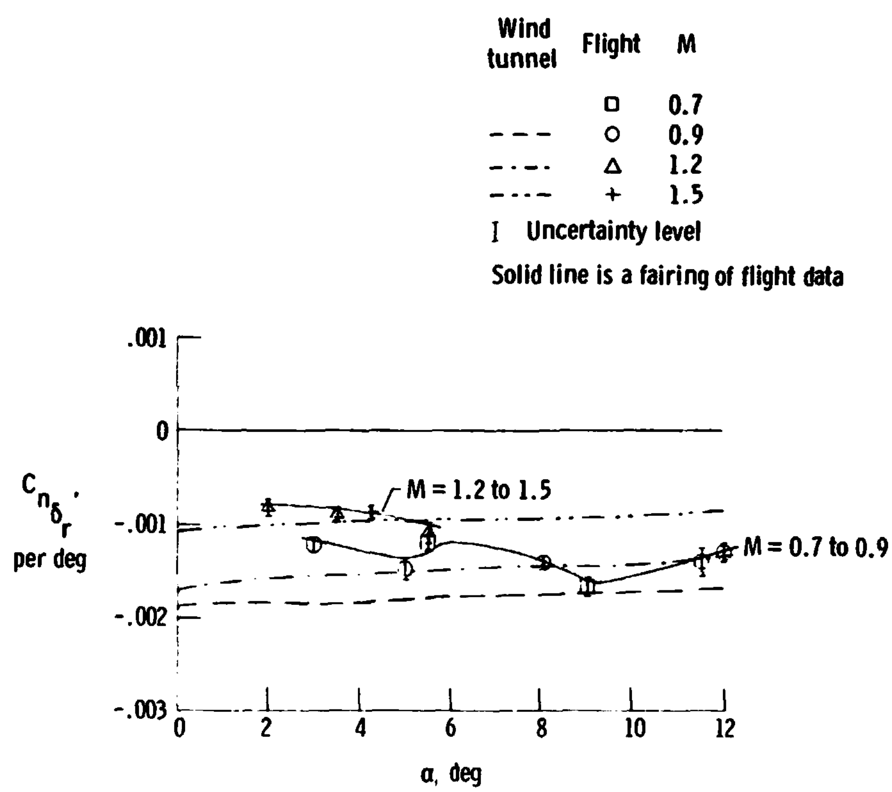
(e) $C_{l_{\delta_a}}$ *and* $C_{n_{\delta_a}}$.

Figure 9. Continued.



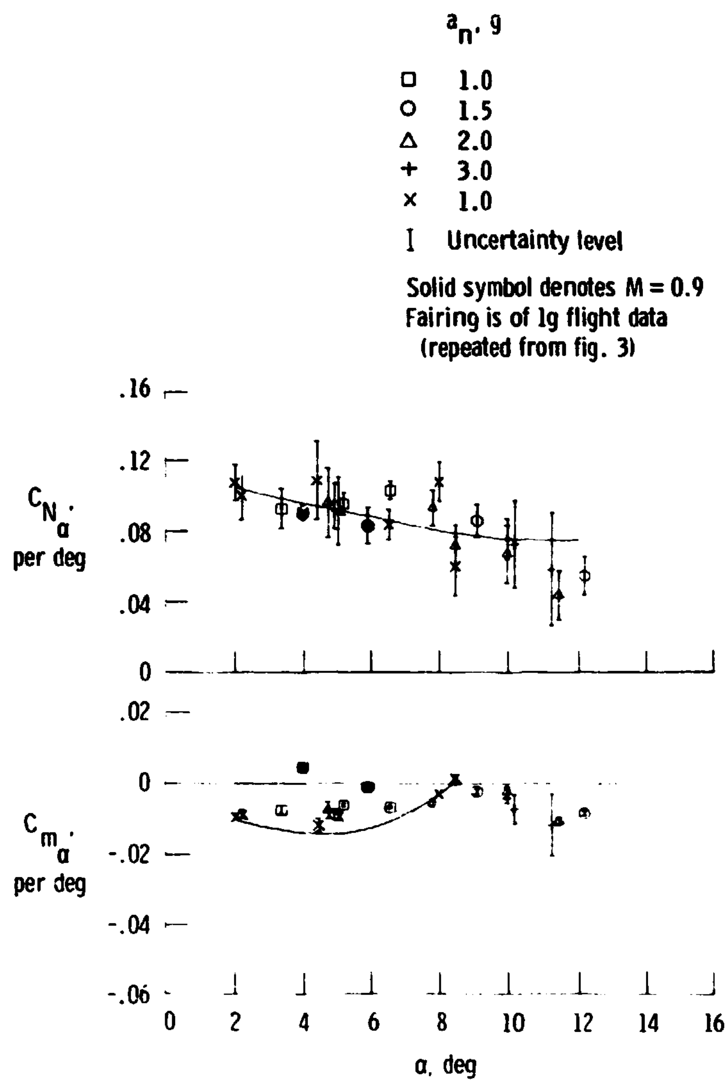
(f) $C_{Y_{\delta_r}}$ *and* $C_{l_{\delta_r}}$.

Figure 9. Continued.



(g) $C_{n_{\delta_r}}$.

Figure 9. Concluded.



(a) C_{N_α} and C_{m_α}.

Figure 10. Longitudinal stability and control derivatives for elevated g flight and 26° wing sweep.

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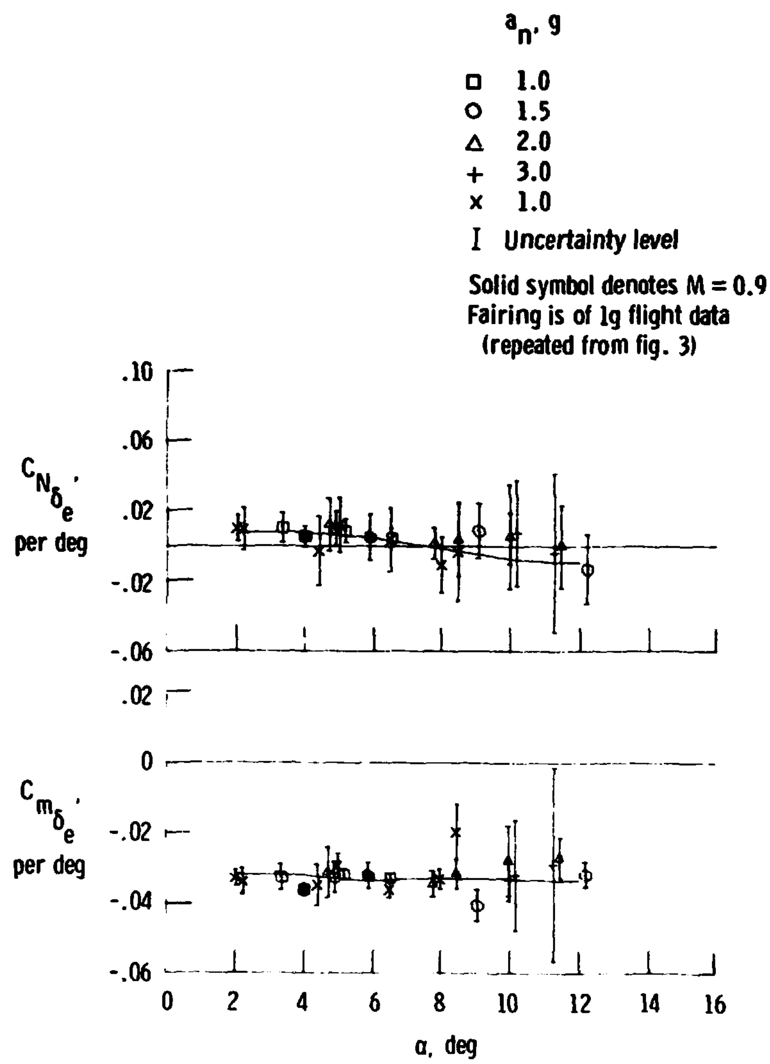
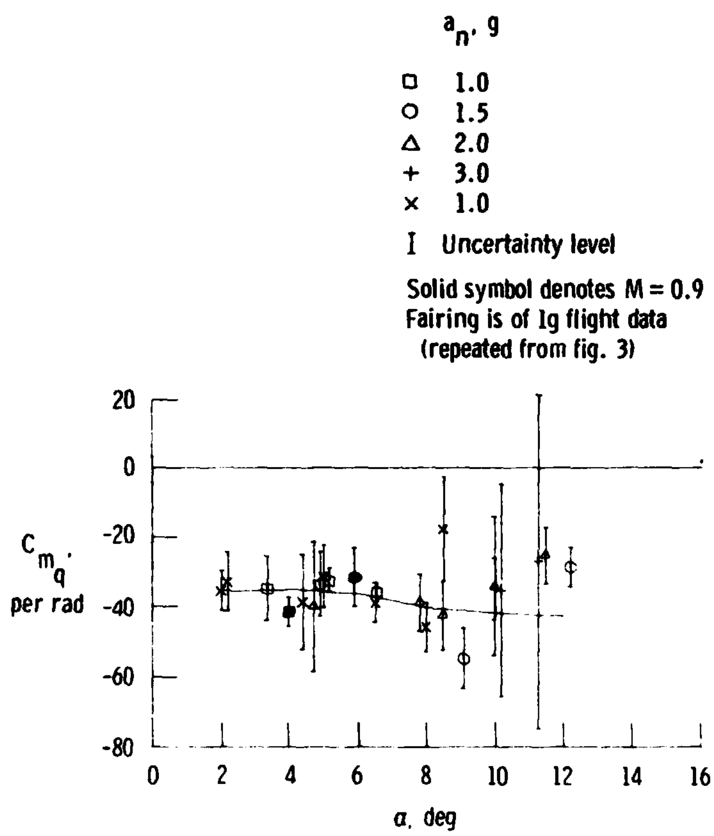


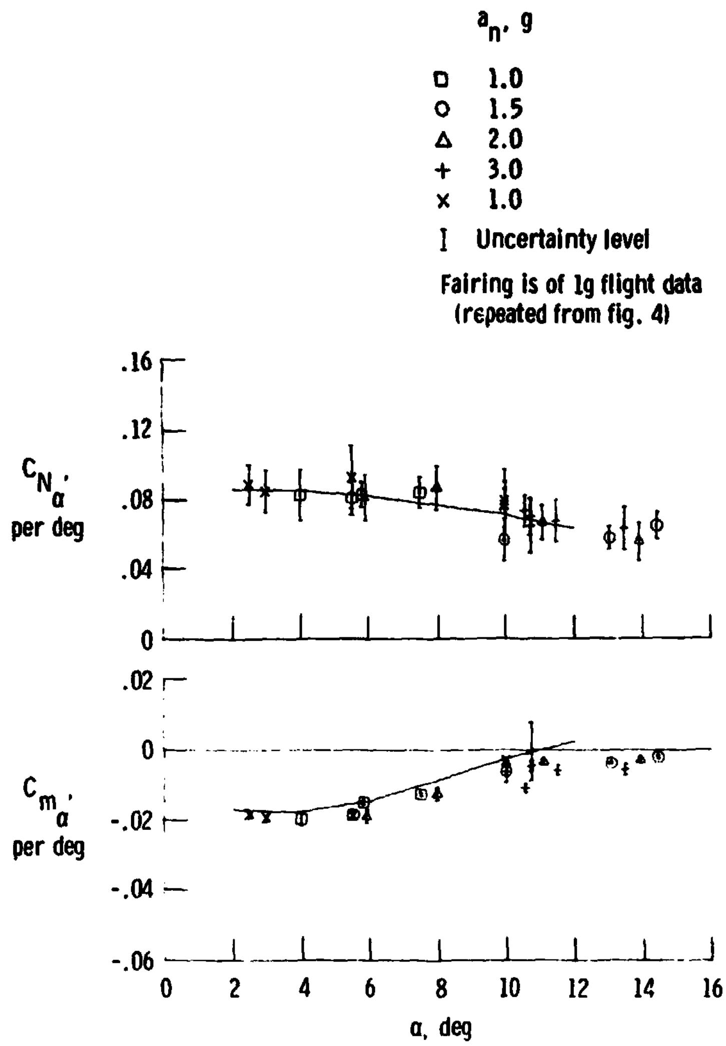
(b) $C_{N_{\delta_e}}$ and $C_{m_{\delta_e}}$.

Figure 10. Continued.



(c) C_{m_q}.

Figure 10. Concluded.



(a) C_{N_α} *and* C_{m_α}.

Figure 11. Longitudinal stability and control derivatives for elevated g flight and 35° wing sweep.

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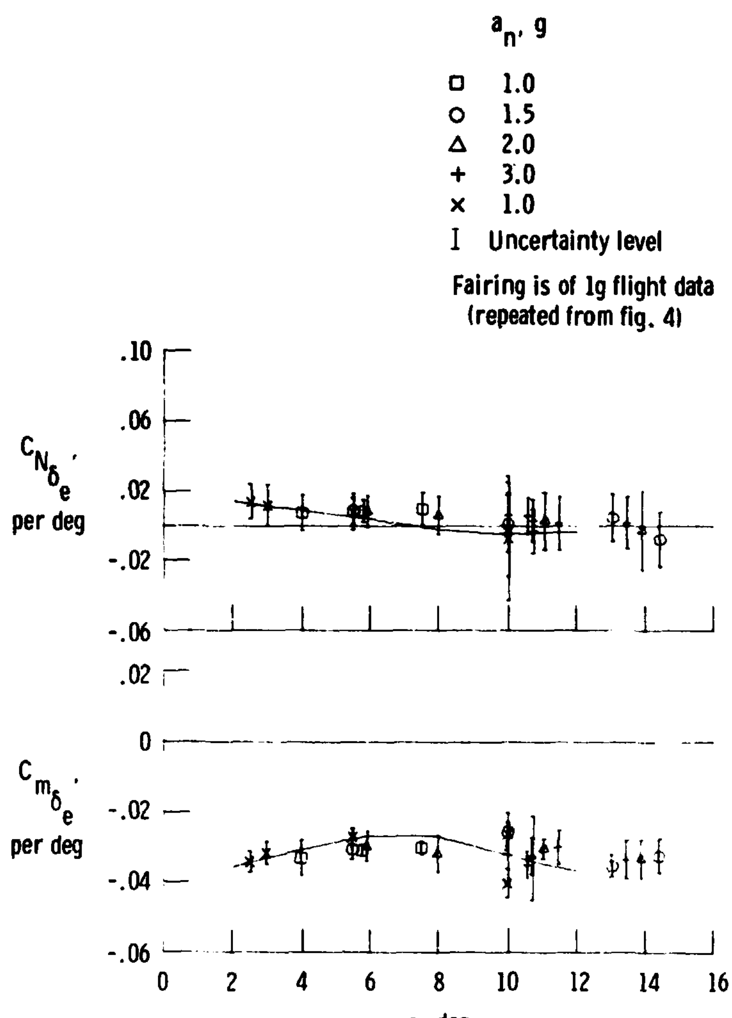
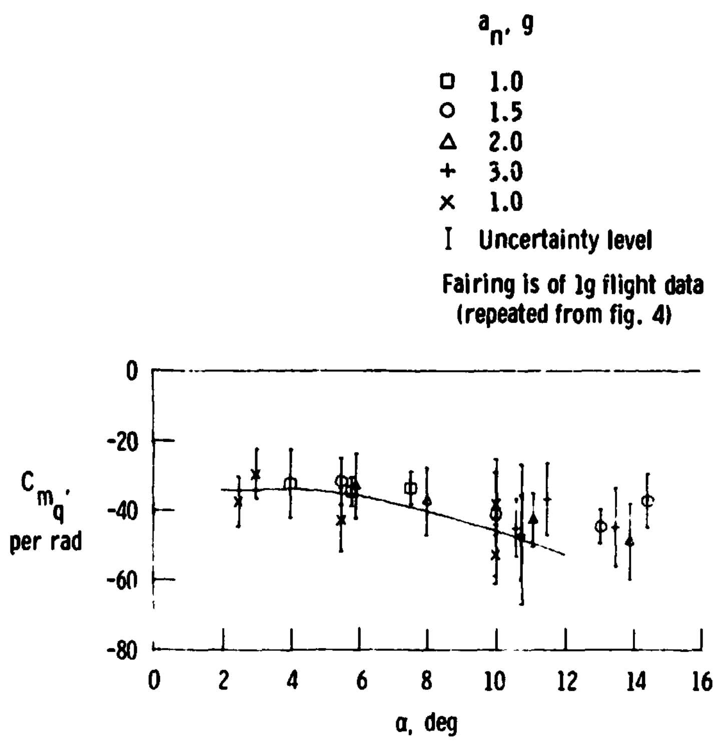


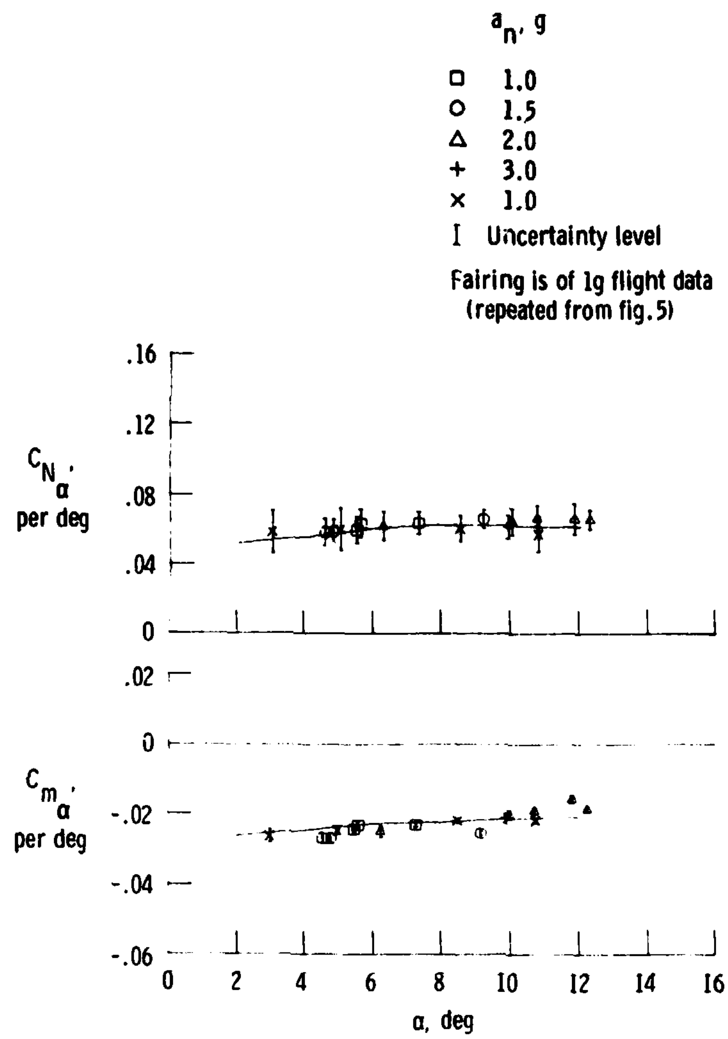
(b) $C_{N_{\delta_e}}$ and $C_{m_{\delta_e}}$.

Figure 11. Continued.



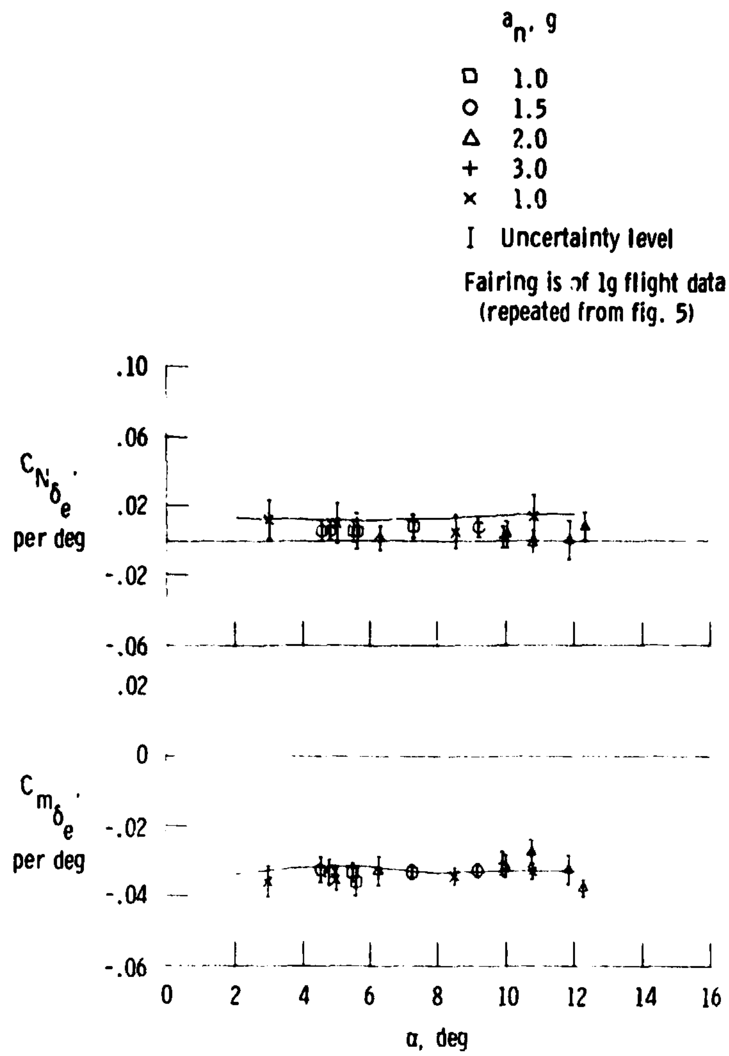
(c) C_{m_q}.

Figure 11. Concluded.



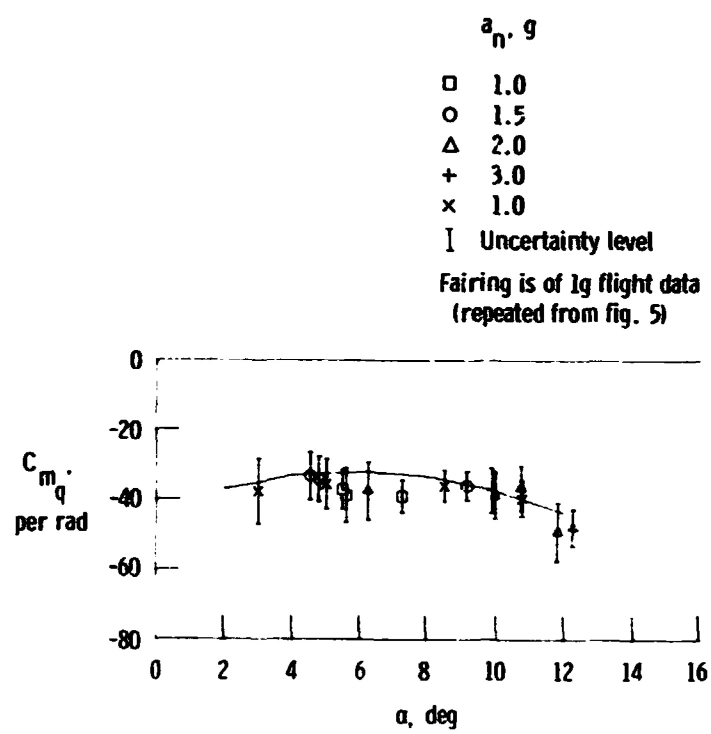
(a) C_{N_α} and C_{m_α}.

Figure 12. Longitudinal stability and control derivatives for elevated g flight and 58° wing sweep.



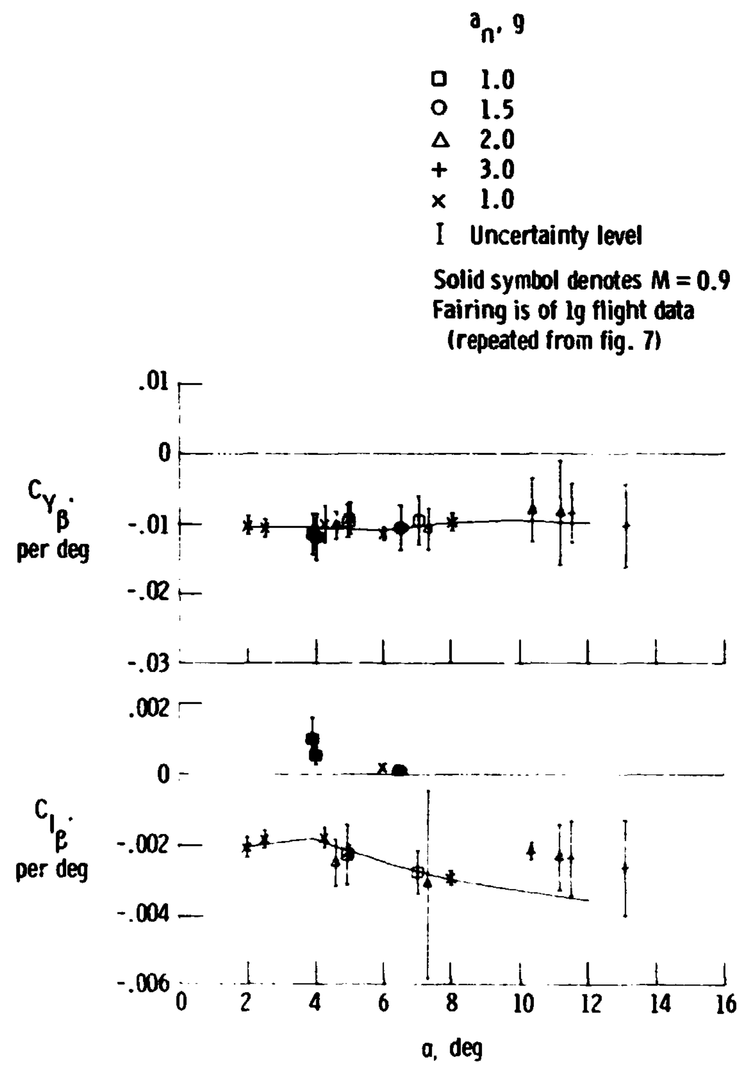
(b) $C_{N_{\delta_e}}$ and $C_{m_{\delta_e}}$.

Figure 12. Continued.



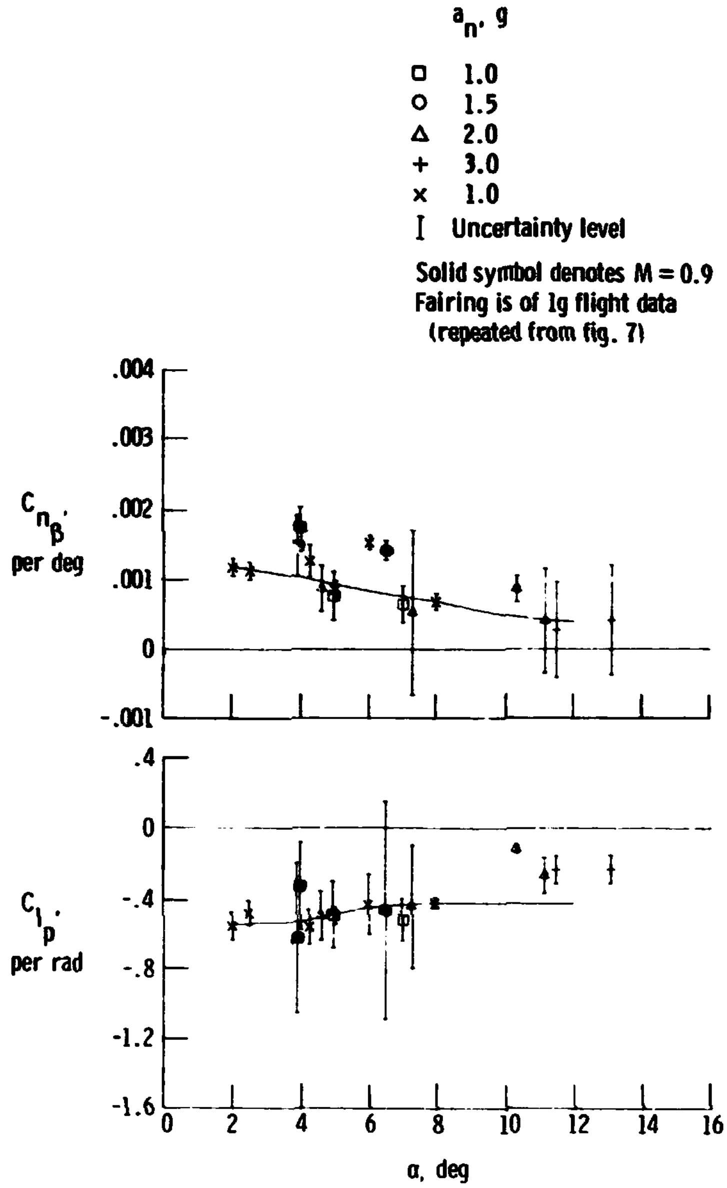
(c) C_{m_q}.

Figure 12. Concluded.



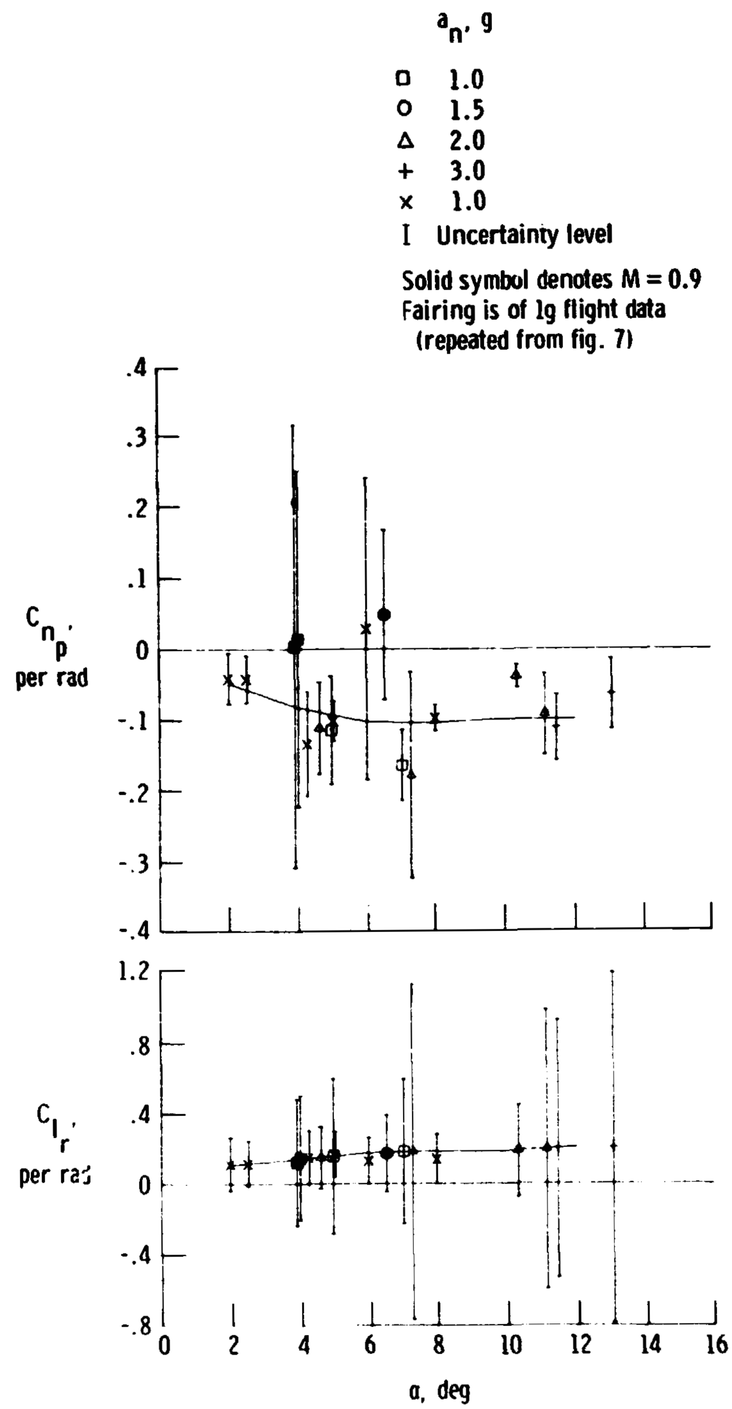
(a) C_{Y_β} and C_{l_β}.

Figure 13. Lateral-directional stability and control derivatives for elevated g flight and 26° wing sweep.



(b) C_{n_β} and C_{l_p}.

Figure 13. Continued.



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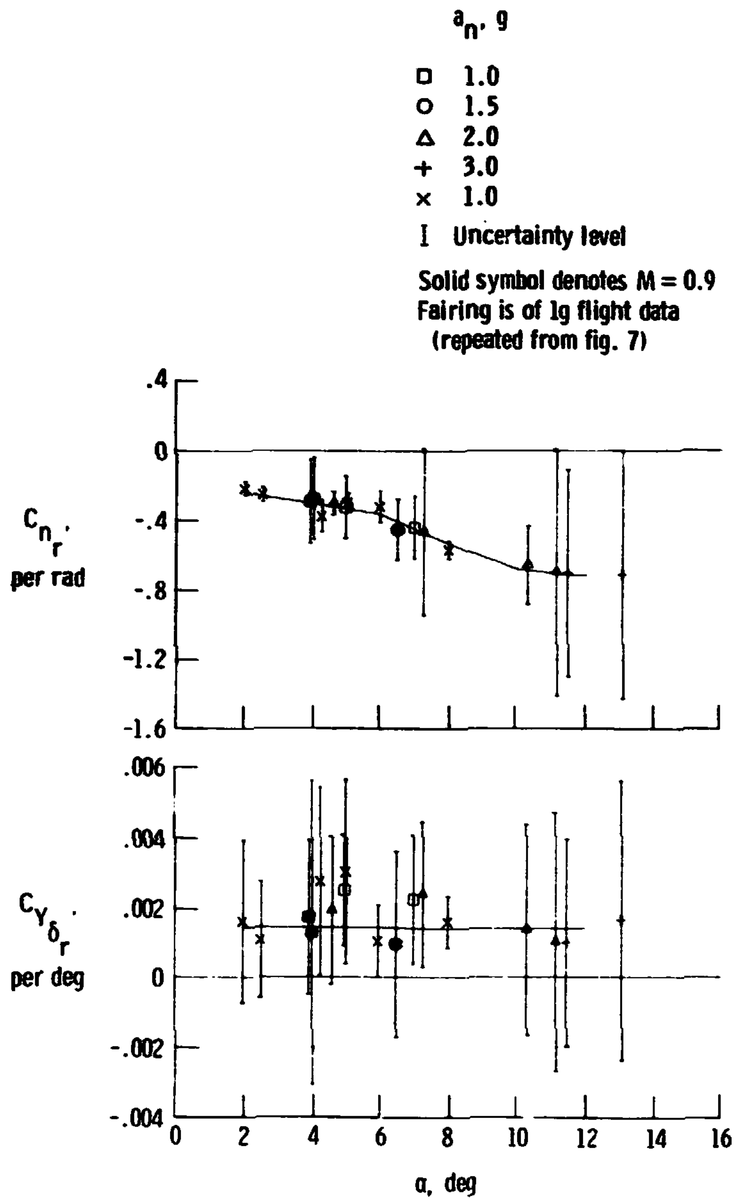
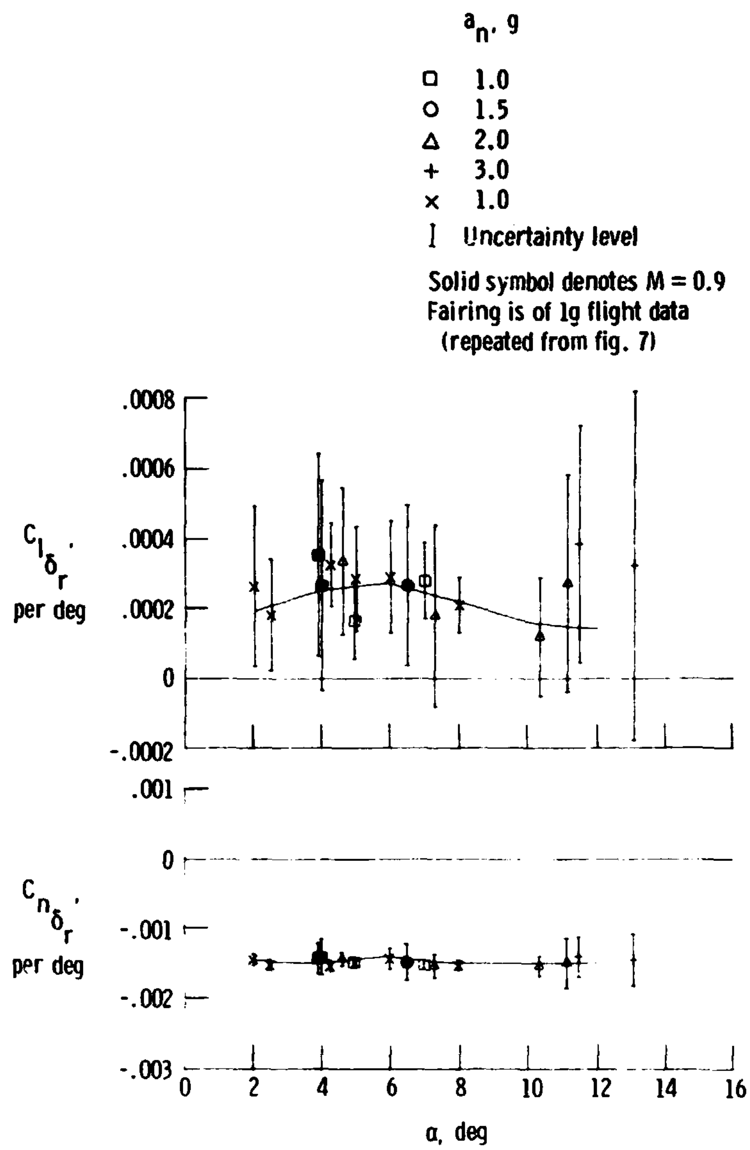
(c) C_{n_p} *and* C_{l_r}.

Figure 13. Continued.



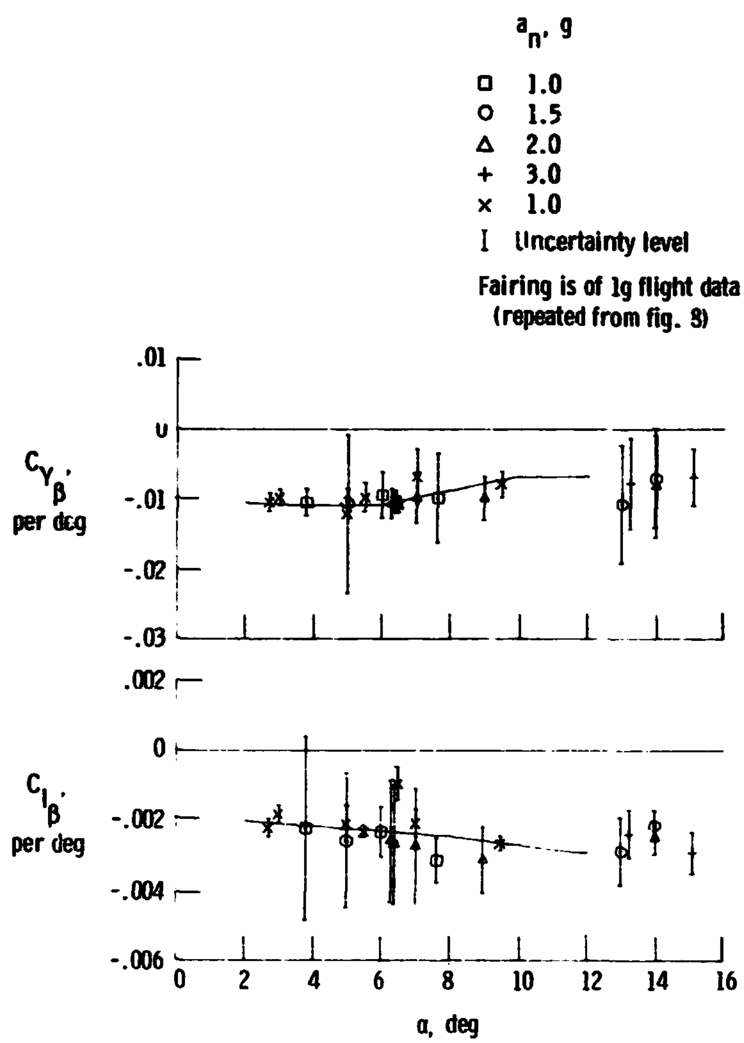
(d) C_{n_r} and $C_{Y_{\delta_r}}$.

Figure 13. Continued.



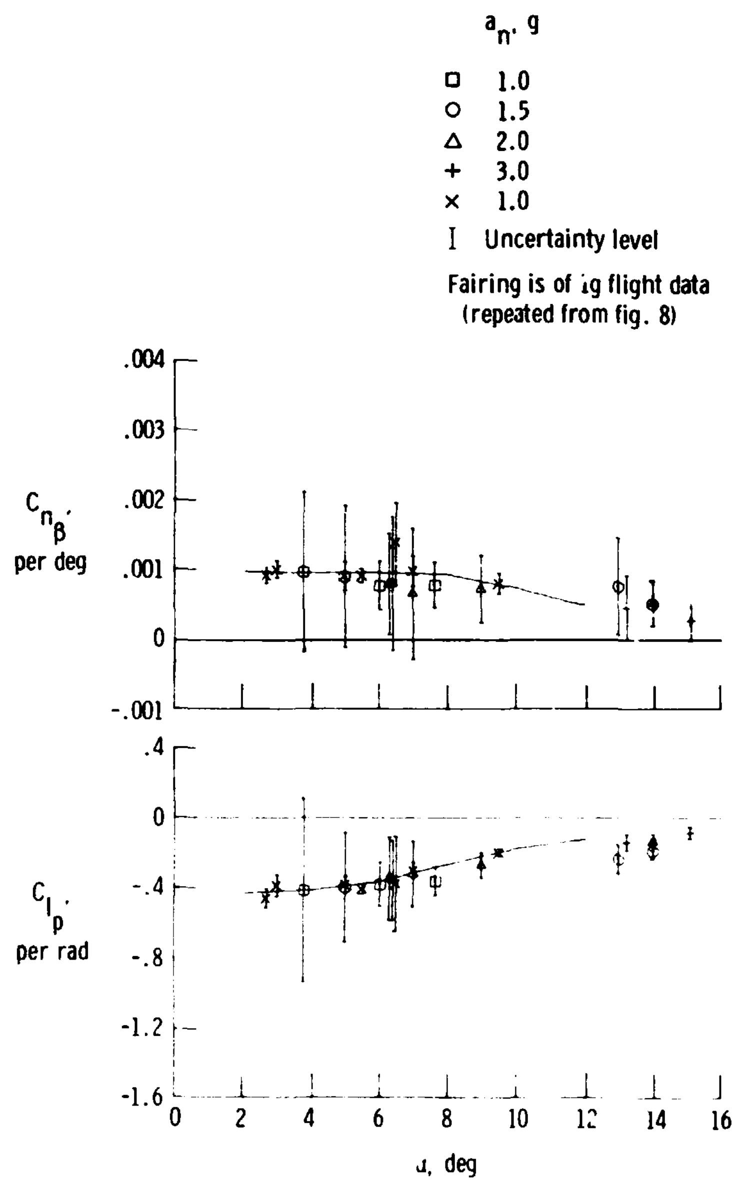
(e) $C_{l_{\delta_r}}$ and $C_{n_{\delta_r}}$.

Figure 13. Concluded.



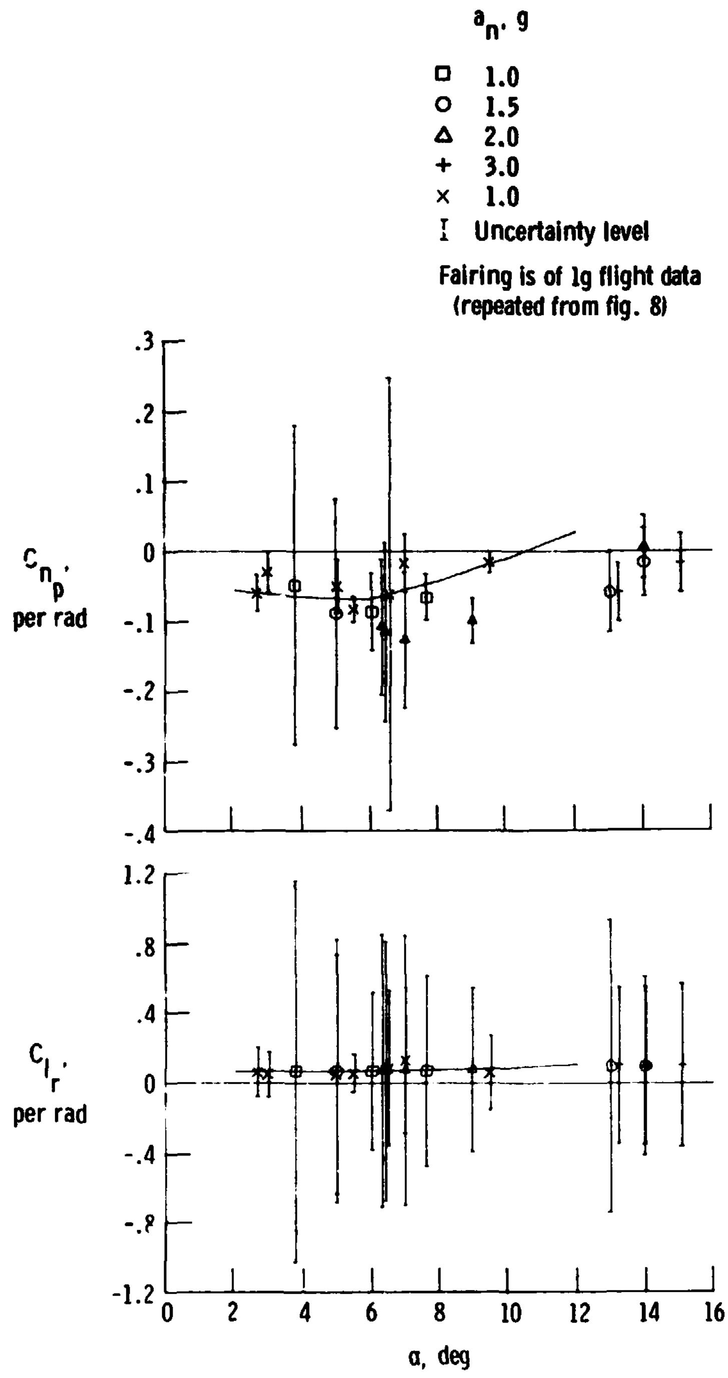
(a) C_{Y_β} and C_{l_β}.

Figure 14. Lateral-directional stability and control derivatives for elevated g flight and 35° wing sweep.



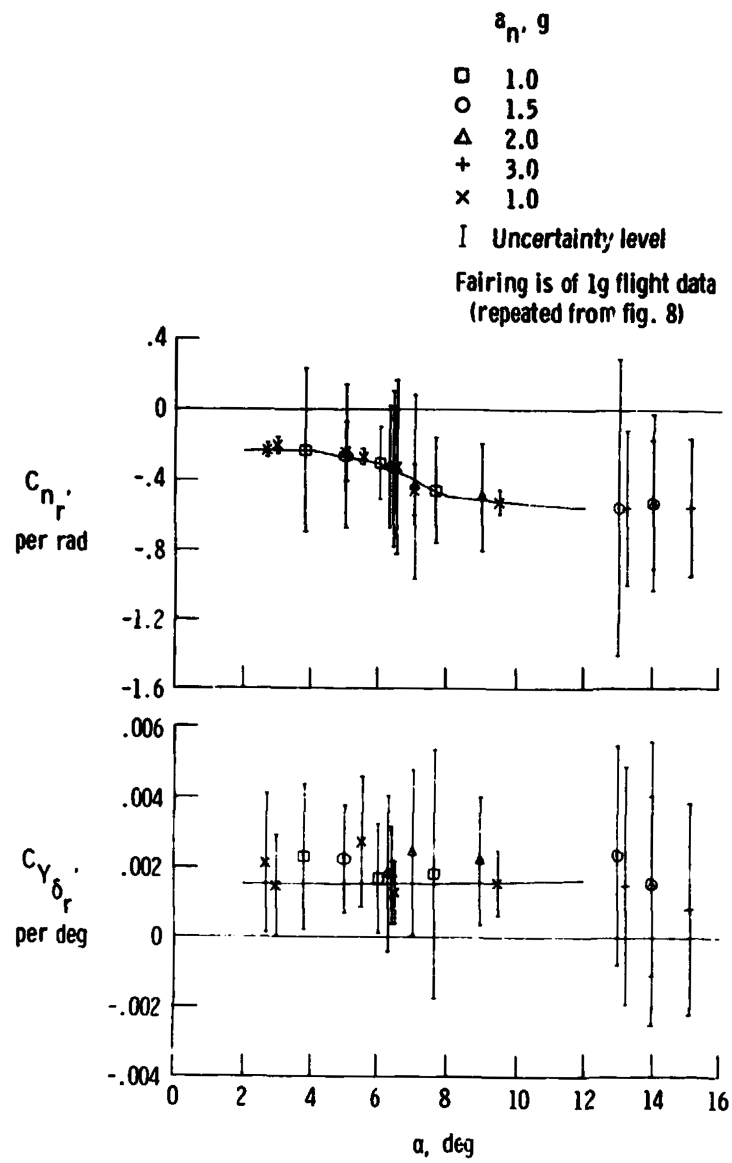
(b) C_{n_β} and C_{l_p}.

Figure 14. Continued.



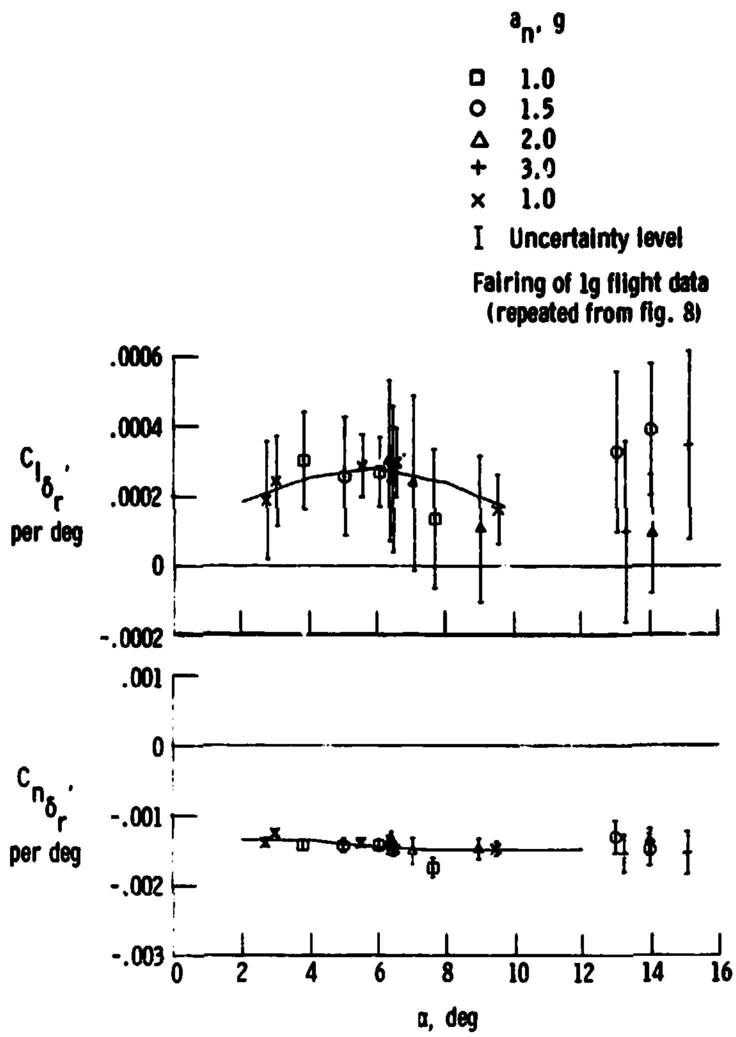
(c) C_{n_p} and C_{l_r}.

Figure 14. Continued.



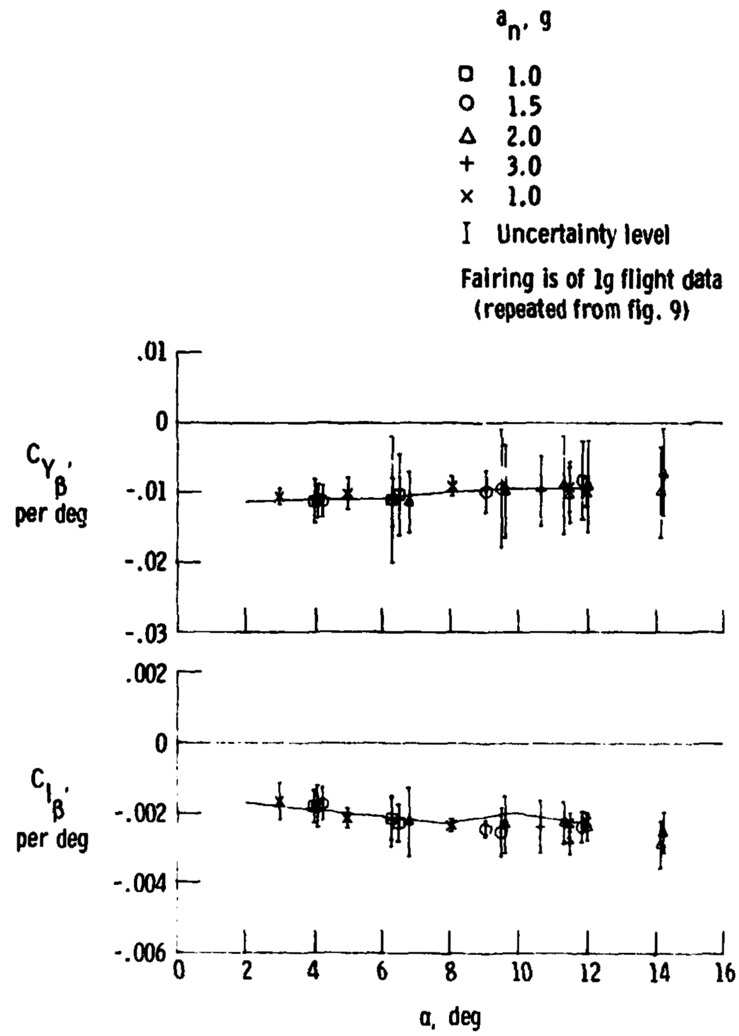
(d) C_{n_r} and $C_{Y_{\delta_r}}$.

Figure 14. Continued.



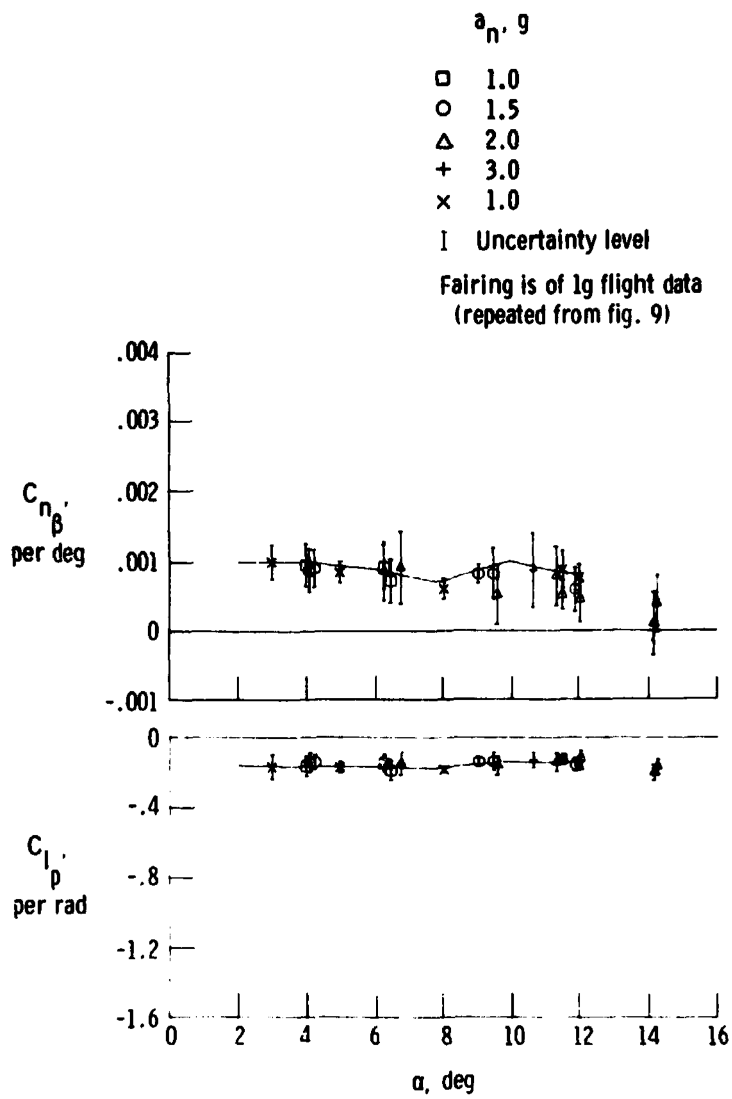
(e) $C_{l_{\delta_r}}$ and $C_{n_{\delta_r}}$.

Figure 14. Concluded.



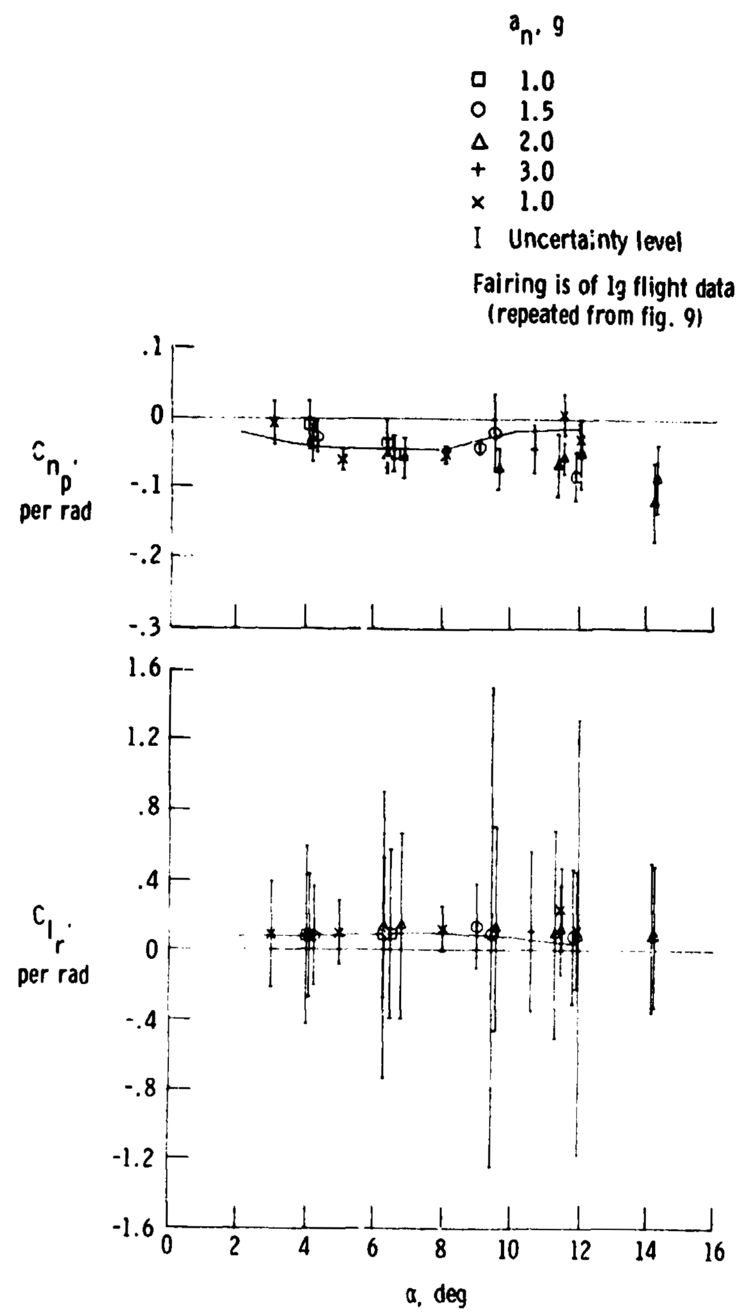
(a) C_{Y_β} *and* C_{l_β}.

Figure 15. Lateral-directional stability and control derivatives for elevated g flight and 58° wing sweep.



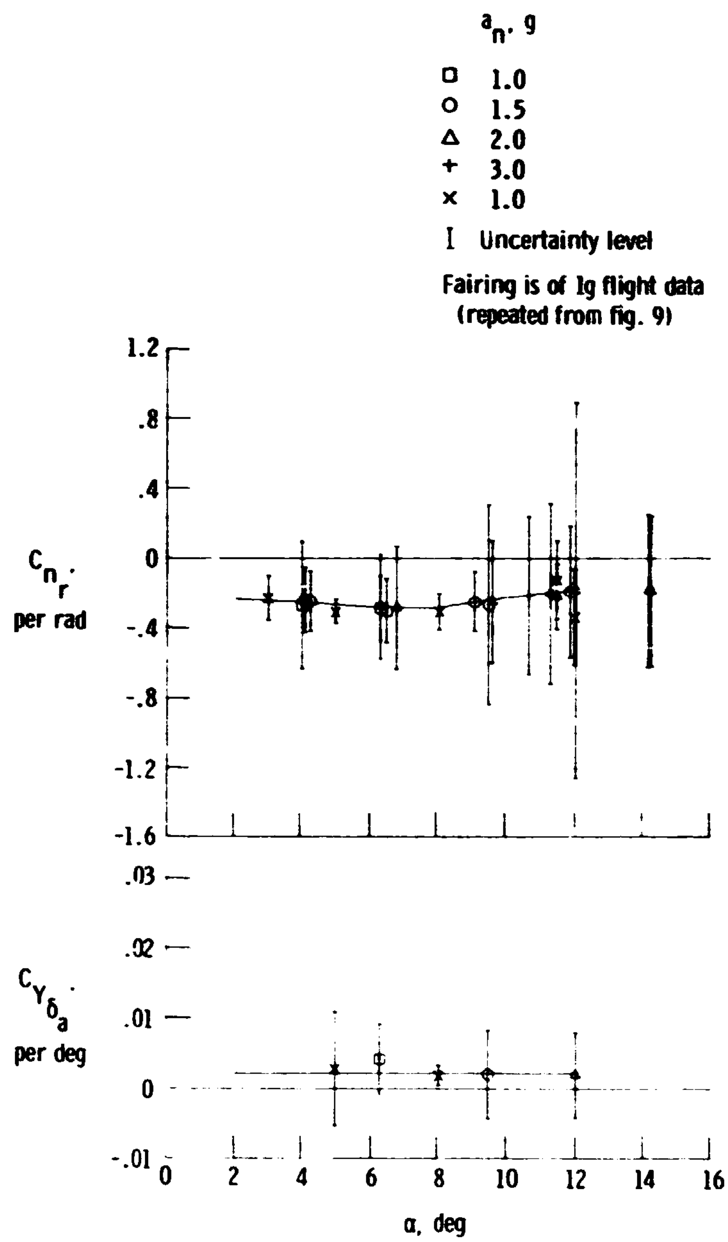
(b) C_{n_β} and C_{l_p}.

Figure 15. Continued.



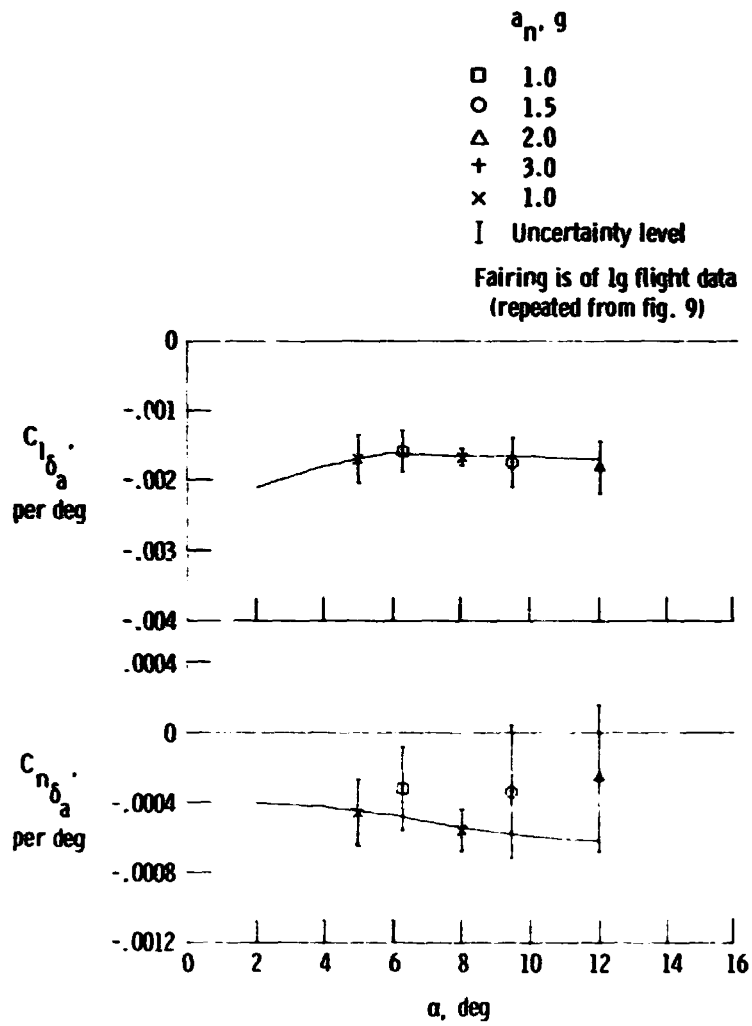
(c) C_{n_p} and C_{l_r}.

Figure 15. Continued.



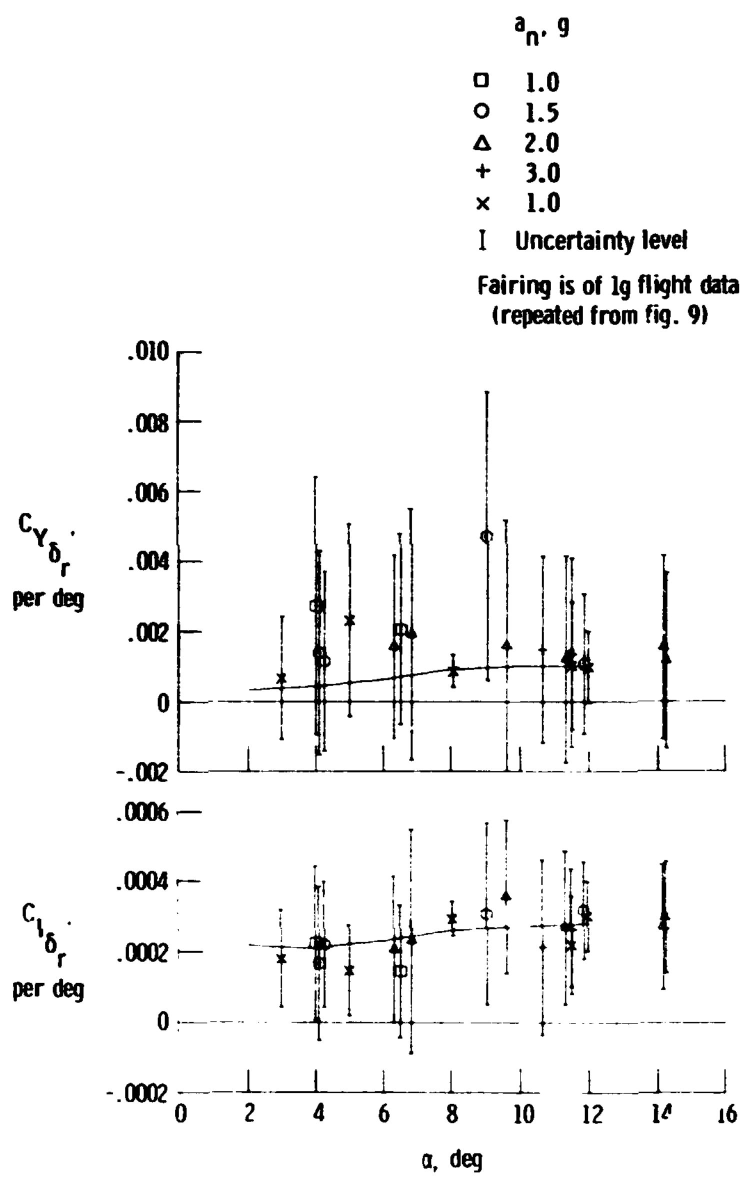
(d) C_{n_r} and $C_{Y_{\delta_a}}$.

Figure 15. Continued.



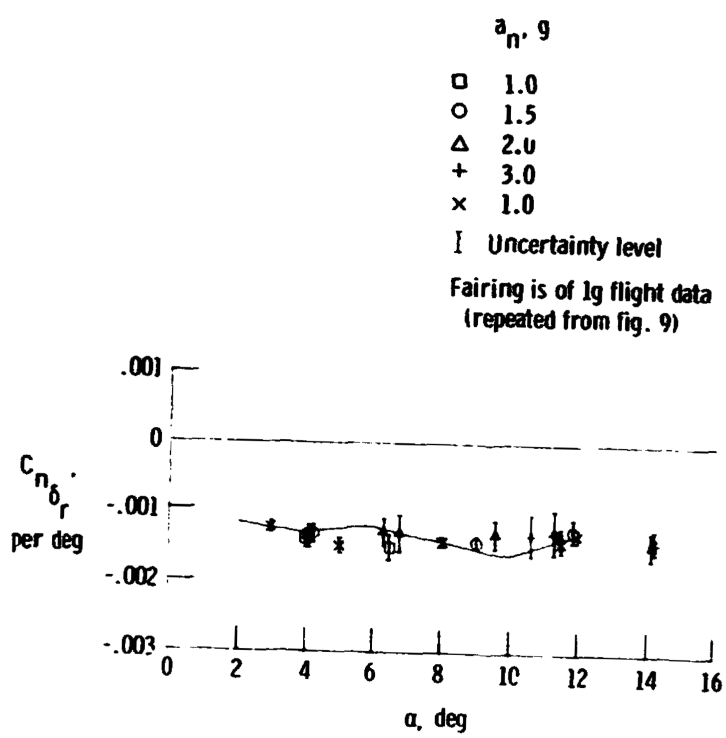
(e) $C_{l_{\delta_a}}$ and $C_{n_{\delta_a}}$.

Figure 15. Continued.



(f) $C_{Y_{\delta_r}}$ and $C_{l_{\delta_r}}$.

Figure 15. Continued.



(g) $C_{n_{\delta_r}}$.

Figure 15. Concluded.

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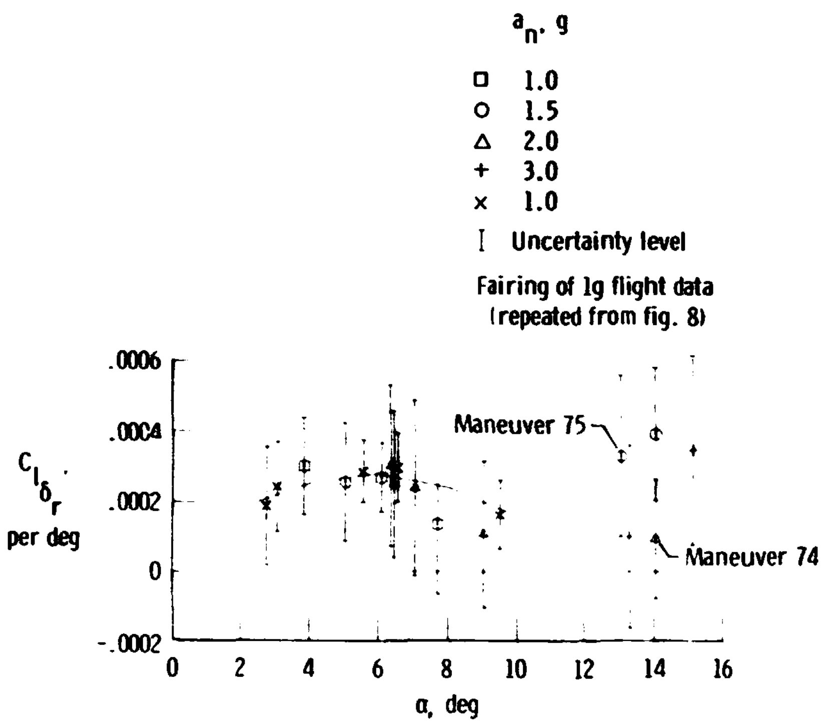

Figure 16. $C_{l_{\delta_r}}$ *as a function of angle attack, showing uncertainties at high angle of attack.*

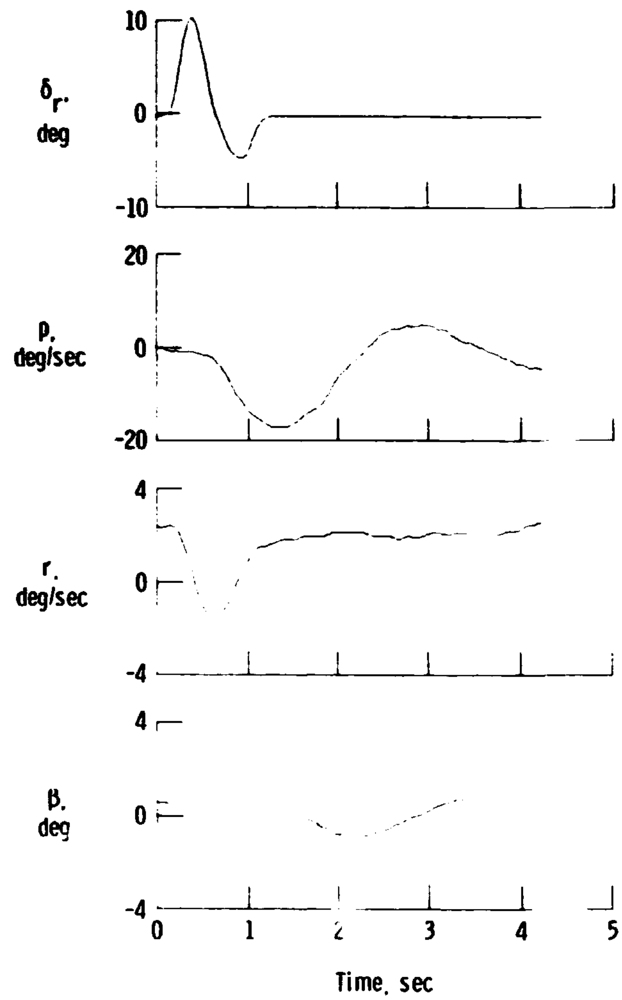

Figure 17. Time history of maneuver 74.

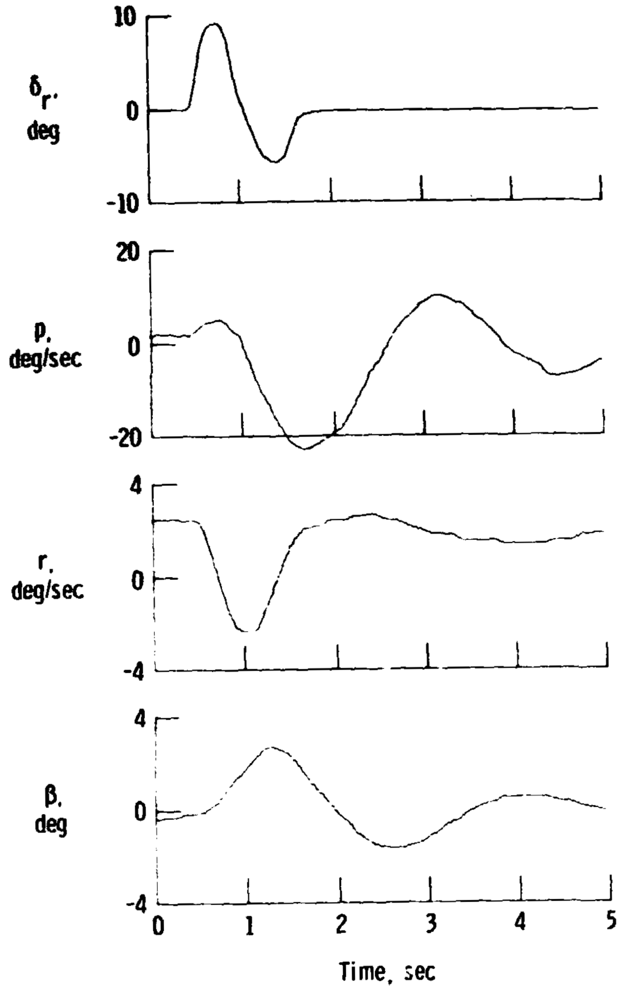

Figure 18. Time history of maneuver 75.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-72851		
4. Title and Subtitle FLIGHT-DETERMINED STABILITY AND CONTROL COEFFICIENTS OF THE F-111A AIRPLANE		5. Report Date March 1978 6. Performing Organization Code
7. Author(s) Kenneth W. Iliff, Richard E. Maine, and Sandra Thornberry Steers		8. Performing Organization Report No. H-999
9. Performing Organization Name and Address NASA Dryden Flight Research Center P.O. Box 273 Edwards, California 93523		10. Work Unit No. 505-06-64 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A complete set of linear stability and control derivatives of the F-111A airplane was determined with a modified maximum likelihood estimator. The derivatives were determined at wing-sweep angles of 26°, 35°, and 58°. The flight conditions included a Mach number range of 0.63 to 1.43 and an angle of attack range of 2° to 15°. Maneuvers were performed at normal accelerations from 0.9g to 3.8g during steady turns to assess the aeroelastic effects on the stability and control characteristics.

The derivatives generally showed consistent trends and reasonable agreement with the wind tunnel estimates. Significant Mach effects were observed for Mach numbers as low as 0.82. No large effects attributable to aeroelasticity were noted.

17. Key Words (Suggested by Author(s))	18. Distribution Statement		
F-111A airplane Stability and control derivatives Maximum likelihood estimation Flight test	Unclassified–Unlimited Category: 08		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	92	

*For sale by the National Technical Information Service, Springfield, Virginia 22161