NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2103

MAXIMUM PITCHING ANGULAR ACCELERATIONS OF AIRPLANES MEASURED IN FLIGHT

By Cloyce E. Matheny

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

Washington
May 1950

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SUMMARY

Existing flight-test data on pitching angular accelerations have been compiled. The sources from which the data were taken were manufacturer's reports, NACA papers, and unpublished tests which were conducted at the Langley Aeronautical Laboratory. The compilation has been made for conventional airplanes that had moments of inertia which ranged from 535 to 572,000 slug-feet^2. All the data available are for Mach numbers below 0.80.

In addition to the compilation, an analysis was made of the data to establish methods for determining maximum pitching accelerations. The methods presented follow several elementary approaches and include variables which are usually available at the design stage.

INTRODUCTION

Knowledge of the maximum values of pitching angular accelerations to which an airplane may be subjected is necessary in the structural design of various airplane components. For example, critical loads occur on the horizontal tail either when maximum negative angular accelerations are combined with maximum positive load factors or when maximum positive angular accelerations are combined with maximum negative load factors.

Analytical methods such as those given in references 1 to 4 are available which may be used to obtain maximum values of pitching accelerations. These methods are based on either (1) a prescribed load-factor variation, (2) a maximum constant rate of force application, or (3) a maximum constant rate of elevator motion. At the design stage, however, any of these methods are complicated by the problem of determining several aerodynamic quantities to a high degree of refinement for use in the equations of motion.

The purpose of this paper is to present existing flight-test data on maximum pitching accelerations that have been collected during the past 19 years and to analyze these data by elementary concepts in which consideration is given to the possible effects of airplane geometry, weight, load factor, and rapidity of maneuver. The results may be used in the preliminary design of an airplane.

SYMBOLS

$\ddot{\theta}$	angular acceleration in pitch, radians per second per second
$\dot{\theta}$	angular velocity in pitch, radians per second
I_Y	airplane moment of inertia in pitch, slug-feet^2
W	airplane weight, pounds
λ	time from start of maneuver to peak normal load factor, seconds
δ	elevator deflection, radians
b	horizontal surface span, feet
h_p	pressure altitude, feet
n	load factor
Δn	increment in load factor $(n - 1)$
S	gross area including area within fuselage, square feet
V_e	equivalent airspeed, miles per hour
t	time, seconds

Subscripts:

max	maximum value
min	minimum value
t	horizontal tail
meas	measured value

SCOPE OF DATA

The pitching-angular-acceleration data available for analysis were compiled from various NACA papers (references 5 to 9), from unpublished tests which were conducted at the Langley Aeronautical Laboratory, as well as from material furnished by several airplane manufacturers.

Table I presents the geometric characteristics of the airplanes considered in this analysis, which have moments of inertia that range from 535 to 572,000 slug-feet^2. The center-of-gravity position, the weight, and the moment of inertia listed therein apply at the time of the tests and are not necessarily the values used in design. Of the airplanes comprising this investigation, all are of conventional configuration and had conventional cable or rod control systems except airplane 20, which had hydraulic boost.

From the data available, only the more severe maneuvers were used. All these maneuvers were made at Mach numbers below 0.80. The following quantities for the airplanes of table I are tabulated in table II:

(1) The equivalent airspeed V_e

(2) The maximum positive increment in load factor Δn obtained in each maneuver

(3) The increment in time λ from the start of the maneuver to the maximum positive load factor

(4) The maximum rate of elevator movement $d\delta/dt$

(5) The maximum positive and negative angular acceleration $\ddot{\theta}$ obtained in the maneuver (These values do not necessarily coincide with the maximum load factor.)

(6) The maximum positive angular velocity $\dot{\theta}$ attained in the maneuver (This value occurs near the time of maximum load factor.)

(7) The pressure altitude h_p of the maneuver

(8) Remarks as to type of maneuver, degree of abruptness, and so forth

Figure 1 is illustrative of the method used in obtaining the slopes and shows a graphical representation of some of the quantities listed.

ANALYSIS AND RESULTS

A detailed examination of the more important variables indicates that the maximum pitching angular acceleration in a maneuver is a function of the following variables:

(1) Airplane mass and/or pitching moment of inertia

(2) Acceleration or load factor obtained in the maneuver

(3) Degree of abruptness of the maneuver

(4) Dynamic pressure or airspeed

(5) Stability and control characteristics of the airplane

These variables are not necessarily listed in order of their importance.

The available data on maximum angular accelerations were generally obtained as by-products of tests made for other purposes and, for this reason, no one series of tests is sufficient to define completely the influence of any one variable. The data have consequently been analyzed by simply establishing envelopes of the maximum measured values of angular accelerations obtained in various maneuvers in combination with several groupings of the main variables entering the problem.

Effect of weight.- For a series of airplanes in which all lengths vary directly as the scale, referred to hereinafter as a "geometric series of airplanes," the angular acceleration for a given airspeed and type of elevator motion should vary as a function of some geometric parameter. The possible geometric parameters might include such quantities as span, tail length, wing area, moment of inertia, weight, or wing loading. In figure 2, as well as in subsequent figures, the measured maximum values of pitching angular acceleration are plotted as a function of airplane weight. Weight instead of pitching moment of inertia was chosen as the parameter because this quantity is more easily determined in the early stages of design. The solid-line curve in figure 2 represents the relation for an exact geometric series, whereas the dashed-line curve represents a variation obtained by modifying the exponent of the weight to fit the results better. The constants have been determined so as to include all the available data.

Effect of load factor.- Theoretical studies indicate that, for a geometric series of airplanes performing a maneuver prescribed by a given load-factor variation in which the load factor reaches a maximum and quickly subsides, as for example a checked pull-up, the angular acceleration should vary directly with the peak load factor obtained, inversely with the time required to attain it, and inversely with the initial airspeed. The variation with time and airspeed, however, are more complicated functions than that for the load factor. Although all the maneuvers available for analysis were not of the same type, the next step was to plot values of $\frac{\ddot{\theta}_{meas}}{\Delta n}$ as a function of W. The solid-line curve in figure 3, which is given by the equation

$$\ddot{\theta}_{max} = 830\Delta n W^{-2/3} \tag{1}$$

represents the boundary that includes the data. As in the previous case, the exponent of W has been modified to obtain a closer envelope of the data. This envelope is given in figure 3 by the dashed line, the equation of which is

$$\ddot{\theta}_{max} = 125\Delta n W^{-1/2} \tag{2}$$

Rapidity of maneuver.- The inclusion of the load-factor increment Δn did not result in any reduction in the scatter of data nor result in the establishment of a better envelope. Successive refinements, made to include the rapidity of the maneuver and airspeed, not only failed to reduce the scatter but actually resulted in less well-defined envelopes. A plot of the time required to reach peak load factor for the various maneuvers of table I indicated (see fig. 4) that the minimum time to reach peak load factor increased as the airplane weight was increased from a minimum value of approximately 0.4 at 5,000 pounds to a value of approximately 1.4 at 75,000 pounds.

DISCUSSION

When the available data are considered, it appears that either of the empirical relations given in figures 2 and 3 could, with judgement, be used as a guide in preliminary design. The simplest relation

$$\ddot{\theta}_{max} = \frac{40000}{W} \tag{3}$$

gives values of pitching angular acceleration that exceed the maximum measured values only at low airplane weights. The relation

$$\ddot{\theta}_{max} = \frac{125}{W^{1/2}}(n - 1) \tag{4}$$

is likely to furnish values of pitching angular acceleration greater than the maximum measured values for light high-load-factor airplanes.

Both equations (3) and (4) have terms in them which are known at the design stage. Although equation (3) fits the data over a greater range of weights, it may underestimate the angular accelerations for possible future high-weight, high-load-factor airplanes. Equation (4), on the other hand, has been included as a possible relation since the effect of load factor on the maximum pitching angular acceleration is taken into consideration. The tabulated data, however, indicate that computed values of maximum pitching angular acceleration need not exceed 10.0 radians per second per second.

The failure to obtain better correlation as successive improvements were attempted can only mean that a number of factors which cannot be included in a simple approach contribute materially to the maximum angular acceleration obtained in a maneuver. The most important factor contributing to the scatter appears to be that the maneuvers considered were not all the same type, although different accuracies of the data from various sources may also have contributed to the scatter. It is apparent that the best over-all correlation between the experimental and calculated values of maximum angular accelerations would be obtained by using the values calculated from the equations of motion and by using the actual elevator deflections. The procedure of obtaining maximum angular accelerations may not be a practical one at the early design stages because the required parameters would be difficult to obtain to a high degree of accuracy.

The maximum values of pitching angular acceleration shown in figure 2 are absolute values and include the largest ones occurring in the maneuver regardless of the sign. Earlier attempts at correlation for which the positive and negative values were separated showed no reduction in the scatter. An examination of the tabulated values in table II shows that, for all practical purposes, the positive and negative values of pitching angular acceleration are the same; slightly less than 50 percent have larger negative values than positive values.

Although the assumption of the geometric series is known not to hold exactly, the results given in figure 5, in which $I_Y^{2/5}$ is given as a function of $W^{2/3}$, indicate that insofar as the relations between weight and moment of inertia for the airplanes of this investigation are concerned the assumption is justified.

The importance of the rapidity of the maneuver has been established in reference 4. If an envelope of the minimum measured values of λ had been drawn from the data in figure 4 of the present paper, the value would increase with airplane weight. This increase indicates that for the larger airplanes a greater time is taken to perform the maneuver and hence less pitching angular acceleration results, as may be seen from figure 2. Thus, W and λ_{min} appear to be interrelated.

CONCLUDING REMARKS

Available flight-test data on pitching angular acceleration have been tabulated and these results indicate the following conclusions:

1. The tabulated data indicated that the maximum pitching angular acceleration need not exceed 10.0 radians per second per second for all intentional maneuvers.

2. The assumption of a geometric series of airplanes is justified for the relationship between airplane moment of inertia and weight for the airplanes considered.

3. An analysis that followed elementary concepts by use of these tabulated data indicates that

   (a) At the design stage of an airplane, an expression involving only the weight will give a quick and fairly accurate value for the maximum pitching angular acceleration.

   (b) An expression which makes use of the weight and load factor allows for the prediction of maximum pitching angular acceleration for possible future high-weight, high-load-factor airplanes.

   (c) The minimum values of time from the start of the maneuver to peak normal load factor have been shown to be a function of airplane weight.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., March 6, 1950

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TABLE I.- GEOMETRIC CHARACTERISTICS OF AIRPLANES

Airplane	Moment of inertia, I_Y (slug-ft^2)	Weight (lb)	Wing area, S (sq ft)	Tail area, S_t (sq ft)	Wing span, b (ft)	Tail span, b_t (ft)	Center of gravity (percent M.A.C.)	Reference
1	535	1,100	179	25.3	35.2	9.5	27.1	Unpublished
2	550	1,050	180	25.8	36.0	10:0	27.1	Unpublished
3	1,790	2,582	252	32.9	31.5	10.5	------	5
4	1,875	2,960	252	32.9	31.5	10.5	------	6
5	1,875	2,970	241	29.8	32.0	10.0	------	7
6	4,204	4,775	310	42.2	34.5	-----	22.1	Unpublished
7	4,267	4,662	205	43.2	35.0	12.0	32.0	Unpublished
8	5,000	4,600	248	49.0	42.0	13.0	34.0	Unpublished
9	5,278	5,330	327	44.8	33.3	13.0	20.3	Unpublished
10	6,380	7,600	213	41.0	34.0	13.0	30.3	3
11	7,000	7,780	233	42.0	37.0	13.18	Varied	Unpublished
12	7,200	7,074	130	26.0	28.0	11.4	25.0	Unpublished
13	7,995	6,220	305	40.2	42.0	13.33	24.4	Unpublished
14	8,000	8,800	240	41.0	37.0	13.18	26.4	Unpublished
15	8,800	8,243	236	48.6	37.3	12.8	30.0	8
16	15,600	12,000	423	107.4	50.0	19.04	27.0	Unpublished
17	100,000	32,050	664	-----	65.0	-----	20.3	Unpublished
18	163,750	48,000	1,048	198.0	110.0	26.0	29.0	Unpublished
19	314,200	45,000	1,407	242.0	118.0	28.0	28.0	9
20	572,000	72,000	1,654	463.6	123.0	50.0	Varied	Unpublished

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TABLE II.- TABULATION OF FLIGHT DATA

Airplane	Speed, V_o (mph)	Load-factor increment, Δn	Time to reach peak load, λ (sec)	Max. elevator rate, $d\delta/dt$ (radians/sec)	Angular acceleration (radians/sec²)		Angular velocity, $\dot{\theta}$ (radians/sec)	Pressure altitude, h_p (ft)	Remarks
					$+\ddot{\theta}$	$-\ddot{\theta}$			
1	74	2.95	0.65	2.44	6.90	----	1.55	------	Abrupt pull-up, power on
	74	2.90	.65	3.51	5.70	----	1.48	------	Abrupt pull-up, power on
2	78	3.25	.65	3.84	6.30	----	1.20	------	Abrupt pull-up, power on
	77	2.60	.65	2.27	6.00	----	1.10	------	Abrupt pull-up, power off
3	130	6.80	.80	3.00	3.40	2.20	1.74	------	Abrupt pull-out
	140	7.50	.83	1.50	5.80	3.00	2.50	------	Abrupt pull-out
	175	9.30	.75	2.09	7.00	3.60	1.80	------	Abrupt pull-out
	80	1.90	.80	1.40	2.70	1.75	1.00	------	Abrupt pull-up
	80	1.80	1.00	1.22	2.85	1.75	.85	------	Intermediate pull-up
	125	5.20	.65	2.27	3.30	2.00	1.60	------	Abrupt pull-up
	125	3.30	1.50	.27	1.60	----	.85	------	Intermediate pull-up
	150	6.80	.60	1.68	3.80	1.82	1.66	------	Abrupt pull-up
	150	5.80	.65	1.50	3.30	2.00	1.48	------	Intermediate pull-up
4	140	7.50	1.25	4.00	4.80	1.30	1.45	------	Abrupt pull-out
	137	5.20	3.00	.52	1.00	----	.70	------	Pull-out
	135	5.70	.60	2.19	3.70	4.00	1.50	------	Abrupt pull-up
	130	3.70	1.80	.18	1.00	1.40	.84	------	Intermediate pull-up
	120	4.00	.53	3.49	4.00	4.00	1.30	------	Abrupt pull-up
	117	2.80	1.70	.16	1.00	----	.73	------	Intermediate pull-up
	90	2.00	.60	----	3.30	2.00	1.10	------	Abrupt pull-up
5	79	.80	1.13	1.54	.80	----	.50	------	Abrupt pull-up, power on
	94	1.50	1.07	2.27	1.80	1.10	.68	------	Abrupt pull-up, power on
	100	1.80	1.00	1.75	1.40	1.20	.70	------	Abrupt pull-up, power on
	110	2.00	1.13	1.50	1.30	1.37	.80	------	Abrupt pull-up, power on
	116	2.80	1.13	2.44	2.30	----	1.12	------	Abrupt pull-up, power on, stall
	126	3.60	.90	2.44	2.70	2.00	1.28	------	Abrupt pull-up, power on, stall
	137	3.95	.92	2.00	2.60	2.35	1.31	------	Abrupt pull-up, power on, stall
	149	5.30	.80	2.96	2.80	1.82	1.40	------	Abrupt pull-up, power on, stall
	154	5.60	.65	2.83	4.60	2.25	1.44	------	Abrupt pull-up, power on
	163	6.30	.87	2.27	3.60	3.20	1.60	------	Abrupt pull-up, power on, stall
	172	7.30	.87	1.36	3.80	2.62	1.64	------	Abrupt pull-up, power on
	181	8.00	.87	4.00	5.50	3.00	1.68	------	Abrupt pull-up, power on
	105	1.40	2.37	.23	.40	----	.37	------	Pull-up, power off
	105	1.90	2.00	.30	.70	----	.70	------	Pull-up, power off
	73	.75	1.13	2.58	.90	----	.51	------	Abrupt pull-up, power off
	93	1.70	.82	4.54	1.80	----	.82	------	Abrupt pull-up, power off
	103	2.40	1.13	1.96	2.30	1.51	.96	------	Abrupt pull-up, power off
	118	2.80	.80	5.75	2.90	2.40	1.10	------	Abrupt pull-up, power off
	135	4.50	.87	4.88	4.10	2.38	1.26	------	Abrupt pull-up, power off
	160	5.60	.80	4.34	4.20	3.25	1.28	------	Abrupt pull-up, power off
	184	6.70	.82	2.70	4.80	3.75	1.40	------	Abrupt pull-up, power off
6	134	3.60	.90	2.67	3.75	2.60	1.07	4,000	Abrupt pull-up, level flight
	148	4.60	.82	2.37	4.81	4.35	1.20	4,000	Abrupt pull-up, level flight
	164	5.60	.85	3.06	5.60	3.54	1.27	4,000	Abrupt pull-up, level flight
	133	3.50	.75	3.00	3.60	1.87	1.00	4,000	Abrupt pull-up, level flight
	150	4.50	.70	2.91	4.82	1.95	1.13	4,000	Abrupt pull-up, level flight
	164	5.40	.70	3.76	5.25	2.73	1.19	4,000	Abrupt pull-up, level flight
	138	5.40	1.05	1.04	2.85	1.10	1.11	4,550	Abrupt dive pull-out
	152	6.00	.80	2.79	2.75	2.27	1.25	9,150	Abrupt dive pull-out
	170	6.30	1.14	1.35	2.05	1.00	1.01	5,200	Abrupt dive pull-out
	212	6.10	.70	1.31	3.53	1.30	.90	5,730	Abrupt dive pull-out
	300	5.10	.48	1.31	2.00	.90	.53	6,160	Abrupt dive pull-out
	222	6.90	.70	1.18	3.95	.74	.93	8,000	Abrupt dive pull-out

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TABLE II.- TABULATION OF FLIGHT DATA - Continued

Airplane	Speed, V_c (mph)	Load-factor increment, Δn	Time to reach peak load, λ (sec)	Max. elevator rate, $d\delta/dt$ (radians/sec)	Angular acceleration (radians/sec^2)		Angular velocity, $\dot{\theta}$ (radians/sec)	Pressure altitude, h_p (ft)	Remarks
					$+\ddot{\theta}$	$-\ddot{\theta}$			
7	164	3.30	0.75	1.92	4.25	5.40	----	------	Abrupt pull-up, level flight
	176	3.70	.75	1.47	3.70	6.00	----	------	Abrupt pull-up, level flight
	184	4.20	.68	2.66	4.65	5.65	----	------	Abrupt pull-up, level flight
	182	4.10	.66	3.14	4.65	6.75	----	------	Abrupt pull-up, level flight
	193	4.60	.60	3.14	4.85	6.80	----	------	Abrupt pull-up, level flight
	208	4.60	.71	1.26	3.65	4.55	----	------	Abrupt dive pull-out
	212	4.60	.88	1.15	2.45	3.30	.72	------	Abrupt dive pull-out
	228	5.50	.95	.86	2.00	4.90	.74	------	Abrupt dive pull-out
	271	5.60	.80	1.15	2.90	6.08	.69	------	Abrupt dive pull-out
	219	5.30	.76	1.54	3.40	4.50	.83	------	Abrupt dive pull-out
	238	5.50	.90	1.22	2.20	4.05	.75	------	Abrupt dive pull-out
8	100	1.30	1.25	.42	.60	----	----	6,000	Mild pull-ups, cam-actuated control
	109	1.80	1.35	.43	.80	----	----	6,040	Mild pull-ups, cam-actuated control
	121	2.20	1.37	.44	.90	----	----	6,000	Mild pull-ups, cam-actuated control
	137	2.80	1.27	.46	1.00	----	----	6,000	Mild pull-ups, cam-actuated control
	147	3.30	1.30	.46	1.00	----	----	6,000	Mild pull-ups, cam-actuated control
9	197	4.40	1.03	1.06	1.70	.67	.56	6,050	Dive pull-out
	221	4.70	.86	1.23	2.65	.52	.62	9,600	Dive pull-out, stick release
	206	5.90	1.25	2.00	4.10	.75	.75	6,950	Dive pull-out, stick release
	277	6.90	.63	1.90	6.10	.62	.70	6,350	Dive pull-out, stick release
	133	3.30	.80	3.50	4.38	2.34	1.11	6,350	Abrupt pull-up, level flight
	138	3.50	.90	3.56	3.80	1.85	.94	6,900	Abrupt pull-up, glide stall
10	358	5.60	.50	.95	2.50	3.40	.60	20,400	Pull-up
	262	4.40	.50	1.66	4.00	4.40	.90	24,700	Pull-up
	378	5.00	.60	.44	1.30	1.51	.30	10,200	Pull-up
11	406	3.10	1.40	.12	.66	----	.21	19,400	Pull-out
	435	6.00	.90	.12	1.23	----	.44	19,400	Pull-out
	463	3.80	.75	.15	.90	----	.27	19,400	Pull-out
	403	5.00	.90	.24	1.27	----	.40	19,900	Pull-out
	497	2.20	.60	.03	.28	----	.18	18,750	Pull-out
	510	2.50	.60	.06	.60	----	.19	18,250	Pull-out
	502	4.30	1.10	.07	.22	----	.20	19,500	Pull-out
	527	2.00	1.05	.05	.17	----	.16	18,600	Pull-out
	516	2.60	1.25	.03	.10	----	.09	19,000	Pull-out
	408	5.90	1.45	.04	.60	----	.44	19,600	Pull-out
	454	5.20	1.60	.04	.28	----	.28	18,950	Pull-out
	383	3.80	1.25	.09	.69	----	.64	19,850	Pull-out
	535	4.60	2.05	.02	.09	----	.19	16,900	Pull-out
12	435	6.00	.42	.66	1.50	2.20	.60	14,000	Acceptance tests, pull-up
	440	7.30	.66	.55	1.40	2.25	.65	11,600	Abrupt-stall buffeting pull-up
13	97	1.30	1.10	3.78	1.78	1.40	.68	3,600	Abrupt pull-up, full stick
	126	2.70	.91	2.94	3.05	4.33	1.02	3,750	Abrupt pull-up, power on
	144	3.80	.85	3.22	3.60	5.43	1.25	3,900	Abrupt pull-up
	164	5.00	.78	3.57	4.10	4.30	1.41	3,450	Abrupt pull-up
	184	6.30	.73	3.79	4.50	4.80	1.30	3,400	Abrupt pull-up
	148	3.80	.91	1.82	2.60	3.15	1.15	9,500	Pull-out, power off, full stick
	338	10.00	.90	.23	1.70	1.55	.95	5,400	70° dive pull-out
	280	4.40	.90	.11	.60	.20	.37	6,800	Dive pull-out
	300	6.20	.60	1.74	3.10	.59	.70	5,800	65° dive pull-out
	193	3.20	1.20	1.00	2.10	.20	.47	7,580	Pull-out, glide

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TABLE II.- TABULATION OF FLIGHT DATA - Continued

Airplane	Speed, V_e (mph)	Load-factor increment, Δn	Time to reach peak load, λ (sec)	Max. elevator rate, $d\delta/dt$ (radians/sec)	Angular acceleration (radians/sec^2)		Angular velocity, $\dot{\theta}$ (radians/sec)	Pressure altitude, h_p (ft)	Remarks
					$+\ddot{\theta}$	$-\ddot{\theta}$			
14	192	2.60	0.60	0.93	1.70	----	----	15,000	Abrupt pull-up
	192	2.60	.55	1.08	1.83	----	----	15,000	Abrupt pull-up
	199	2.60	.70	.53	1.31	----	----	15,000	Abrupt pull-up
	199	2.70	.70	.61	1.43	----	----	15,000	Abrupt pull-up
	214	3.40	.73	.57	1.40	----	----	10,000	Abrupt pull-up
	214	3.20	.76	.42	1.20	----	----	10,000	Abrupt pull-up
	214	3.60	.70	.60	1.59	----	----	10,000	Abrupt pull-up
	185	2.10	.70	1.11	1.51	----	----	22,500	Abrupt pull-up
	185	2.10	.75	.95	1.34	----	----	22,500	Abrupt pull-up
	185	1.70	.55	.79	1.37	----	----	22,500	Abrupt pull-up
	141	1.10	.61	1.14	1.21	----	----	30,000	Abrupt pull-up
	141	1.00	.78	.46	1.00	----	----	30,000	Abrupt pull-up
	141	1.30	.55	1.52	1.30	----	----	30,000	Abrupt pull-up
	164	1.5	----	.75	1.40	----	0.47	19,900	Abrupt push-over, pull-ups at increasing Mach numbers
	210	2.3	----	.64	1.60	----	.44	20,200	
	210	2.6	----	.62	1.43	----	.49	20,400	
	236	3.2	----	.44	1.33	----	.51	19,800	
	263	3.8	----	.42	1.74	----	.53	20,100	
	324	5.1	----	.64	2.32	----	.47	19,200	
	338	4.4	----	.35	1.70	----	.42	19,500	
	347	5.4	----	.41	2.22	----	.44	19,850	
	358	4.7	----	.31	1.40	----	.39	19,800	
	368	4.7	----	.39	2.38	----	.40	20,200	
	373	4.1	----	.49	2.20	----	.34	20,300	
	379	4.1	----	.66	3.20	----	.35	20,250	
	375	4.6	----	.50	2.44	----	.40	18,900	
	178	1.2	----	.68	1.58	----	.49	29,300	Abrupt push-over, pull-ups at increasing Mach numbers at high altitude
	197	1.8	----	.86	2.04	----	.52	29,500	
	286	4.0	----	.34	2.13	----	.48	29,000	
	261	2.3	----	.19	1.83	----	.40	29,400	
	315	3.5	----	.21	2.00	----	.38	28,150	
	330	2.4	----	.18	1.56	----	.27	27,400	
	196	2.4	.87	.50	1.32	----	----	30,400	Abrupt pull-ups, buffeting
	220	2.9	.77	.33	1.80	----	----	29,900	Abrupt pull-ups, buffeting
	231	3.5	1.00	.26	1.78	----	----	29,500	Abrupt pull-up, stall
	268	4.7	.93	.27	1.60	----	----	28,200	Abrupt pull-up
	152	1.0	.95	1.04	1.44	----	----	31,000	Abrupt pull-out
	167	1.5	1.00	.90	1.80	----	----	30,600	Abrupt pull-out
	189	1.9	.95	1.14	2.14	----	----	30,600	Abrupt pull-out
	208	2.5	1.00	.74	2.15	----	----	30,700	Abrupt pull-out, severe buffeting
	196	2.2	.90	.71	2.00	----	----	30,500	Abrupt pull-out
	226	3.2	.85	.66	2.10	----	----	29,600	Abrupt pull-out
	233	3.6	.90	.66	2.20	----	----	29,600	Abrupt pull-out
	255	4.3	.85	.58	2.65	----	----	29,600	Abrupt pull-out
	224	3.2	.90	.50	2.03	----	----	29,600	Abrupt pull-out
	234	3.8	.80	.79	2.35	----	----	29,600	Abrupt pull-out
	252	4.3	.75	.59	2.43	----	----	29,600	Abrupt pull-out
	272	4.7	.90	.29	2.09	----	----	29,300	Abrupt pull-out, vicious right roll
	279	4.2	1.20	.21	1.38	----	----	29,600	Abrupt pull-out

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TABLE II.- TABULATION OF FLIGHT DATA - Continued

Airplane	Speed, V_e (mph)	Load-factor increment, Δn	Time to reach peak load, λ (sec)	Max. elevator rate, $d\delta/dt$ (radians/sec)	Angular acceleration (radians/sec²) $+\ddot{\theta}$	Angular acceleration (radians/sec²) $-\ddot{\theta}$	Angular velocity, $\dot{\theta}$ (radians/sec)	Pressure altitude, h_p (ft)	Remarks
15	126	0.8	0.80	2.93	1.2	----	0.59	25,100	Abrupt pull-up
	156	1.9	.70	2.82	2.5	----	.69	25,200	Abrupt pull-up
	184	2.6	.80	2.05	2.4	----	.62	25,250	Abrupt pull-up
	111	.8	.84	3.07	1.3	----	.49	25,000	Abrupt pull-up
	158	2.0	.70	2.58	1.8	----	.74	24,900	Abrupt pull-up
	182	2.6	.75	2.79	2.1	----	.78	24,400	Abrupt pull-up
	188	2.2	.88	1.40	2.2	----	.50	9,000	Pull-up
	186	2.9	.80	1.88	2.6	----	.49	9,000	Pull-up
	184	2.6	.82	----	2.2	----	.40	9,000	Pull-up
	183	2.8	.77	----	2.5	----	.60	9,000	Pull-up
	211	3.3	.85	1.12	1.8	----	.41	7,020	Pull-up
	213	3.8	.80	1.61	2.6	----	.51	7,000	Pull-up
	209	4.1	.85	1.26	2.3	----	.60	6,970	Pull-up
	232	4.4	.80	1.40	2.5	----	.46	6,800	Pull-up
	241	1.1	1.05	.42	.8	----	.25	8,500	Pull-up
	241	1.5	1.35	.39	.9	----	.29	8,670	Pull-up
	241	3.8	.95	.38	.9	----	.44	8,670	Pull-up
	161	1.4	1.25	.98	.7	----	.15	7,800	Pull-up
	163	2.1	1.60	1.40	.9	----	.35	7,700	Stalled pull-up
	161	1.2	1.50	.89	.5	----	.18	7,900	Pull-up
	293	3.8	1.20	.18	.5	----	.26	7,000	Pull-out
	288	4.6	1.05	.31	.9	----	.35	7,000	Pull-out
	297	4.0	2.05	.07	.3	----	.25	7,000	Pull-out
	293	4.3	1.60	.09	.5	----	.28	7,000	Pull-out
	290	3.9	1.80	.11	.4	----	.33	7,000	Pull-out
	290	4.0	1.45	.19	.6	----	.30	6,000	Pull-out
	285	4.5	.80	.45	1.2	----	.39	7,500	Pull-out
	286	3.8	2.50	.04	.3	----	.30	7,500	Pull-out
	260	2.8	.93	.38	.7	----	.32	8,500	Pull-out
	252	4.1	1.00	.38	.8	----	.40	8,000	Pull-out
	227	3.8	1.35	.30	.8	----	.31	8,900	Pull-out
	236	3.5	1.00	.82	1.2	----	.41	9,000	Pull-out
	275	2.9	.95	.49	.7	----	.24	7,500	Pull-out
	263	3.0	1.00	.35	.6	----	.33	7,500	Pull-out
	259	3.7	1.05	.34	.7	----	.32	7,500	Pull-out
	259	3.1	1.10	.27	.7	----	.27	7,500	Pull-out
	288	2.7	.90	.27	.8	----	.07	7,300	Pull-out
	296	2.9	1.10	.19	.5	----	.23	------	Pull-out
	261	3.4	1.30	.28	.6	----	.20	8,500	Pull-out
	---	3.2	1.15	----	.6	----	.26	8,500	Pull-out
	253	3.1	1.00	----	1.1	----	.28	4,500	Pull-out
	241	3.3	1.10	----	1.0	----	.32	6,500	Pull-out
	227	3.0	1.25	----	.7	----	.33	7,000	Pull-out
	231	3.7	1.14	----	1.0	----	.41	7,000	Pull-out
	291	3.6	1.00	----	.6	----	.20	7,000	Pull-out
	290	3.6	.90	----	.6	----	.28	8,100	Pull-out
	284	2.9	1.10	----	.5	----	.22	8,000	Pull-out
	289	3.5	1.25	----	.5	----	.28	8,000	Pull-out
	373	4.5	1.55	----	.5	----	.26	6,000	Pull-out
	379	4.7	1.40	----	.3	----	----	6,000	Pull-out
	384	4.7	1.90	----	.3	----	.22	5,000	Pull-out
	263	4.6	1.00	----	1.1	----	.36	8,400	Pull-out
	289	4.9	1.30	----	.6	----	.34	8,000	Pull-out

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TABLE II.- TABULATION OF FLIGHT DATA - Concluded

Airplane	Speed, V_e (mph)	Load-factor increment, Δn	Time to reach peak load, λ (sec)	Max. elevator rate, $d\delta/dt$ (radians/sec)	Angular acceleration (radians/sec^2) $+\ddot{\theta}$	$-\ddot{\theta}$	Angular velocity, $\dot{\theta}$ (radians/sec)	Pressure altitude, h_p (ft)	Remarks
16	396	4.4	2.00	0.02	0.50	----	----	8,800	Pull-out
	400	5.7	1.57	.04	.40	----	0.28	8,670	Pull-out
	280	4.2	2.00	.03	.40	----	.45	7,000	Split flaps, pull-out
	160	2.8	.70	.40	1.83	----	1.16	12,250	Stall pull-up
	333	5.0	1.25	.09	.74	----	.42	7,000	Pull-out
	290	6.2	1.37	.22	.72	----	.55	4,800	Pull-out
	335	4.0	3.37	.02	.50	----	----	8,200	Pull-out
17	210	1.9	.98	1.80	.64	1.00	----	10,000	Sharp pull-up
	210	2.1	.93	1.92	.88	.96	----	10,000	Sharp pull-up
	240	2.2	1.10	.80	.89	1.23	----	10,000	Sharp pull-up
	240	2.6	1.10	.52	.87	.72	----	10,000	Sharp pull-up
	270	1.9	1.00	.61	.64	.42	----	10,000	Sharp pull-up
	270	2.1	.97	.47	.60	.91	----	10,000	Sharp pull-up
	300	2.1	.87	.28	.63	.81	----	10,000	Sharp pull-up
	300	2.0	.98	.52	.92	.90	----	10,000	Sharp pull-up
	330	1.9	.75	.37	.86	.81	----	10,000	Sharp pull-up
	330	2.0	.96	.30	.48	1.11	----	10,000	Sharp pull-up
18	200	1.0	1.50	.52	.43	----	.18	9,500	Pull-out
	250	.7	1.50	.09	.21	----	.11	9,500	Pull-out
	255	1.6	1.85	----	.74	----	.20	9,500	Pull-out
	195	1.1	1.75	.31	.30	----	.13	9,500	Pull-out
	254	1.5	1.35	.33	.36	----	.15	9,500	Pull-out
	254	1.7	1.85	.36	.48	----	.17	9,500	Pull-out
	190	.8	2.00	.35	.29	----	.09	9,500	Pull-out
	255	1.5	2.00	.09	.17	----	.12	9,500	Pull-out
	196	1.2	1.50	.26	.29	----	.18	9,500	Pull-out
	252	1.2	1.40	.32	.48	----	.17	9,500	Pull-out
19	184	1.9	1.50	1.17	.67	.65	.30	8,500	Pull-up
	184	1.8	1.60	1.14	.54	.45	.30	8,500	Pull-up
	184	1.1	1.00	1.19	.52	.24	.23	8,500	Pull-up
	184	1.6	1.10	1.22	.95	.71	.27	8,500	Pull-up
	201	2.0	1.35	.87	.50	.37	.28	8,500	Pull-up
	201	1.8	1.30	1.20	.97	.42	.26	8,500	Pull-up
	201	1.5	1.15	.82	.58	.20	.23	8,500	Pull-up
	201	1.8	1.17	1.05	.65	.37	.27	8,500	Pull-up
	219	1.9	1.20	.87	.95	.28	.25	8,500	Pull-up
	219	1.6	.95	.79	.55	.40	.23	8,500	Pull-up — A study in control motion of abrupt pull-ups and recovery
	219	1.7	1.15	.89	.70	.32	.23	8,500	Pull-up
	219	1.7	1.00	.79	.58	.35	.23	8,500	Pull-up
	184	1.6	1.35	.60	.62	.21	.25	8,500	Pull-up
	184	1.7	1.30	.87	.50	.42	.29	8,500	Pull-up
	184	1.6	1.25	.86	.53	.21	.25	8,500	Pull-up
	184	1.5	1.15	.84	.52	.33	.26	8,500	Pull-up
	201	2.1	1.25	.86	.50	.34	.28	8,500	Pull-up
	201	1.5	1.00	.75	.61	.30	.23	8,500	Pull-up
	201	2.1	1.30	.77	.46	----	.28	8,500	Pull-up
20	196	1.1	1.90	.30	.26	.16	----	5,000	Intermediate pull-up
	166	1.1	1.65	.56	.35	.21	----	3,000	Intermediate pull-up
	178	.9	1.45	.80	.43	.21	----	10,100	Abrupt pull-up
	230	1.7	2.50	.13	.16	.26	----	10,000	Stall, mild pull-up
	189	.7	1.70	.24	.22	.09	----	10,000	Mild pull-up
	189	1.2	1.65	.95	.49	.16	----	9,500	Abrupt pull-up
	191	1.5	1.50	.81	.51	.29	----	9,500	Abrupt pull-up

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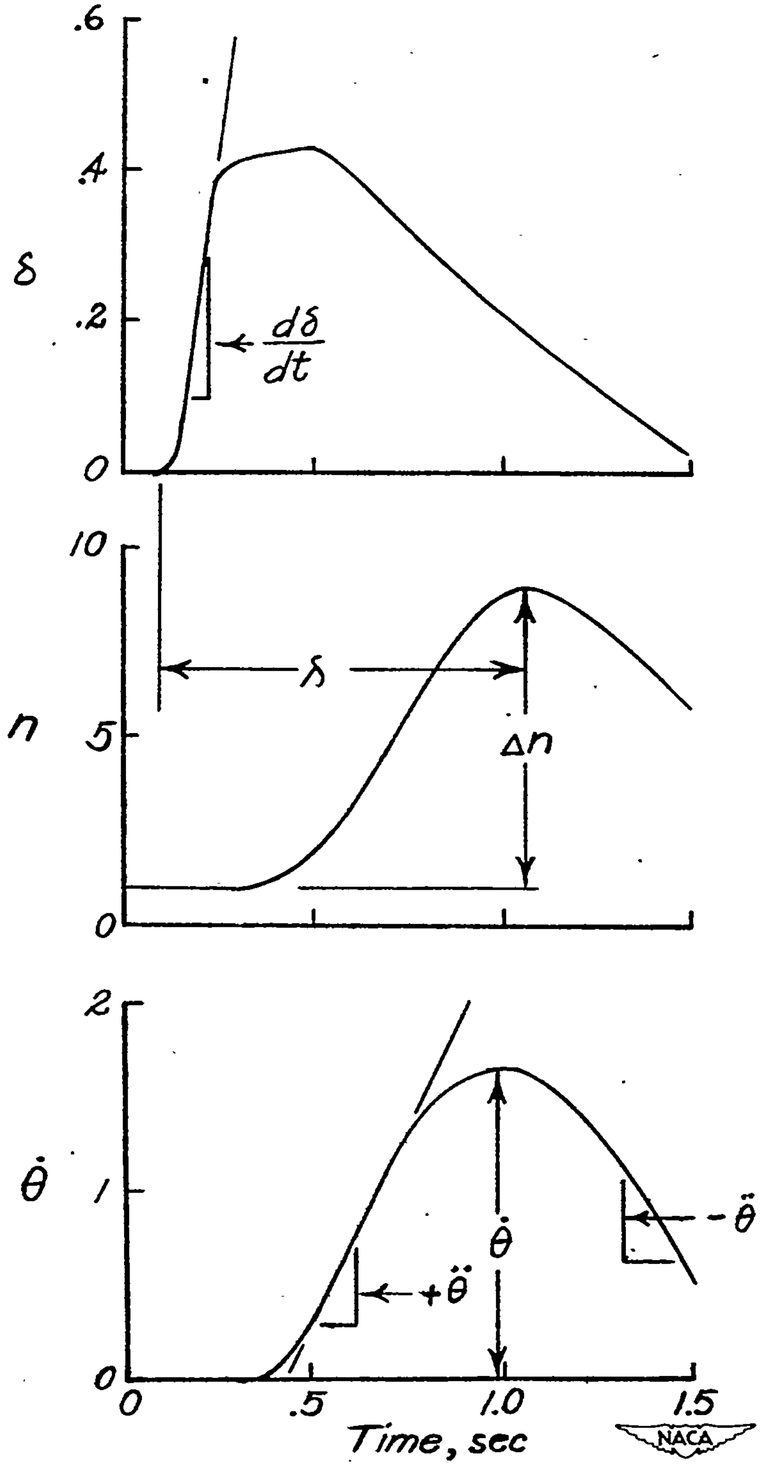

Figure 1.- Typical time histories showing method by which the slopes were taken.

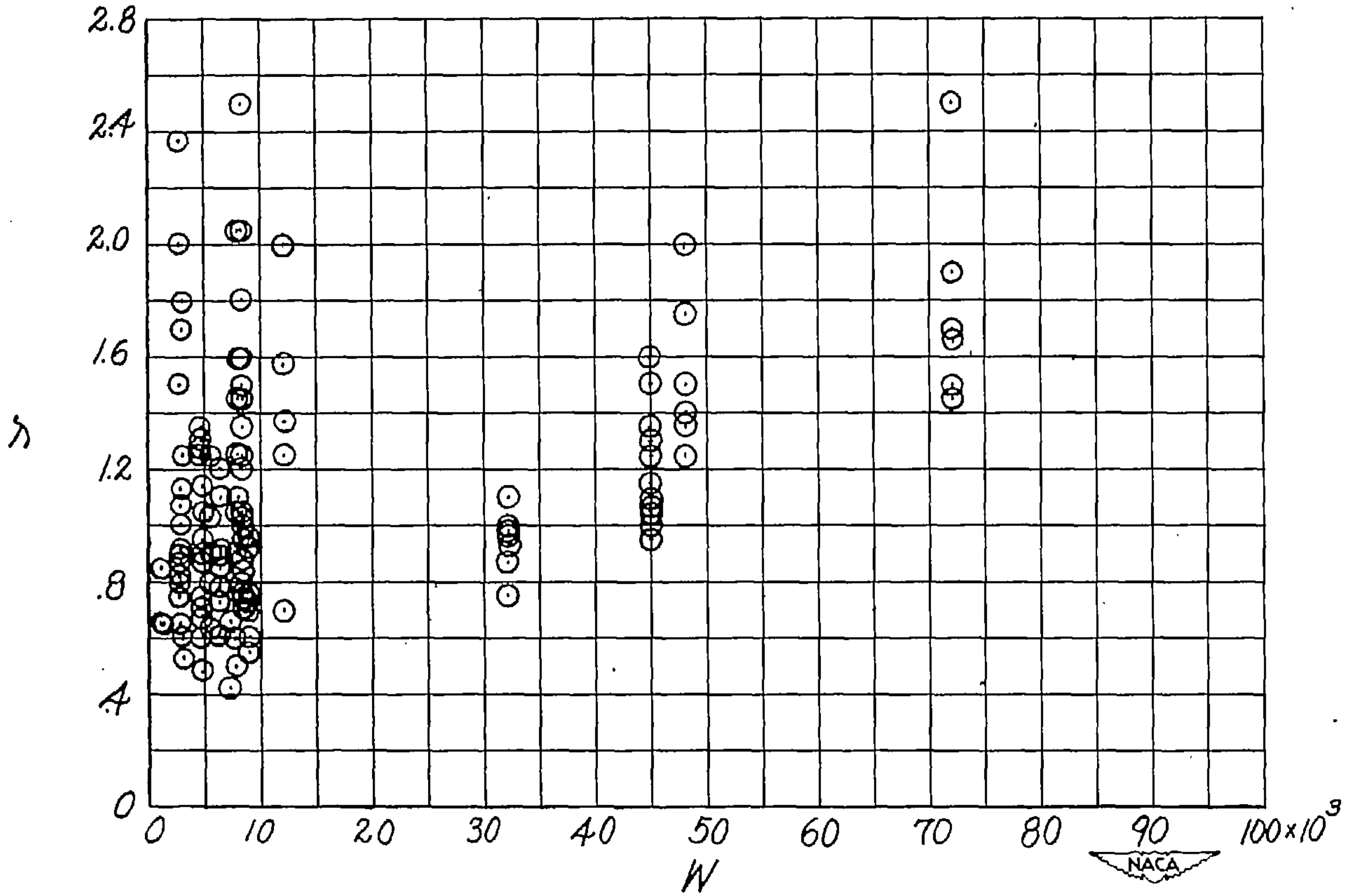

Figure 4.- Time to reach peak acceleration as a function of airplane weight.

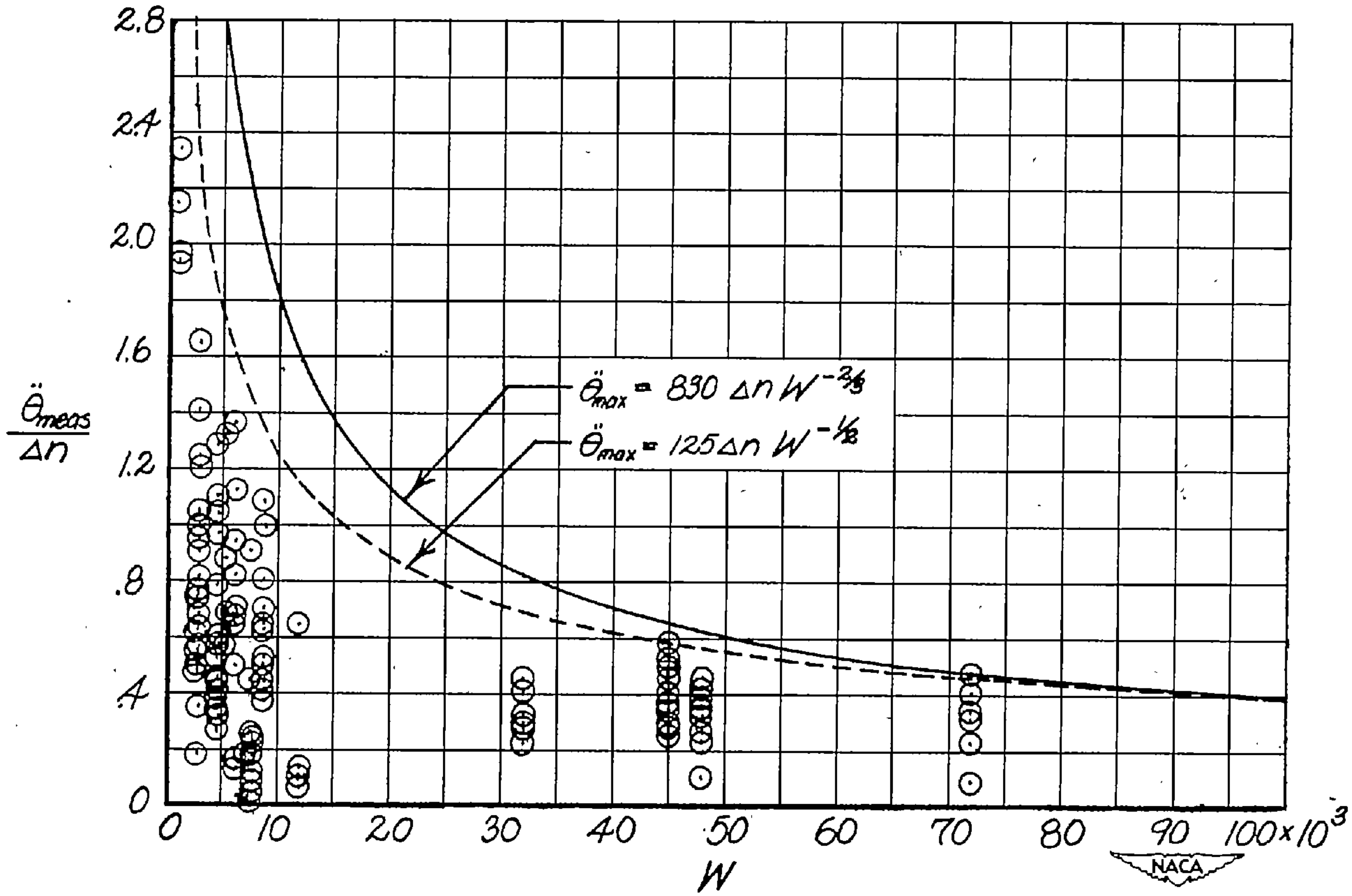

Figure 3.- Variation between measured maximum pitching acceleration for unit value of load factor and airplane weight.

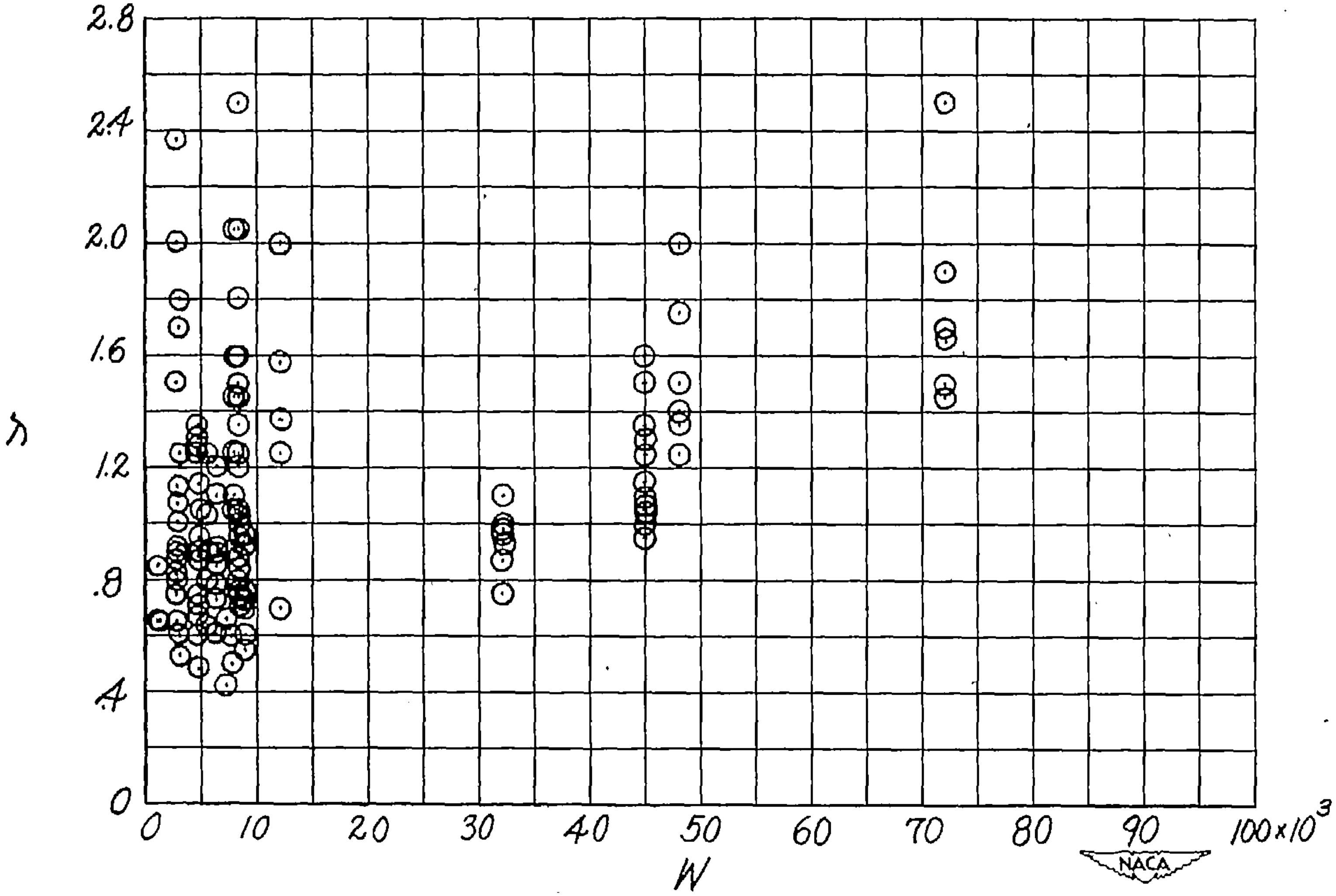

Figure 4.- Time to reach peak acceleration as a function of airplane weight.

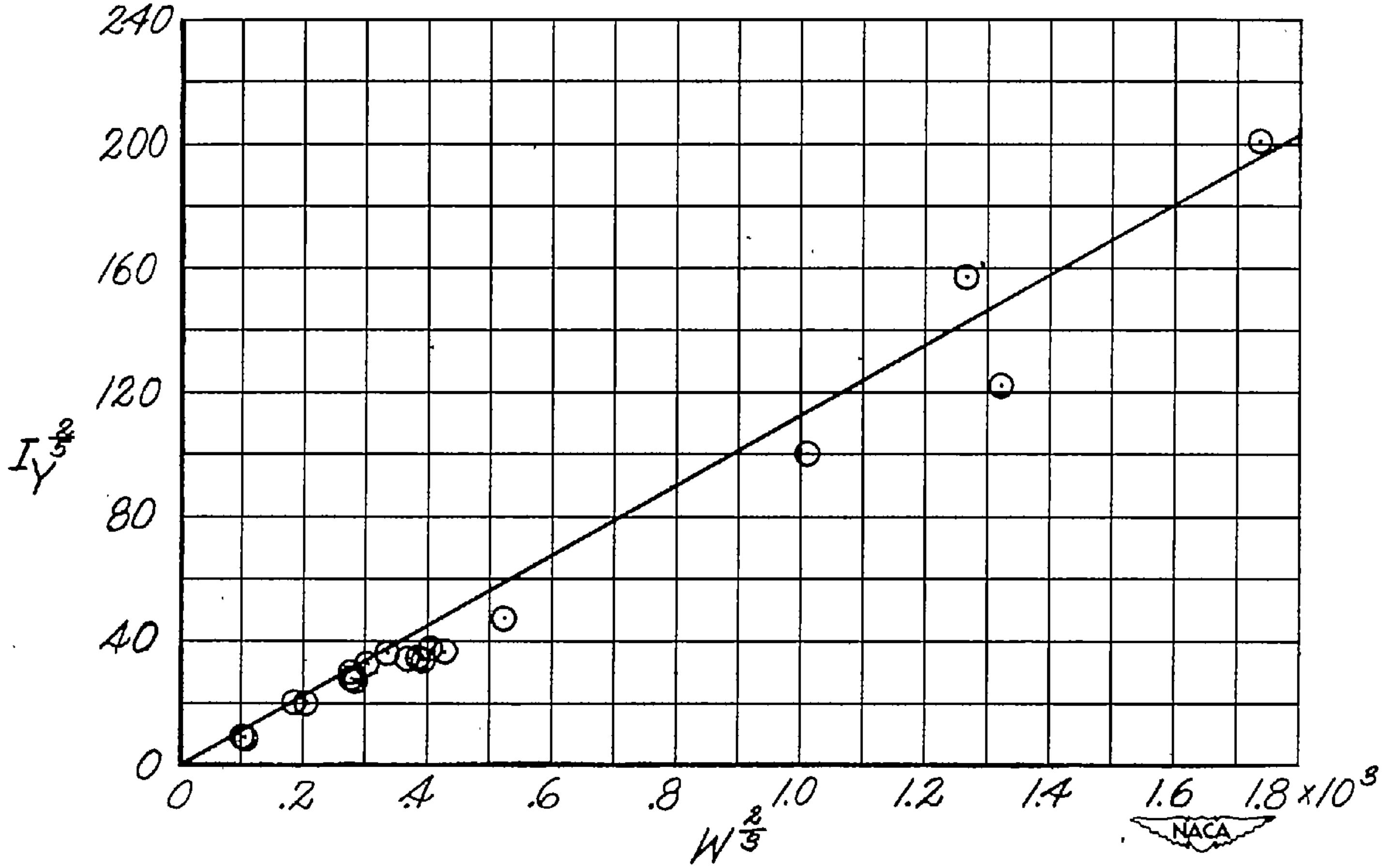

Figure 5.- Relation between pitching moment of inertia and weight.

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