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RESEARCH MEMORANDUM

EFFECT OF FORMATION POSITION ON LOAD FACTORS OBTAINED ON F2H AIRPLANES

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SUMMARY

Results of a four-plane formation flight consisting of twelve pull-up maneuvers are presented in the form of plots of maximum load factor attained against airplane position for three combinations of the four F2H airplanes. Several time histories are also presented for two of the airplanes. It is shown that the trend was for the load factor to increase toward the end of the formation. A maximum increment in load factor of about 2g over the lead-airplane load factor was experienced on the fourth airplane.

INTRODUCTION

The National Advisory Committee for Aeronautics in cooperation with the Bureau of Aeronautics and the U. S. Marine Corps has conducted a flight program on a McDonnell F2H-2 airplane during the performance of its regular squadron missions. This program is part of a control-motion-study project being made on several types of airplanes to determine the rates, amounts, and combination of control motions actually used by pilots in carrying out normal squadron missions. During the course of these tests, interest was expressed regarding the effect of airplane position in formation on the normal-load factor. Since no quantitative data existed concerning this subject, four airplanes were instrumented and flown in formation. This paper presents the results of the formation flights.

TEST AIRPLANES

For the purpose of identification the four participating airplanes are designated by the letters A, B, C, and D. The actual airplane serial numbers, take-off weights, take-off center-of-gravity locations, and the quantities measured on each airplane are given in table I. The pertinent

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physical characteristics are given in table II. A three-view drawing of the F2H airplane is presented in figure 1.

The airplanes used were normal service airplanes with the exception of the installation of NACA instrumentation. An F2H-1 airplane, which was already instrumented and undergoing flight tests by the NACA, was employed as airplane A. Airplanes B, C, and D were F2H-2 airplanes and were all assigned to a U. S. Marine service squadron, airplane B being the airplane used in the previously mentioned flight program.

The only major external difference between the F2H-1 and the F2H-2 airplanes is the addition of wing-tip tanks to the F2H-2. In the present tests, however, the F2H-2 airplanes were flown with the wing-tip tanks empty.

INSTRUMENTATION AND ACCURACIES

Airplanes A and B were equipped with rather complete instrumentation, while airplanes C and D had only recording accelerometers. All instruments were standard NACA recorders which give time histories of various quantities. Table I lists the quantities recorded for each airplane. For each of the two completely instrumented airplanes the individual records were synchronized by a timer. An approximate synchronization of records between all four airplanes was accomplished by a voice signal from the lead airplane indicating when the recorders were to be turned on and off for each run.

For the range and frequency of the recorded quantities, the instruments used are accurate to within ±1 percent for full-scale deflection. The estimated accuracies, based on the recorder calibrations and an assumed reading accuracy of 0.01 inch, are as follows:

Indicated airspeed, V_i, knots	1
Pressure altitude, H_p, feet	50
Control position, degrees	0.1
Normal linear acceleration, g units	0.03
Longitudinal and transverse linear acceleration, g units	0.01
Rolling angular velocity, radians per second	0.02
Pitching and yawing angular velocity, radians per second	0.005
Sideslip angle, degrees	0.1

It was impractical to install the accelerometers at the centers of gravity of the airplanes. The location of the accelerometers, measured forward from the take-off center-of-gravity locations, was 76.2 inches in airplane A, 76.5 inches in airplane B, and 128 inches in airplanes C and D. In airplanes A and B the accelerometers were located 14 inches to the right of the longitudinal axis and in airplanes C and D the accelerometers were on the longitudinal axis. The vertical location of the accelerometers in all the airplanes was in a horizontal plane through the longitudinal axis.

Since the accelerometers were not located at the centers of gravity of the airplanes, the linear accelerations are subject to corrections of an additional amount depending on the angular accelerations. In the present paper, however, the corrections were not applied because they were found to be small, averaging about 0.03g and 0.07g for airplanes A and B, respectively, at the time of maximum load factor. The corrections for airplanes C and D may be twice that for airplane B because of the further forward location of the accelerometers.

The linear accelerations and angular velocities were measured with respect to three mutually perpendicular axes in which the X-axis is parallel to the leveling line. The control angles were measured by electrical control-position recorders, the transmitter elements being located at the control surfaces. The sideslip angle was measured by a vane on a boom 6 feet ahead of the fuselage nose. The pressure altitude and indicated airspeed were obtained from measurements using the airplane airspeed system.

TEST PROCEDURE

The tests consisted of twelve pull-up maneuvers in which airplane A controlled the severity of the maneuvers. The maneuvers were made with the airplanes in the following sequences ABCD, ADBC, and ACDB; four pull-ups were made in each sequence. The airplanes were in a stepped-down line-astern formation. Spacing of the formation was about 1 plane length astern and with each airplane enough below the other to avoid jet wash on the vertical tail.

The pull-ups were made in smooth air at altitudes from 6,500 feet to 8,500 feet and at airspeeds from 330 knots to 375 knots. Pilots of airplanes B, C, and D were not forewarned as to when to pull up; they merely tried to hold their formation position.

Regular U. S. Marine Corps service pilots flew the airplanes for these tests and each pilot was assigned to one particular airplane.

RESULTS

The results of the formation pull-ups are given in table III and in figure 2. A tabulation of the maximum accelerations in g units measured during each run for the various combinations flown is given in table III. A plot of the recorded values given in table III is shown in figure 2. The horizontal scale of this figure identifies the airplanes as to their formation position; that is, position 1, 2, 3, or 4.

A typical time history of all the measured quantities of airplane A is given in figure 3. Time histories of the normal acceleration on airplanes A, B, C, and D for the run corresponding to figure 3 are presented in figure 4. For comparison, time histories of the normal acceleration on airplanes A and B for all the runs are shown in figures 5, 6, and 7. All of the time histories are typical and are identified to fit the results given in table III. The flight values of airplane weight and center-of-gravity location are included in figures 3 to 7. The time scales of these figures cannot be used for correlation purposes because of the method of synchronization used.

DISCUSSION

Although there is scatter in the maximum accelerations, the results shown in figure 2 indicate a tendency for the loads to increase toward the end of the formation. The largest difference between the maximum load factor experienced by the lead airplane and any other airplane in the formation is 1.76g and occurs on airplane D in the second run of combination ABCD.

By averaging the differences in the maximum accelerations recorded at various positions with the maximum accelerations recorded by the lead airplane, the following values were obtained:

Δn_{av} for position 2 . . . . 0.84
Δn_{av} for position 3 . . . . 1.05
Δn_{av} for position 4 . . . . 1.20

These values indicate that, although the tendency is for the loads to increase toward the end of the formation, the most rapid increase occurs between positions 1 and 2. This result is to be expected since in a good formation the pilot in position 2 has about the same warning time as to when the lead pilot starts to pull up as the pilots in positions 3 and 4.

Some of the scatter in figure 2 is probably due to the fact that the airplanes were not always in good formation at the time of the pull-up. In order to determine the degree to which different pilots affected the scatter in figure 2, the average increments in load factor obtained by pilots of airplanes B, C, and D relative to those obtained by the pilot of airplane A were determined for each pilot regardless of his position in the formation. The results indicate, on the average, that pilot B obtained 1.03g's more than pilot A, pilot C obtained 0.95g's more than pilot A, and pilot D obtained 1.10g's more than pilot A. These results seem to indicate that regardless of position all the pilots obtained approximately the same g increment above the load factor of pilot A; thus the pilot's effect on the scatter of figure 2 is small.

The fact that airplane A did not have tip tanks while airplanes B, C, and D did should not have any effect on the scatter noted in figure 2 because the lead airplane merely serves to define a path in space for the others to follow.

By comparing the time histories of normal accelerations given in figure 4 for airplanes A, B, C, and D and in figures 5 to 7 for airplanes A and B, it is apparent that the accelerations for the lead airplane are smoother than for the airplanes flying in the other positions. Since airplanes B, C, and D were flown with empty wing-tip tanks, the wing nodal points and wing frequencies of all four airplanes should not be too different, so that the differences in the character of the accelerometer records or, for that matter, in the maximum accelerations cannot be entirely associated with elastic effects. It is believed that the two main factors which contribute to the difference in appearance of the normal-acceleration curves are the attempt of the pilots to maintain position in the formation and the possibility of one airplane operating in or near the jet wash of the preceding airplanes.

CONCLUDING REMARKS

From the discussion of pull-up maneuvers of four F2H airplanes, it appears that increments of 2g between the lead airplane and the fourth airplane can occur at the airspeeds of these tests in a close stepped-down line-astern formation. When it is considered that increments due to jet wash and gusts may be superimposed on the increment due to formation position, then it becomes apparent that excessive loads might be obtained on the last plane in the formation if the lead plane were to execute too sharp a maneuver.

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TABLE I

TEST AIRPLANES AND RECORDED QUANTITIES

	Airplane A	Airplane B	Airplane C	Airplane D
Type	F2H-1	F2H-2	F2H-2	F2H-2
BuAer serial number	122540	123256	123215	123213
Tip tanks	Off	On	On	On
Take-off weight, pounds . . .	15956	17900	17600	17600
Take-off center-of-gravity location in percent of the mean aerodynamic chord . . .	26.2	26.6	26.0	26.0
Recorded quantities:				
Indicated airspeed	Yes	Yes	No	No
Pressure altitude	Yes	Yes	No	No
Aileron angle	Yes	Yes	No	No
Rudder angle	Yes	Yes	No	No
Elevator angle	Yes	Yes	No	No
Longitudinal acceleration .	Yes	Yes	No	No
Transverse acceleration . .	Yes	Yes	No	No
Normal acceleration	Yes	Yes	Yes	Yes
Rolling velocity	Yes	Yes	No	No
Pitching velocity	Yes	Yes	No	No
Yawing velocity	Yes	Yes	No	No
Yaw angle	Yes	Yes	No	No

TABLE II

PHYSICAL CHARACTERISTICS OF WING AND

HORIZONTAL TAIL OF TEST AIRPLANES

Wing:	
Total area (including flaps, ailerons, and 33.3 square feet covered by the fuselage), square feet	294.1
Span (without tip tanks), inches	500.8
Span (with tip tanks), inches	539.9
Aspect ratio	5.89
Taper ratio	0.52
Mean aerodynamic chord (at wing station 111.0 measured normal to center line), inches	88.37
Sweepback (leading edge), degrees	0
Root airfoil section	NACA 65_1-212
Tip airfoil section	NACA 63-209
Horizontal tail:	
Total area (including 17.66 square feet of elevator), square feet	69.8
Span, inches	224.7
Aspect ratio	4.65
Taper ratio	0.603
Mean aerodynamic chord (horizontal-tail station 49.63 measured normal to center line), inches	47.4
Airfoil section	NACA $65_{(10)}$-011
Tail length (leading edge of wing mean aerodynamic chord to 25 percent of mean aerodynamic chord of horizontal tail), inches	225.24

TABLE III

MAXIMUM POSITIVE NORMAL ACCELERATIONS FOR PULL-UP MANEUVERS

[Airspeed, 330 to 375 knots;
altitude, 6,500 to 8,500 feet]

Formation	Maximum positive accelerations, "g" units			
	Run 1	Run 2	Run 3	Run 4
A	1.92	2.34	2.68	3.87
B	2.55	3.38	3.55	5.25
C	3.10	3.65	3.45	4.63
D	3.35	4.10	3.95	4.80
A	2.87	3.40	3.45	4.30
D	3.70	3.85	3.75	5.65
B	3.55	4.43	4.48	5.15
C	3.75	4.75	4.30	5.45
A	2.57	4.30	3.77	4.42
C	3.85	4.55	4.62	5.35
D	4.15	5.00	5.00	5.80
B	3.67	5.35	5.05	5.75

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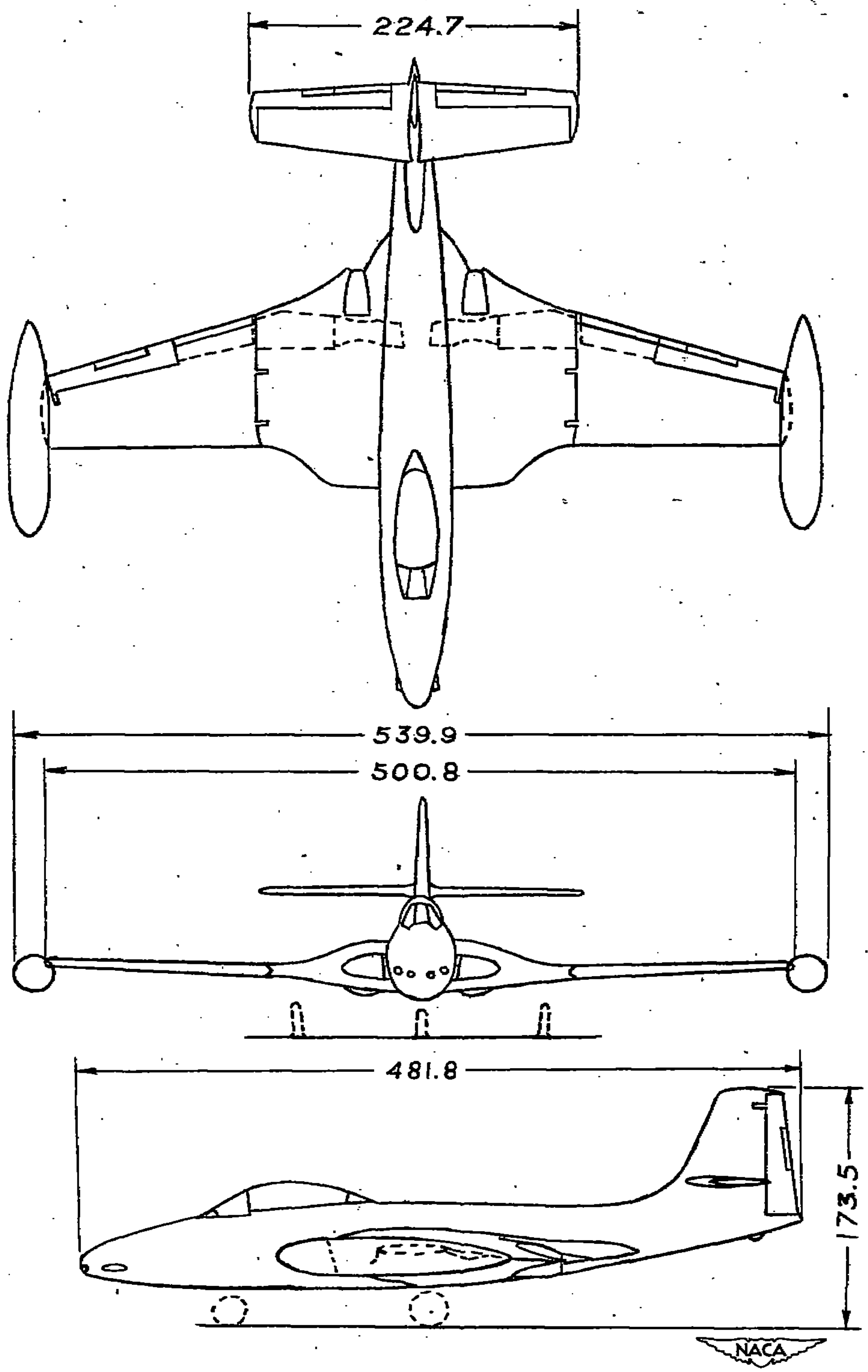

Figure 1.- Three-view drawing of a McDonnell F2H fighter airplane. All dimensions in inches.

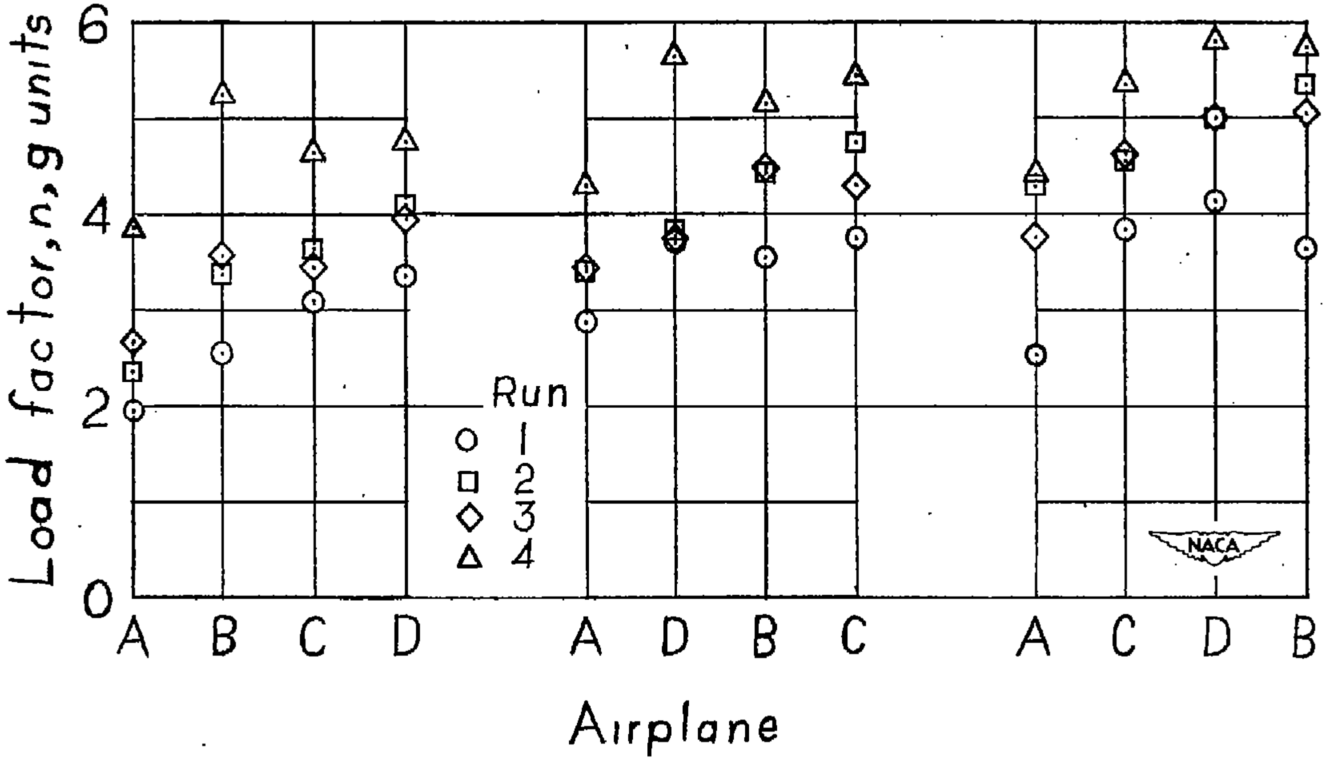

Figure 2.- Effect of airplane position on maneuver load factor in formations ABCD, ADBC, and ACDB.

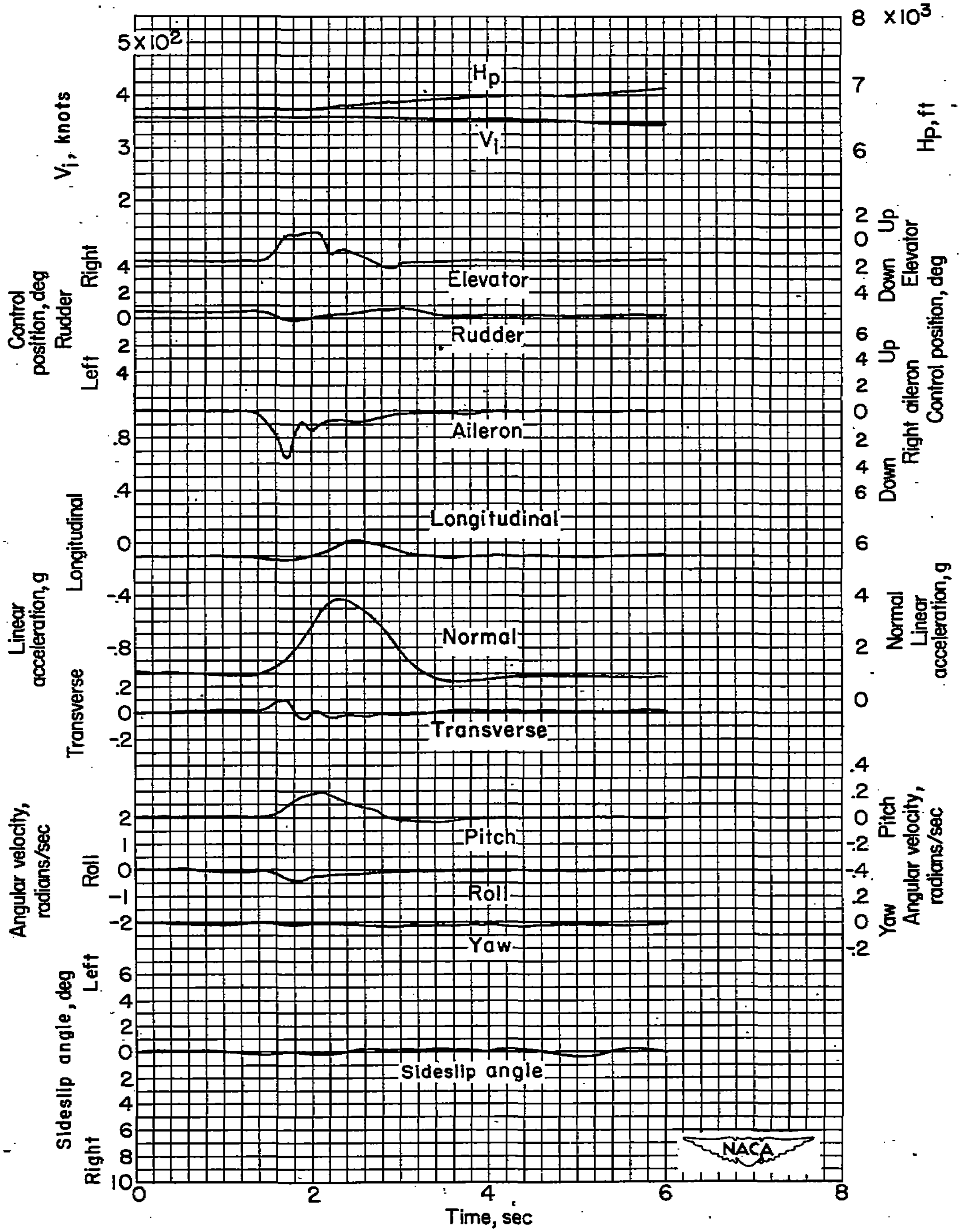

Figure 3.- Time history of recorded quantities on airplane A in formation ABCD, run 4; pull-up to the left; airplane weight, 14,844 pounds; center-of-gravity location, 25.5 percent of the mean aerodynamic chord.

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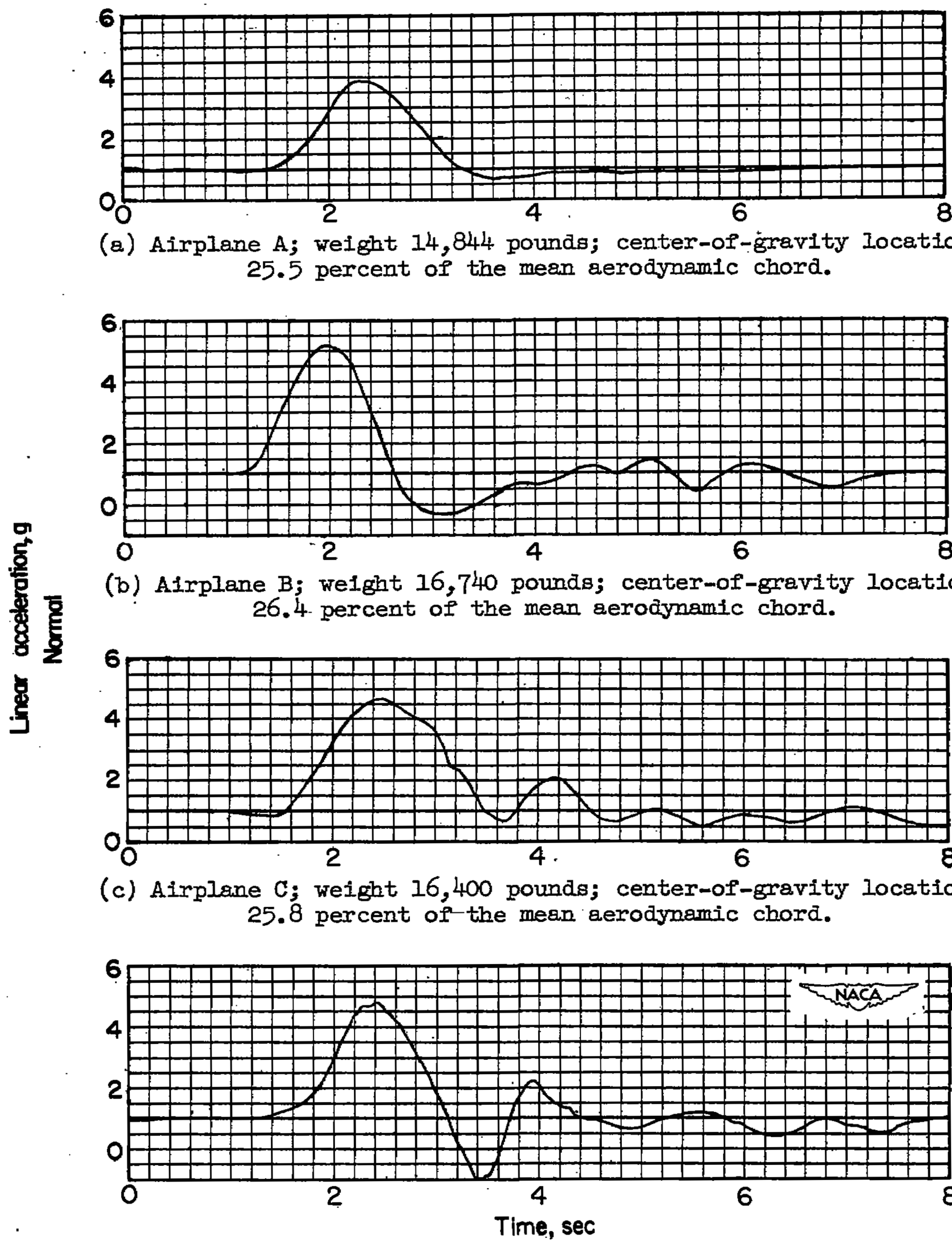


(a) Airplane A; weight 14,844 pounds; center-of-gravity location, 25.5 percent of the mean aerodynamic chord.

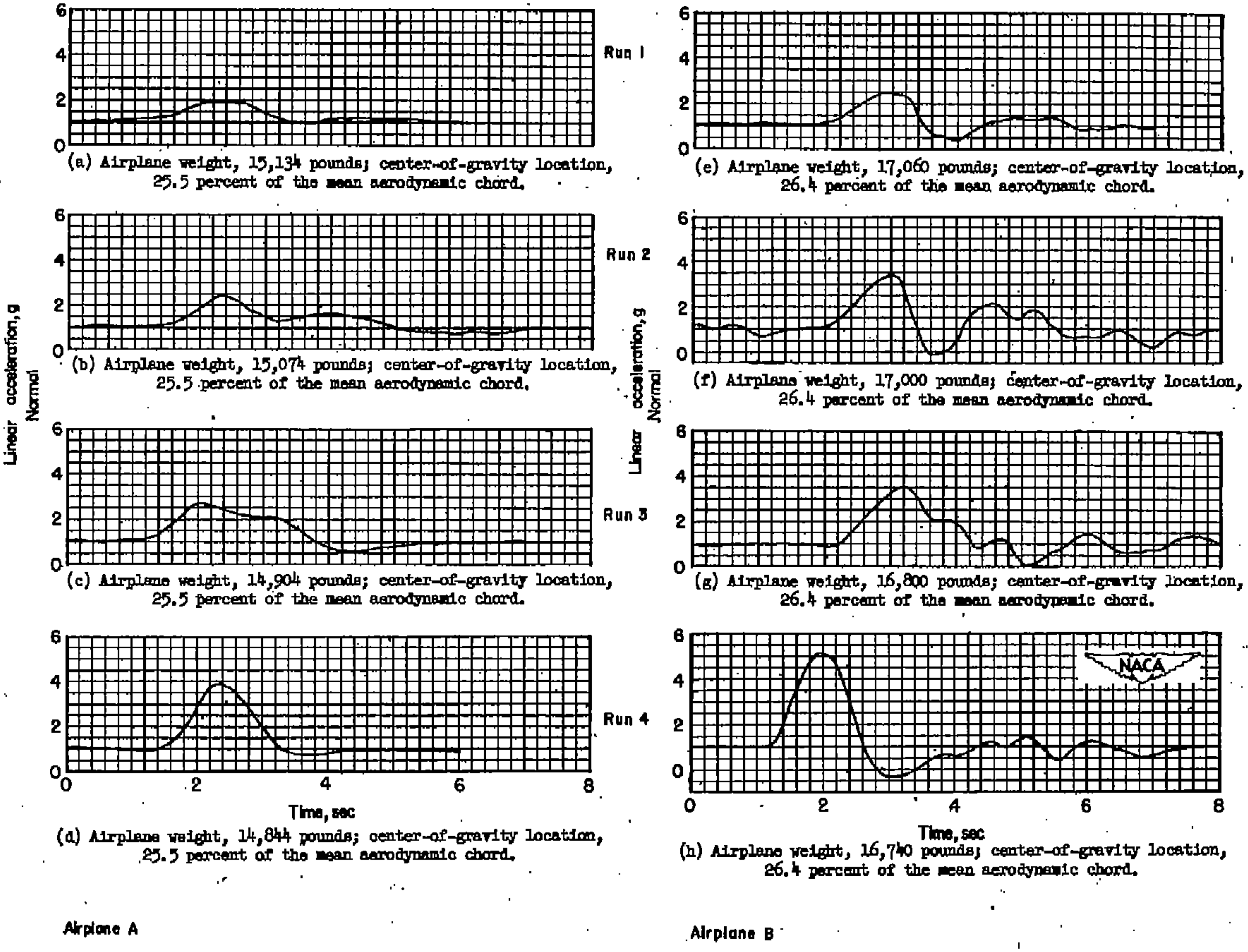
(b) Airplane B; weight 16,740 pounds; center-of-gravity location, 26.4 percent of the mean aerodynamic chord.

(c) Airplane C; weight 16,400 pounds; center-of-gravity location, 25.8 percent of the mean aerodynamic chord.

(d) Airplane D; weight 16,400 pounds; center-of-gravity location, 25.8 percent of the mean aerodynamic chord.

Figure 4.- Time histories of normal acceleration on airplanes A, B, C, and D in formation ABCD, run 4; pull-up to the left.

[redacted]



(a) Airplane weight, 15,134 pounds; center-of-gravity location, 25.5 percent of the mean aerodynamic chord.

(b) Airplane weight, 15,074 pounds; center-of-gravity location, 25.5 percent of the mean aerodynamic chord.

(c) Airplane weight, 14,904 pounds; center-of-gravity location, 25.5 percent of the mean aerodynamic chord.

(d) Airplane weight, 14,844 pounds; center-of-gravity location, 25.5 percent of the mean aerodynamic chord.

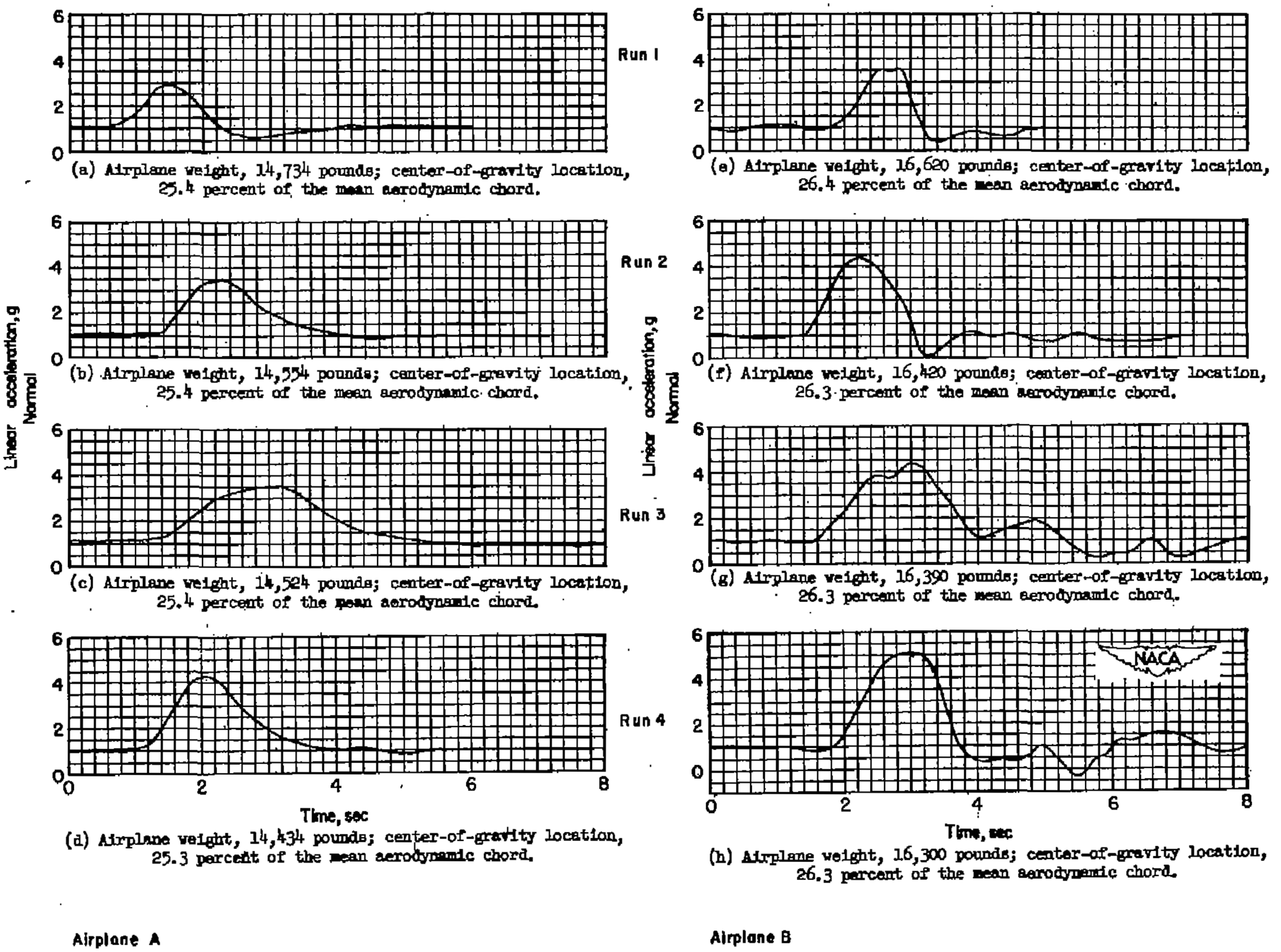
(e) Airplane weight, 17,060 pounds; center-of-gravity location, 26.4 percent of the mean aerodynamic chord.

(f) Airplane weight, 17,000 pounds; center-of-gravity location, 26.4 percent of the mean aerodynamic chord.

(g) Airplane weight, 16,800 pounds; center-of-gravity location, 26.4 percent of the mean aerodynamic chord.

(h) Airplane weight, 16,740 pounds; center-of-gravity location, 26.4 percent of the mean aerodynamic chord.

Figure 5.- Time histories at normal acceleration during pull-ups to the left for airplanes A and B in formation ABCD.



(a) Airplane weight, 14,734 pounds; center-of-gravity location, 25.4 percent of the mean aerodynamic chord.

(b) Airplane weight, 14,554 pounds; center-of-gravity location, 25.4 percent of the mean aerodynamic chord.

(c) Airplane weight, 14,524 pounds; center-of-gravity location, 25.4 percent of the mean aerodynamic chord.

(d) Airplane weight, 14,434 pounds; center-of-gravity location, 25.3 percent of the mean aerodynamic chord.

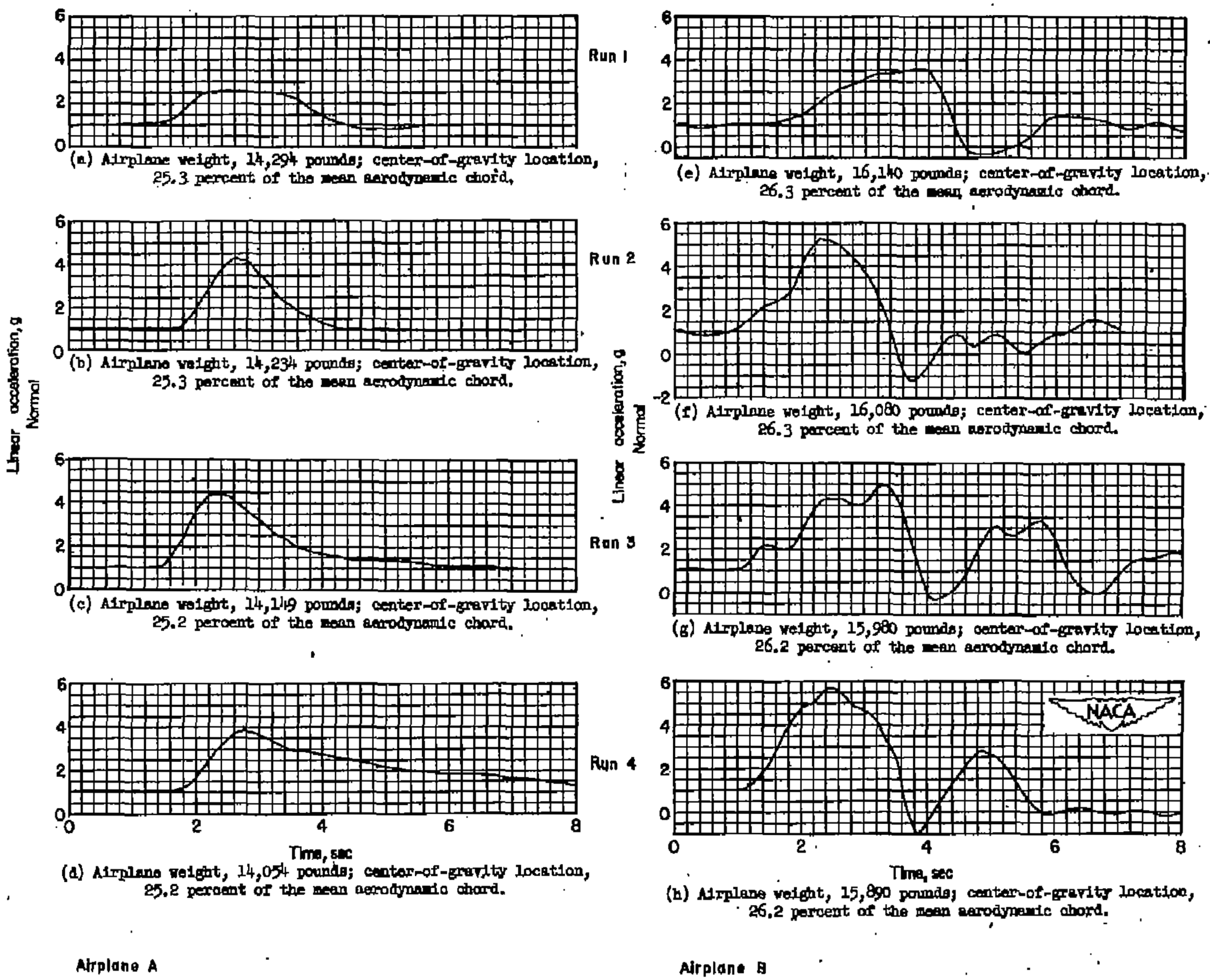
(e) Airplane weight, 16,620 pounds; center-of-gravity location, 26.4 percent of the mean aerodynamic chord.

(f) Airplane weight, 16,420 pounds; center-of-gravity location, 26.3 percent of the mean aerodynamic chord.

(g) Airplane weight, 16,390 pounds; center-of-gravity location, 26.3 percent of the mean aerodynamic chord.

(h) Airplane weight, 16,300 pounds; center-of-gravity location, 26.3 percent of the mean aerodynamic chord.

Figure 6.- Time histories of normal acceleration during pull-ups to the left for airplanes A and B in formation ADBC.



(a) Airplane weight, 14,294 pounds; center-of-gravity location, 25.3 percent of the mean aerodynamic chord.

(b) Airplane weight, 14,234 pounds; center-of-gravity location, 25.3 percent of the mean aerodynamic chord.

(c) Airplane weight, 14,149 pounds; center-of-gravity location, 25.2 percent of the mean aerodynamic chord.

(d) Airplane weight, 14,054 pounds; center-of-gravity location, 25.2 percent of the mean aerodynamic chord.

(e) Airplane weight, 16,140 pounds; center-of-gravity location, 26.3 percent of the mean aerodynamic chord.

(f) Airplane weight, 16,080 pounds; center-of-gravity location, 26.3 percent of the mean aerodynamic chord.

(g) Airplane weight, 15,980 pounds; center-of-gravity location, 26.2 percent of the mean aerodynamic chord.

(h) Airplane weight, 15,890 pounds; center-of-gravity location, 26.2 percent of the mean aerodynamic chord.

Figure 7.- Time histories of normal acceleration during pull-ups to the right for airplanes A and B in formation ACDB.

NACA-Langley - 12-7-51 - 325

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