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NACA TN 3434

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3434

A STUDY OF NORMAL ACCELERATIONS AND OPERATING CONDITIONS EXPERIENCED BY HELICOPTERS IN COMMERCIAL AND MILITARY OPERATIONS

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Washington
April 1955

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A STUDY OF NORMAL ACCELERATIONS AND OPERATING CONDITIONS EXPERIENCED BY HELICOPTERS IN COMMERCIAL AND MILITARY OPERATIONS

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SUMMARY

An analysis is presented of the normal accelerations and operating conditions encountered by two different airmail helicopters and a military pilot-training helicopter. The results, based on 4,325 flights (618 hours of flying time), indicate that maneuvers are usually responsible for the relatively large accelerations encountered, whereas gusts contribute primarily to the large number of smaller accelerations and the corresponding increase in the amount of time spent in the accelerated state.

The largest maneuver loads recorded to date are increments (measured from the 1 g normal-flight condition) of 1.40g and -1.25g, whereas the largest gust-acceleration increment was 0.90g.

The percentages of total flight time spent in the various flight conditions and speed ranges, as well as the acceleration time histories, are very similar for the two airmail helicopters and appear to follow a definite pattern as contrasted to the varied operating conditions of the military pilot-training helicopter.

INTRODUCTION

For many years there has been a growing need for VGH type of information for helicopters. This information - which provides an insight into the operating loads and the corresponding flight conditions, the maximum loads likely to be encountered because of gusts or maneuvers, and the percentage of time spent in the various flight conditions for particular types of helicopter operations - is of particular interest both as an aid in establishing a more rational basis for helicopter design and in more realistically estimating the service life of certain critical helicopter components.

With the cooperation of the military departments and various commercial operators, the National Advisory Committee for Aeronautics is engaged in a survey of the normal accelerations and associated flight conditions encountered by helicopters undergoing service use in several different types of commercial and military operations.

Data for this survey have been obtained over a period of three years by means of NACA helicopter VGH recorders (see fig. 1). This instrument, which weighs only 15 pounds, records airspeed, normal acceleration, and altitude as a function of time. A discussion of the NACA helicopter VGH recorder may be found in reference 1.

The results of the initial phase of this survey have been presented in reference 1, which analyzed the data obtained from an airmail helicopter operating in the vicinity of Los Angeles, California (hereinafter referred to as the "Los Angeles operation"). The present paper will include these results and more recent data obtained with the cooperation of an Army helicopter pilot-training unit located at Fort Sill, Oklahoma, (hereinafter referred to as the "military operation"), and an airmail helicopter operating in the vicinity of Chicago, Illinois (hereinafter referred to as the "Chicago operation"). In addition, a limited amount of data, which are included only in summary plots, were obtained from both the Phase V all-weather testing unit at Wright Field, Ohio, and a Navy helicopter detachment at Norfolk, Virginia.

METHODS AND RESULTS

Scope

The helicopters used for both the Chicago operation and the military operation were similar; both had a seesaw rotor with a diameter of 35 feet 2 inches and a normal gross weight of about 2,350 pounds. The helicopter used in the Los Angeles operation was larger and had a rotor diameter of 48 feet and a gross weight of about 5,000 pounds. Helicopters similar to those used by the three operators are shown in figure 2.

The present data are based on records obtained in helicopters from both the military and the airmail-carrier operations; a limited number of records (which are analyzed and presented only in the final summary plots) were obtained from other military operations. A total of 2,634 flights, which represent 365 hours of flying time, was recorded and analyzed; when these records are combined with the Los Angeles data (ref. 1), a total of 4,325 flights or 618 flying hours is obtained.

Data Presentation

Figure 3(a) is a sample helicopter VGH record for identifying traces, whereas figures 3(b) to 3(d) are typical records from both the military and airmail-carrier operations. All data presented herein are obtained from records similar to the illustrative samples. In the data reduction, only the maximum and minimum acceleration increments per flight which exceeded the commonly used arbitrary threshold value of the acceleration increment $\Delta a_n = \pm 0.2g$ were recorded. All acceleration increments are grouped in 0.1g class intervals to the nearest odd five-hundredths of a g (for example: ±0.25g, ±0.35g, ±0.45g, etc.).

In figures 4 to 9 are plotted the average number of flights or landings required to equal or exceed the given value of acceleration increment. These values were obtained by cumulatively summing the frequency distribution of acceleration levels and then dividing the resulting value at each level into the total number of flights or landings.

For the present case, the number of flights was considered to be more significant than the number of flying hours because the average flight was of short duration and a large percentage of the higher accelerations was encountered during the landing-approach maneuver; however, when helicopters are operationally used for longer flights, the use of the number of flight hours may be considered desirable, particularly for the en-route condition.

For the benefit of those who desire to apply the flying-hours scale for a given operator, table I presents the total number of flights, the number of flying hours, and the average time per flight for each operation analyzed to date.

Survey of Speed Range and Flight Condition

A more thorough study of the records (about 300 flights) from each operation was made to determine the percentage of total flight time spent in each speed range and flight condition. A check survey of the remaining records indicated that those chosen from each operation were representative. The results of this survey for the Los Angeles, Chicago, and military operations are shown in tables II and III.

Percentage of Flight Time Spent in Accelerated Condition

The percentage of flight time spent in the accelerated state, during which the rotating system of the helicopter experiences an added increment to the always present periodic stresses, may be of interest. The records were therefore examined to determine the time spent exceeding an arbitrary acceleration increment of ±0.15g. From this examination the percentage of total flight time spent at or above an acceleration increment of 0.15g was found to be 0.40 percent for the Los Angeles operation, 0.80 percent for the Chicago operation, and 0.65 percent for the military operation. Similarly, the percentage of time spent at or below an increment of -0.15g was 0.05 percent for the Los Angeles operation, 0.77 percent for the Chicago operation, and 0.40 percent for the military operation.

Extended Analysis of Data for All Accelerations Per Flight

For the military and the Chicago operations, more complete data reductions were available; that is, all accelerations per flight which exceeded the 0.2g increment were read and only the maximum and minimum accelerations per flight were used for figures 4 to 9. In order to provide a possible basis for future fatigue work, the results of a more complete data reduction for the military and the Chicago operations are presented in table IV as the actual number of acceleration increments which were recorded in each class interval for each of the three flight conditions. Figure 10 shows the average number of flying hours required in each of the three flight conditions to equal or exceed the given value of acceleration increment. Figure 10(a) presents data for the Chicago operation, whereas figure 10(b) presents data for the military operation.

Figure 11 shows the difference between plotting all acceleration increments per flight as opposed to using only the maximum or minimum acceleration increments. Figure 11(a) presents data for the Chicago operation, whereas figure 11(b) presents data for the military operation.

DISCUSSION

Operating Conditions

Although no detailed analysis of the data was made, a general survey determined the percentage of total flight time spent in certain speed brackets and flight conditions (tables II and III) for the three operations. Also, during the data reduction, some qualitative information on flying conditions was obtained, such as noting the frequent jump takeoffs for the Los Angeles operation as compared with the relative absence of the same maneuver for both the Chicago and the military operations. Autorotative approaches constituted only a small percentage of the landing approaches for either of the airmail helicopters, whereas they were the outstanding maneuvers noted for the military operation.

For all three operations, the normal operating altitude was invariably below a pressure altitude of 2,500 feet, and for the two airmail carriers the altitude-time traces were very similar, as was their average time per flight. In contrast, the altitude-time trace for the military operation showed no consistent pattern and the time per flight varied widely, although the overall average time per flight was only a little less than that for the average airmail-carrier flight.

Gust and Maneuver Loads

Although each operation sampled had varied characteristics, a summary plot combining the data from all five operations is believed to have some value in indicating trends which the average helicopter might be expected to encounter during its service life. The summary plot of flight accelerations is therefore presented in figure 4. The similarity of the positive and negative acceleration increments up to a value of about 0.8g should be noted.

The data obtained from the Phase V all-weather testing unit and the Navy helicopter detachment at Norfolk, Virginia, are used only in the summary plots (figs. 4 and 8) because there were not sufficient data on which to base an operational comparison, as was made for the other three operations.

In figure 4, as in succeeding figures where the problem arises, it is possible to have two or more points for the same curve occurring at the same number of flights. This condition is brought about (particularly at the higher acceleration levels) by the statistical method of presentation when no data are recorded in one or more acceleration class intervals.

A comparison plot of the flight accelerations experienced in the Los Angeles, Chicago, and military operations is presented in figure 5, which shows that the military operation experienced the most severe accelerations recorded to date, whereas the Chicago and Los Angeles operations were progressively less severe. A further breakdown of the data into the three significant flight conditions (take-off and climb, en route, and landing approach) for each operation is shown in figure 6. The most outstanding feature of this figure is that a given acceleration level will be reached sooner (on a basis of the maximum and minimum accelerations per flight) in the landing-approach condition than in either of the other flight conditions, even though less than 20 percent of the total flight time (see table III) was spent in the landing-approach condition.

In the course of the data reduction it was noted that nearly all the larger landing-approach loads were due to maneuvers; the two most frequent ones were the negative load caused by the pushover into the landing approach or autorotative condition and the positive load caused by the landing flareout. For the military operation, in particular, the entry into autorotation and the autorotative flareout were the most severe maneuvers performed, since they produced the largest negative and positive acceleration increments (-1.25g and 1.40g) measured to date.

Take-Off and Climb

Figures 7(a) to 7(c) are a cross plot of figures 6(a) to 6(c) for each of the three flight conditions; thus, a comparison of the variations among the three operations in each given flight condition is provided. A comparison plot for the take-off and climb condition is shown in figure 7(a), from which it is seen that there are only slight differences in acceleration levels regardless of the type of operation. The accelerations in the take-off and climb portion of the flight are, in general, fairly small and apparently result from a combination of rough air and corrective-control motions, except for the jump take-off and the transition from climb to level flight, which are the only two definite maneuver loads noticed in this region.

En Route

The comparison plot for the en-route portion of the flight is shown in figure 7(b). The loads in this region are primarily due (either directly or indirectly) to rough air. In rough air, the records show a large number of positive and negative loads and a corresponding increase in the amount of time spent in the accelerated state, whereas in smooth air only an occasional disturbance is found on the acceleration trace. (Compare figs. 3(c) and 3(d).)

The largest distinct gust-acceleration increment measured to date was 0.90g obtained from a flight of the Chicago operation. No outstanding negative gust loads were noted.

Landing Approach

As mentioned previously, the landing-approach portion of the flight, which takes less than 20 percent of the total flight time, accounts for a large portion of the higher accelerations. Figure 7(c) shows the comparison of the landing-approach loads for the three operations. The military operation experienced by far the most severe loads yet analyzed, both positive and negative loads approaching the design load factor of the helicopter. The design load factor for this helicopter is ±1.5.

The normal acceleration immediately prior to contact was always near 1 g for the airmail operations; however, for the military operation this was not always so. A survey of about 1,000 flight records of the military operation was made, from which it was found that, in some cases, negative acceleration increments were experienced immediately prior to the landing impact (see table V). For the maximum increment of -0.70g, the rotor carried as little as 30 percent of the weight of the helicopter. A careful analysis of the cases where the normal acceleration immediately prior to landing impact was less than 1 g seemed to indicate that they were probably caused by an early landing flareout from an autorotational descent, followed by either a reduction of collective pitch or a loss of rotor speed and a resulting loss of lift just prior to impact.

The records from which the data for table V were obtained were similar to figure 3(a), which has a time scale of 0.6 inch of film per minute. This scale made it difficult in many cases to study the exact sequence of the accelerations in the landing-impact region; therefore, only cases in which the acceleration-time sequence could definitely be established were used in the tabulation of table V.

Landing Loads

The loads occurring at landing impact were also analyzed and the summary plot of the number of landings required to equal or exceed a given value of acceleration increment is shown in figure 8. The positive landing-impact acceleration increments are found to be comparable in magnitude to the flight accelerations, whereas the negative increments, which apparently are due to rebound from initial impact, are considerably less than the corresponding flight accelerations.

A breakdown of the summary plot of the landing-impact accelerations in order to show the comparison among the three operations is shown in figure 9. Again, the military operation experienced by far the largest landing-impact accelerations, whereas the values for the two airmail operations are very similar and much less severe in magnitude.

The large, positive landing-impact accelerations experienced by the military operation are apparently due to the large number of full autorotative landings, the rough terrain, and some night operations. The added effects of skid-type landing gears, which the Chicago and Los Angeles operations did not use, may also be a factor.

Operating Variables

It is interesting to note the number of variables which might affect the acceleration experiences of the Chicago and Los Angeles operations, for example, the operating conditions, pilot techniques, type of helicopter, and geographical location. The operating conditions of the two airmail operations were very similar, as shown in tables I and II. The only evident variation in pilot technique occurred during the take-off; the Los Angeles operation involved frequent jump take-offs (as judged by the normal-acceleration peak) as compared with the relative absence of the same maneuver for the Chicago operation. The design of the two helicopters differed materially (see figs. 2(b) and 2(c)). Careful examination of the records seems to indicate that the primary differences in acceleration are due to differences in air-roughness levels resulting from geographical location. The Chicago operation encountered the rougher air and, therefore, a higher acceleration level (see fig. 5) than the Los Angeles operation. It is felt that, in general, with the exception of accelerations attributable to rough air, the acceleration time histories of the Chicago and the Los Angeles operations are similar.

The military (pilot-training) operation differed radically from the airmail operations. As the name implies, the military pilot-training unit spends most of its time instructing new helicopter pilots. This type of operation, combined with an abnormally large number of full, autorotative landings on various types of terrain and some night operations, is probably one of the most severe routine operations that a helicopter would be expected to encounter. For the operations sampled to date (which includes new and limited data from three other operations not herein presented), this is certainly shown to be true.

Acceleration Frequency of Occurrence

The parts of figures 10 and 11 are considered separately to show the distribution of accelerations and to provide a comparison for both the military pilot-training and the Chicago airmail operations.

Figures 10(a) and 10(b) show the acceleration frequency of occurrence for each of the three flight conditions for the Chicago and military operations, respectively. As in the previous plots, the landing-approach region of flight was again found to be a dominating factor, since it had acceleration frequency of occurrence greater than either of the other two flight conditions. Although the en-route portion of the flight did not show as high an acceleration frequency of occurrence as the landing-approach condition, a much larger percentage of the total flying time is spent in this condition. The en-route portion of the flight may, therefore, be critical from a fuselage-fatigue or passenger-comfort standpoint owing to the large number of smaller accelerations.

Figures 11(a) and 11(b) show, for the Chicago and the military pilot-training operations, the comparison between plotting all acceleration increments per flight as opposed to using only the maximum and minimum increment per flight. For both operations it is found that the two curves are very similar, since they are identical at the higher acceleration levels and diverge gradually at the lower acceleration levels, as might be expected when the average flight is of short duration. In general, it should therefore be concluded that, at this time, the primary value of presenting all accelerations per flight is the possibility of future use of such data as an aid in fuselage-fatigue design or the development of a correlation between stresses in the rotating system and the accelerometer readings in conjunction with other information obtained from the NACA helicopter VGH recorder.

CONCLUDING REMARKS

An analysis has been made of the normal accelerations and operating conditions encountered by two airmail helicopters and a military pilot-training helicopter. The results of this analysis indicate that maneuvers are usually responsible for the relatively large accelerations, whereas gusts contribute primarily to the large number of smaller accelerations and the corresponding increase in the amount of time spent in the accelerated state.

The largest maneuver loads recorded to date are increments (measured from the 1 g normal-flight condition) of 1.40g and -1.25g, whereas the largest gust-acceleration increment was 0.90g.

The operating conditions and acceleration time history of the two airmail helicopters are very similar and appear to follow a definite pattern as contrasted to the varied operating conditions of the military pilot-training helicopter.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 20, 1955.

REFERENCE

1. Crim, Almer D., and Hazen, Marlin E.: Normal Accelerations and Operating Conditions Encountered by a Helicopter in Air-Mail Operations. NACA TN 2714, 1952.

TABLE I.- COMPARISON OF THE FLIGHT TIME FOR

ALL OPERATIONS ANALYZED

Type of operation	Total number of flights	Total flight time, min	Total flight time, hr	Average time per flight, min
Military	1,385	9,714	161.90	7.0
Los Angeles	1,691	15,180	253.00	8.0
Chicago	963	8,430	140.50	8.7
All-weather testing	152	1,515	25.25	10.0
Navy, Norfolk	134	2,262	37.40	16.9
Total	4,325	37,101	618.05	---

TABLE II.- SPEED-RANGE COMPARISON

<table>
<tr><th rowspan="2">Type of operation</th><th colspan="5">Percent of total flight time at indicated airspeed of -</th></tr>
<tr><th>0 to 20 mph</th><th>20 to 40 mph</th><th>40 to 60 mph</th><th>60 to 80 mph</th><th>Over 80 mph</th></tr>
<tr><td>Chicago</td><td>2.0</td><td>3.0</td><td>8.0</td><td>63.0</td><td>24.0</td></tr>
<tr><td>Military</td><td>15.9</td><td>12.5</td><td>45.2</td><td>26.4</td><td>0</td></tr>
<tr><td rowspan="2">Los Angeles</td><td>0 to 20 mph</td><td colspan="2">20 to 65 mph</td><td>65 to 85 mph</td><td>Over 85 mph</td></tr>
<tr><td>5.3</td><td colspan="2">18.7</td><td>67.6</td><td>8.4</td></tr>
</table>

TABLE III.- COMPARISON OF FLIGHT CONDITIONS

Type of operation	Percent of total flight time spent in each flight condition		
	Take-off and climb	En route[a]	Landing approach
Chicago	14.0	77.0	9.0
Los Angeles	14.5	73.8	11.7
Military	17.9	62.6	19.5

[a]En-route condition was considered to begin when the rate of climb was below 300 ft/min and to end when the rate of descent exceeded 300 ft/min.

TABLE IV.- NUMBER OF ACCELERATIONS RECORDED IN EACH

CLASS INTERVAL AND FOR EACH FLIGHT CONDITION

Acceleration increment, Δa_n, g units	Military operation				Chicago operation			
	Take-off and climb	En route	Landing approach	Total	Take-off and climb	En route	Landing approach	Total
0.25	862	4,827	1,400	7,089	506	2,963	1,074	4,543
.35	100	744	347	1,191	69	644	213	926
.45	24	156	173	353	17	171	60	248
.55	2	47	70	119	3	31	15	49
.65	1	18	33	52	1	15	11	27
.75	1	9	22	32		5	0	5
.85	1	3	18	22		1	0	1
.95			5	5		1	1	2
1.05			3	3				
1.15			1	1				
1.25			0	0				
1.35			1	1				
1.45			1	1				
-.25	244	1,593	390	2,227	269	2,971	669	3,909
-.35	18	201	139	358	39	487	105	631
-.45	5	48	119	172	8	87	41	136
-.55	2	14	65	81	1	13	16	30
-.65		17	46	63		2	15	17
-.75		8	36	44			5	5
-.85		1	15	16			1	1
-.95		0	8	8				
-1.05		1	7	8				
-1.15			3	3				
-1.25			2	2				

TABLE V.- NEGATIVE ACCELERATION INCREMENTS EXPERIENCED IMMEDIATELY PRIOR TO LANDING IMPACT

[Survey of 1,000 landings]

Number of landings	Acceleration increment, Δa_n, g units
14	-0.25
12	-.30
4	-.35
1	-.65
1	-.70

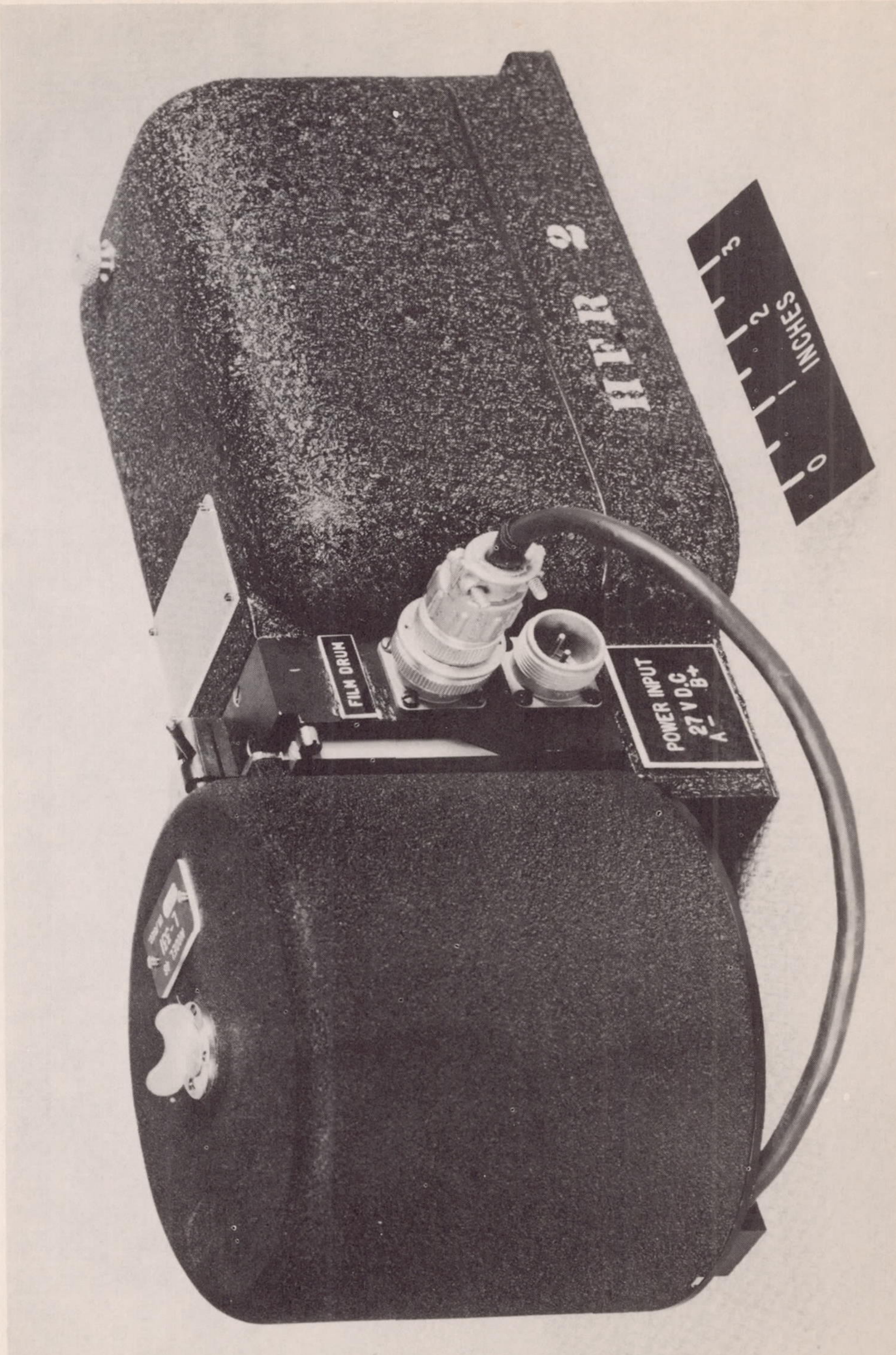

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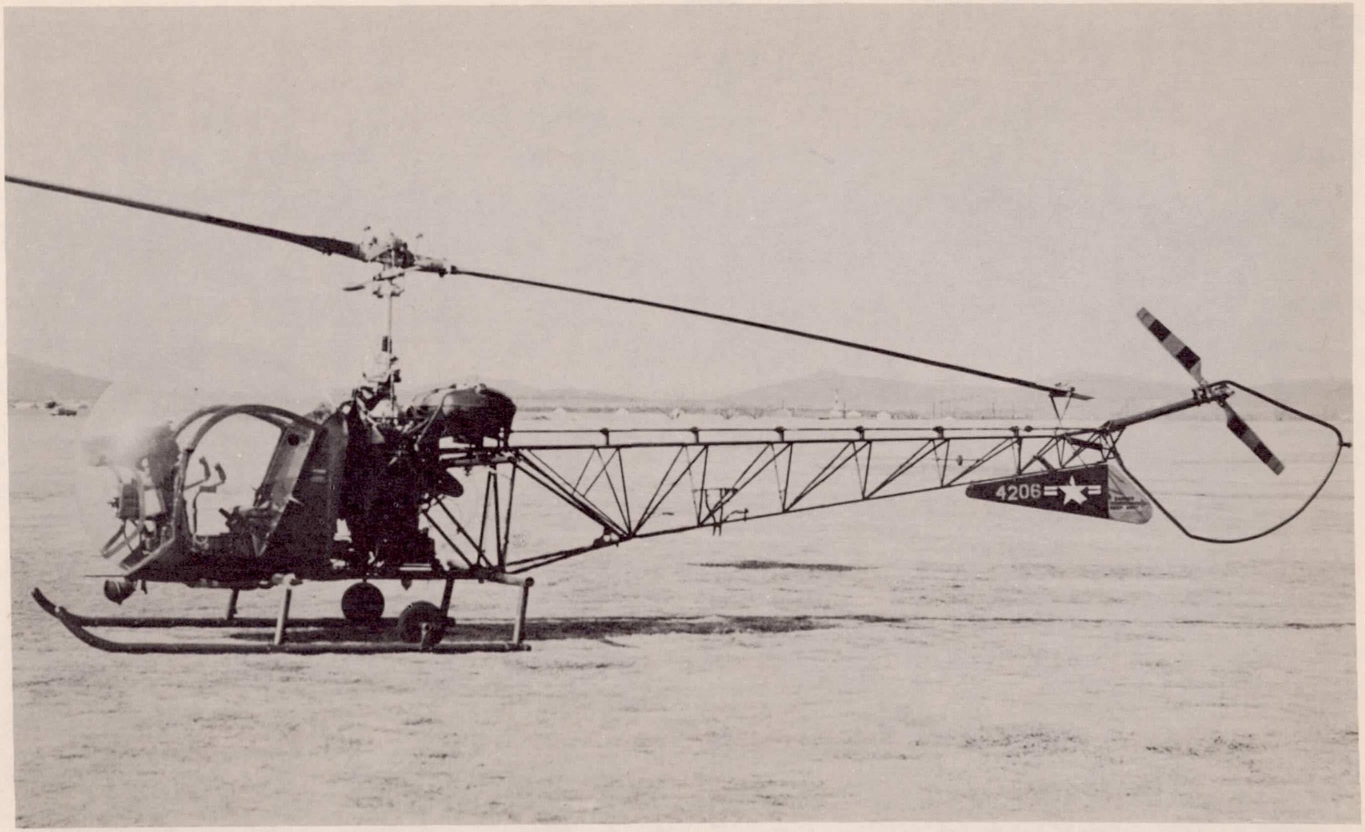
Figure 1.- NACA helicopter VGH recorder.



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(a) Military pilot-training helicopter.

Figure 2.- Helicopters similar to those used in recording data.

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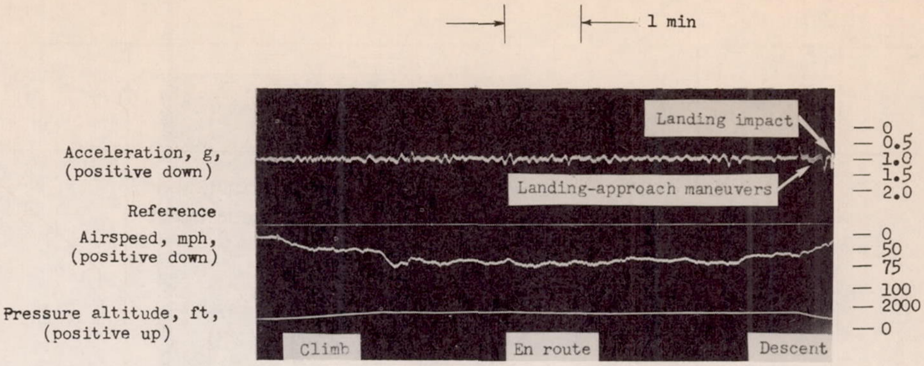
(b) Chicago airmail helicopter.

Figure 2.- Continued.

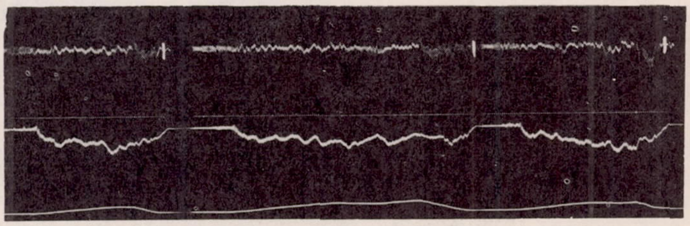
L-74369

(c) Los Angeles airmail helicopter.

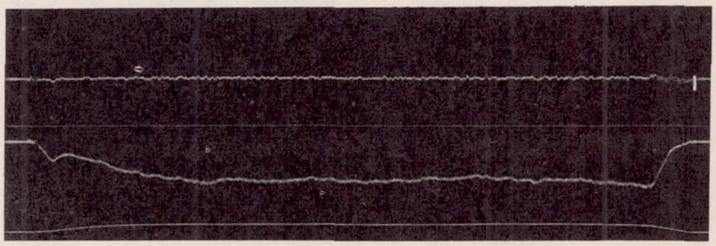
Figure 2.- Concluded.



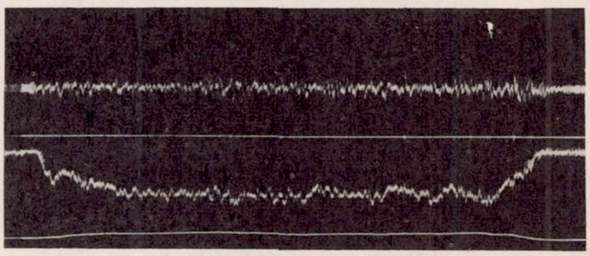
(a) Sample record identifying traces.



(b) Typical record of military pilot-training operations.



(c) Typical record of airmail operations in smooth air.



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(d) Typical record of airmail operations in rough air.

Figure 3.- Sample flight records.

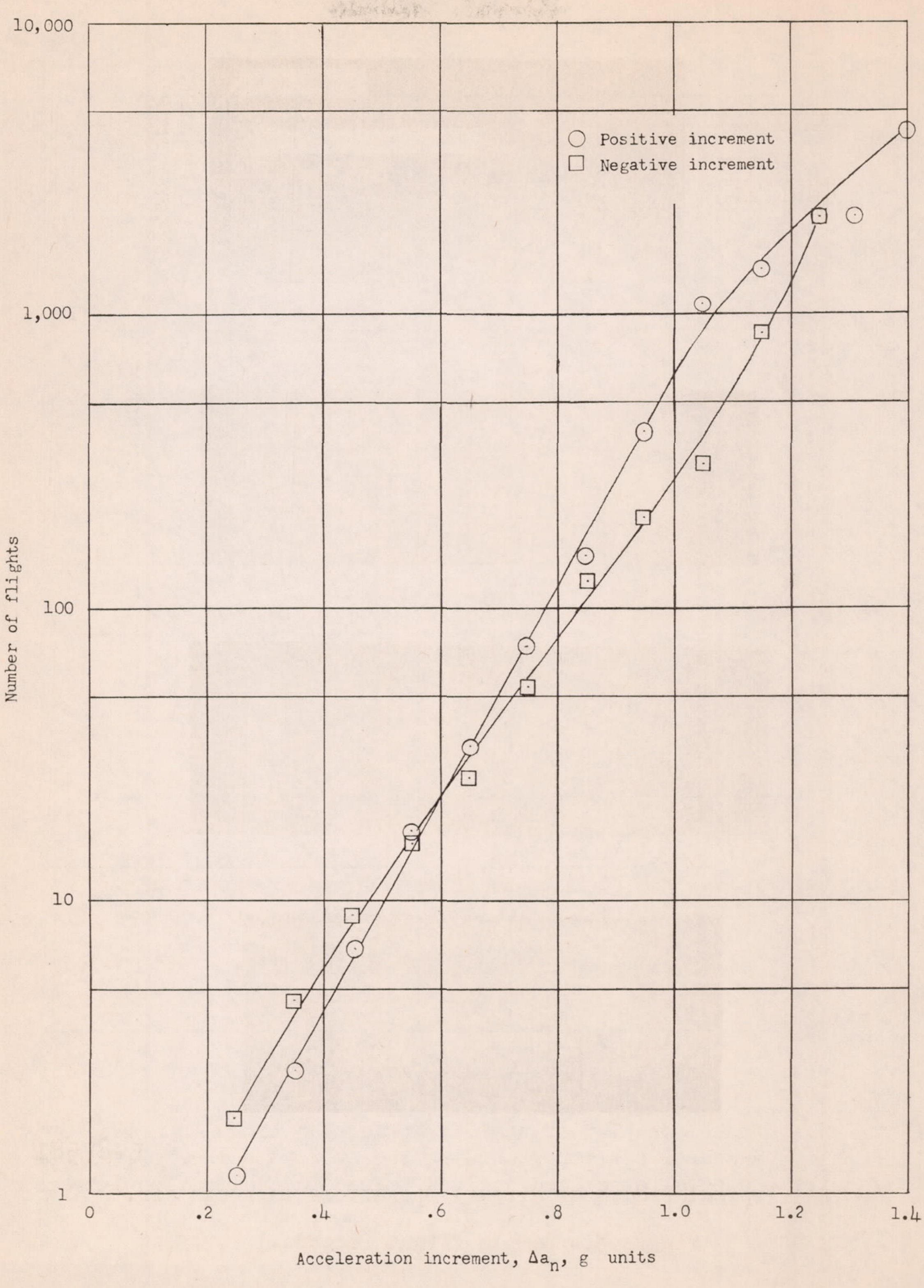


Figure 4.- Summary plot of the average number of flights required to equal or exceed a given value of acceleration increment.

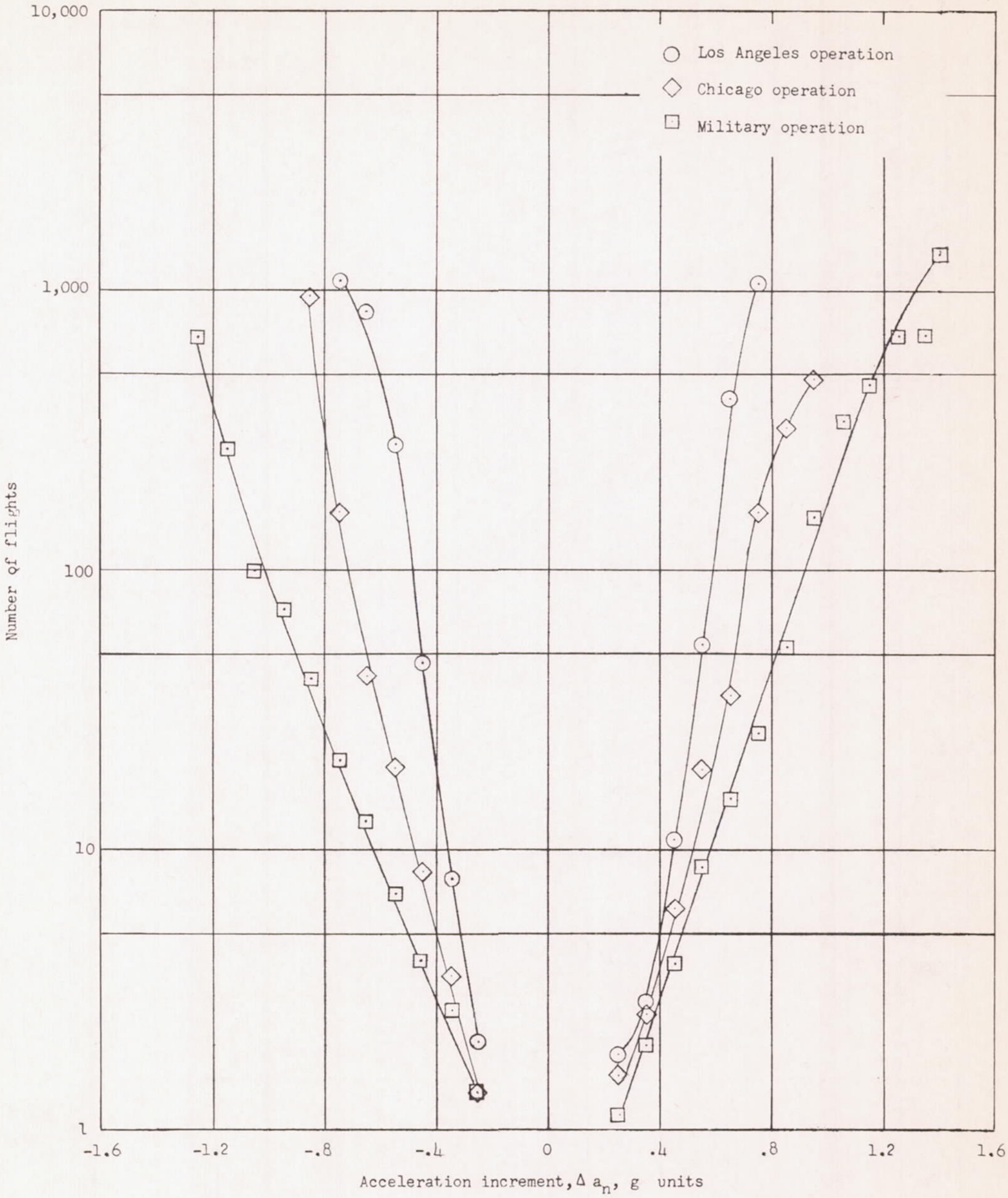
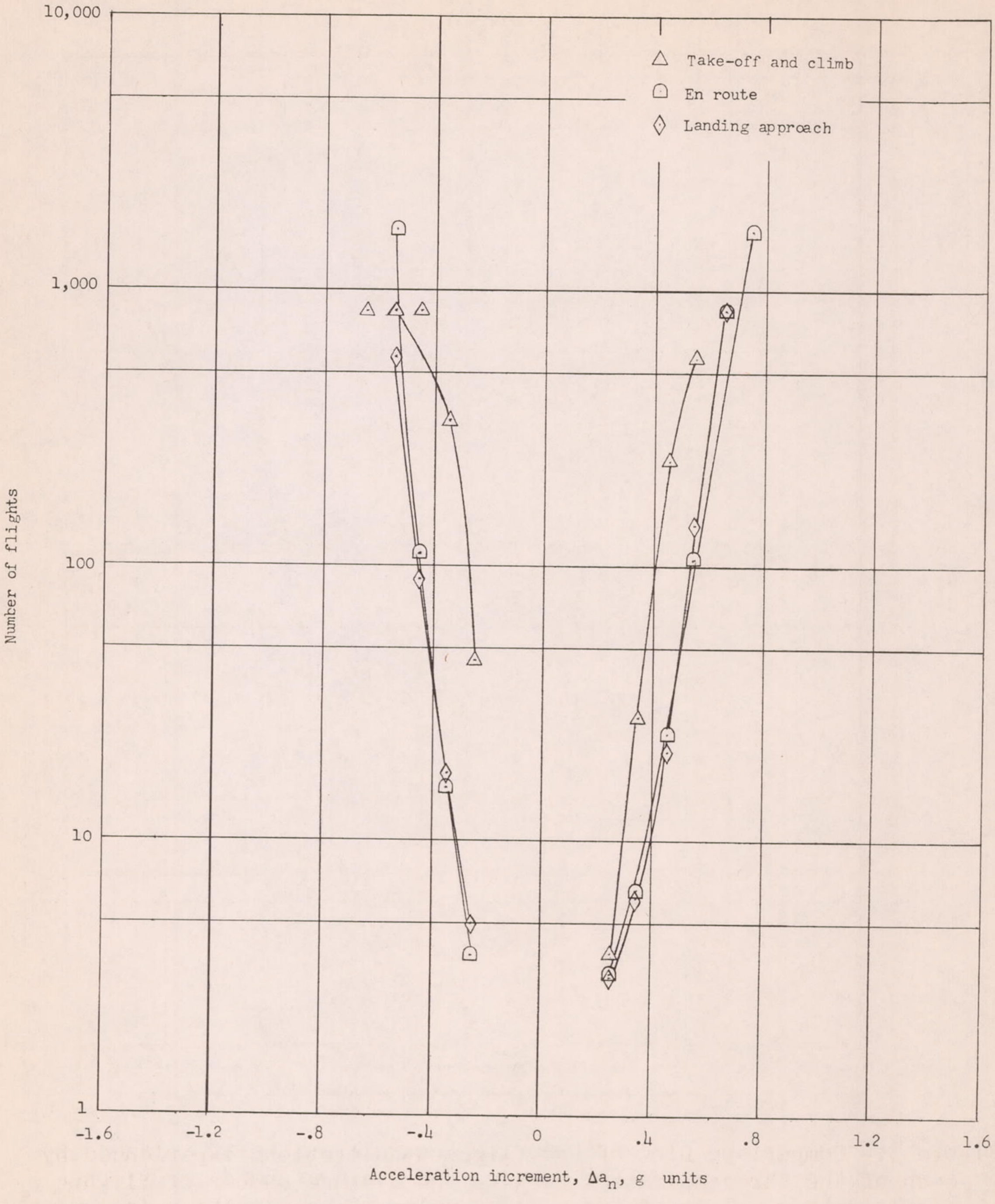
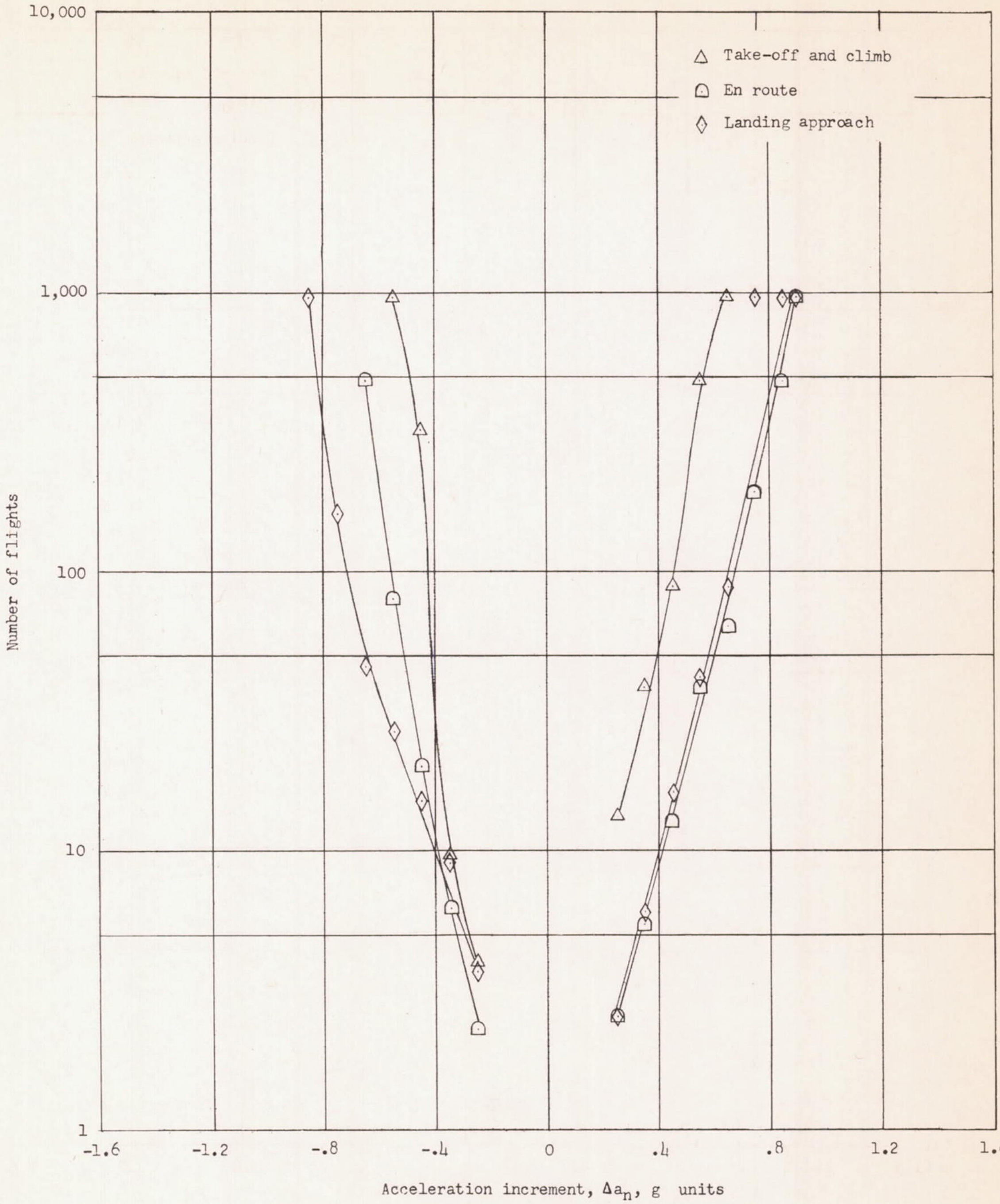


Figure 5.- Comparison plot of the flight accelerations experienced by each of the three operators showing the average number of flights required to equal or exceed a given value of acceleration increment.



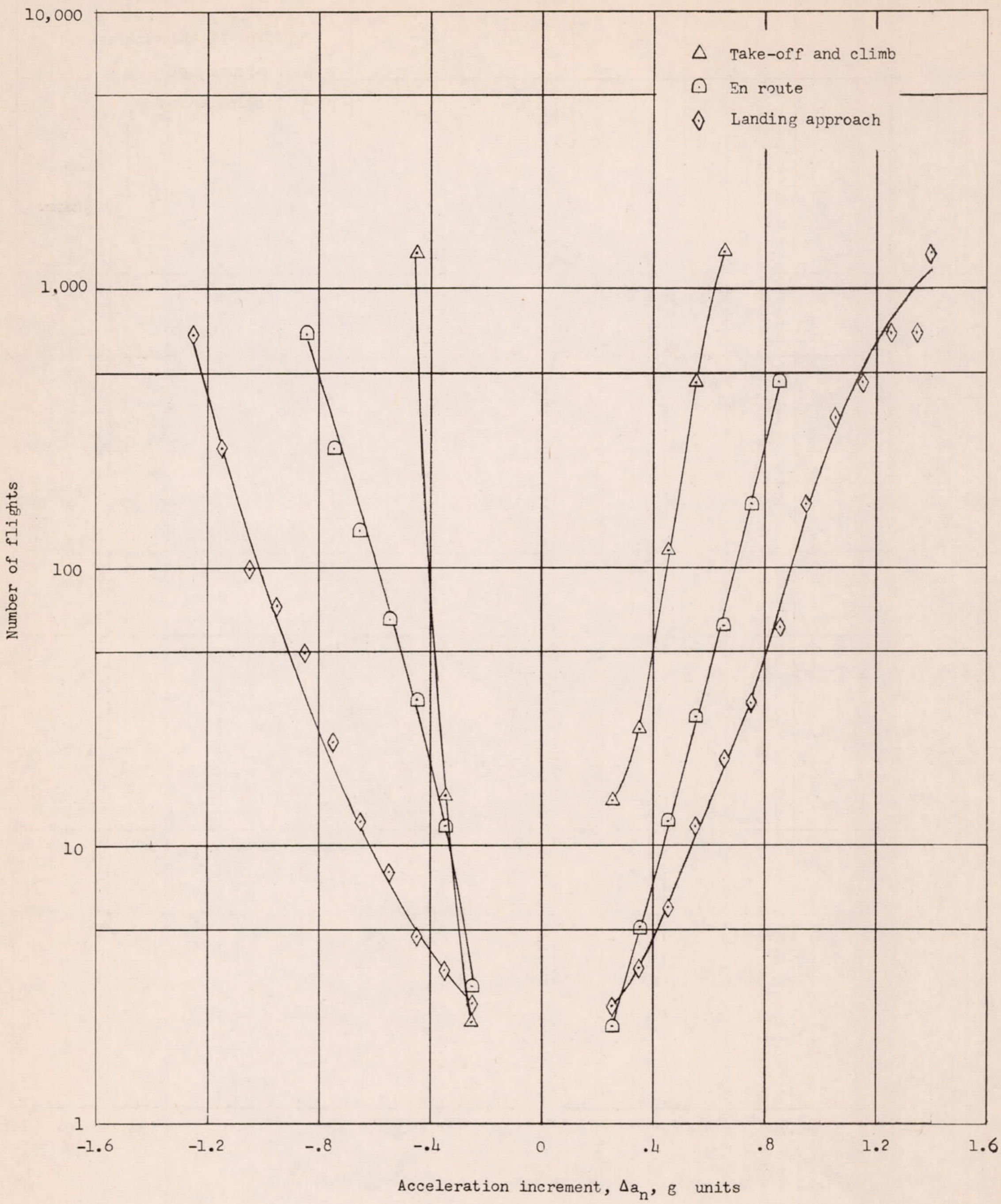
(a) Los Angeles operation.

Figure 6.- Comparison for the three flight conditions, for each operator, of the average number of flights required to equal or exceed a given value of acceleration increment.



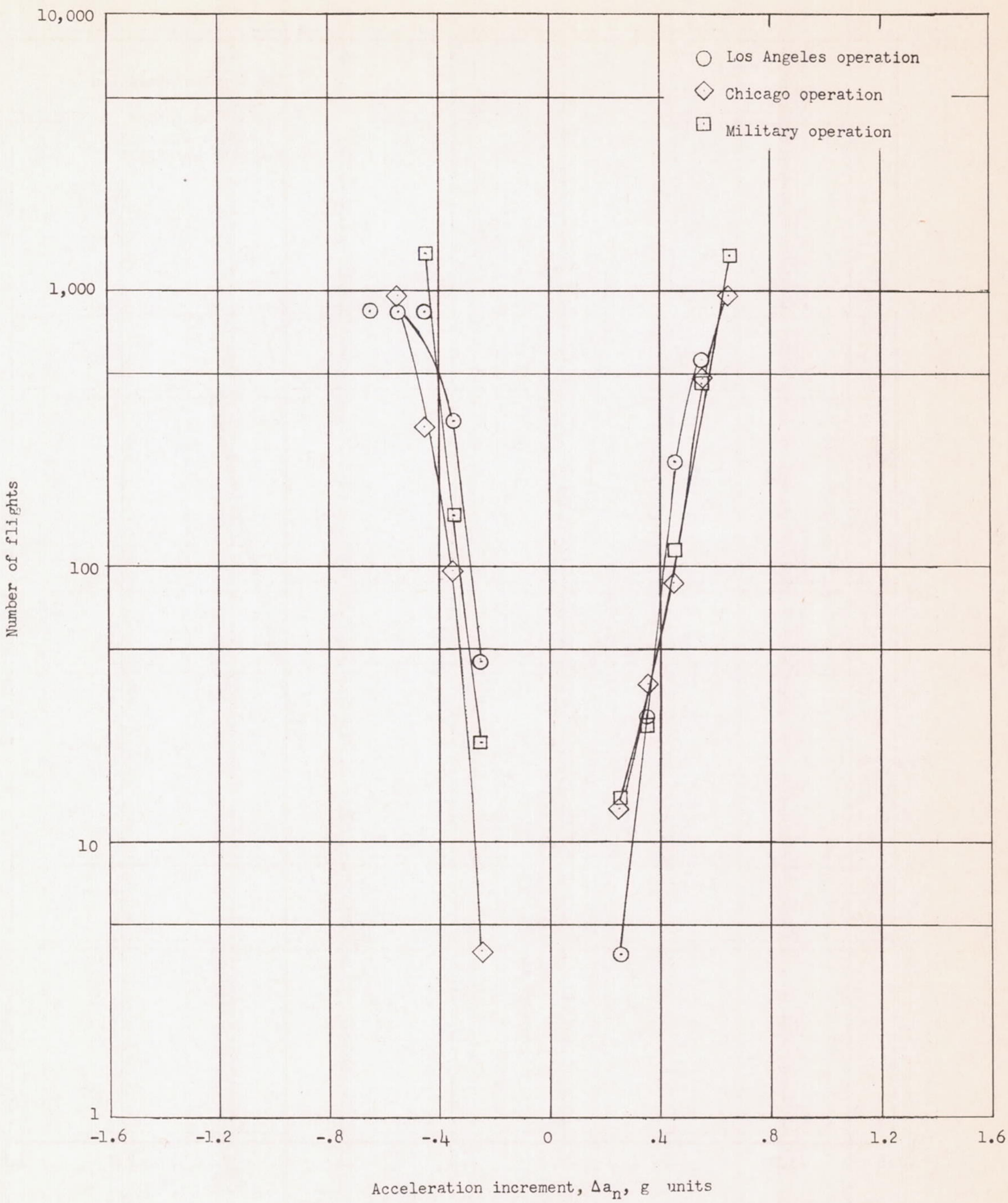
(b) Chicago operation.

Figure 6.- Continued.



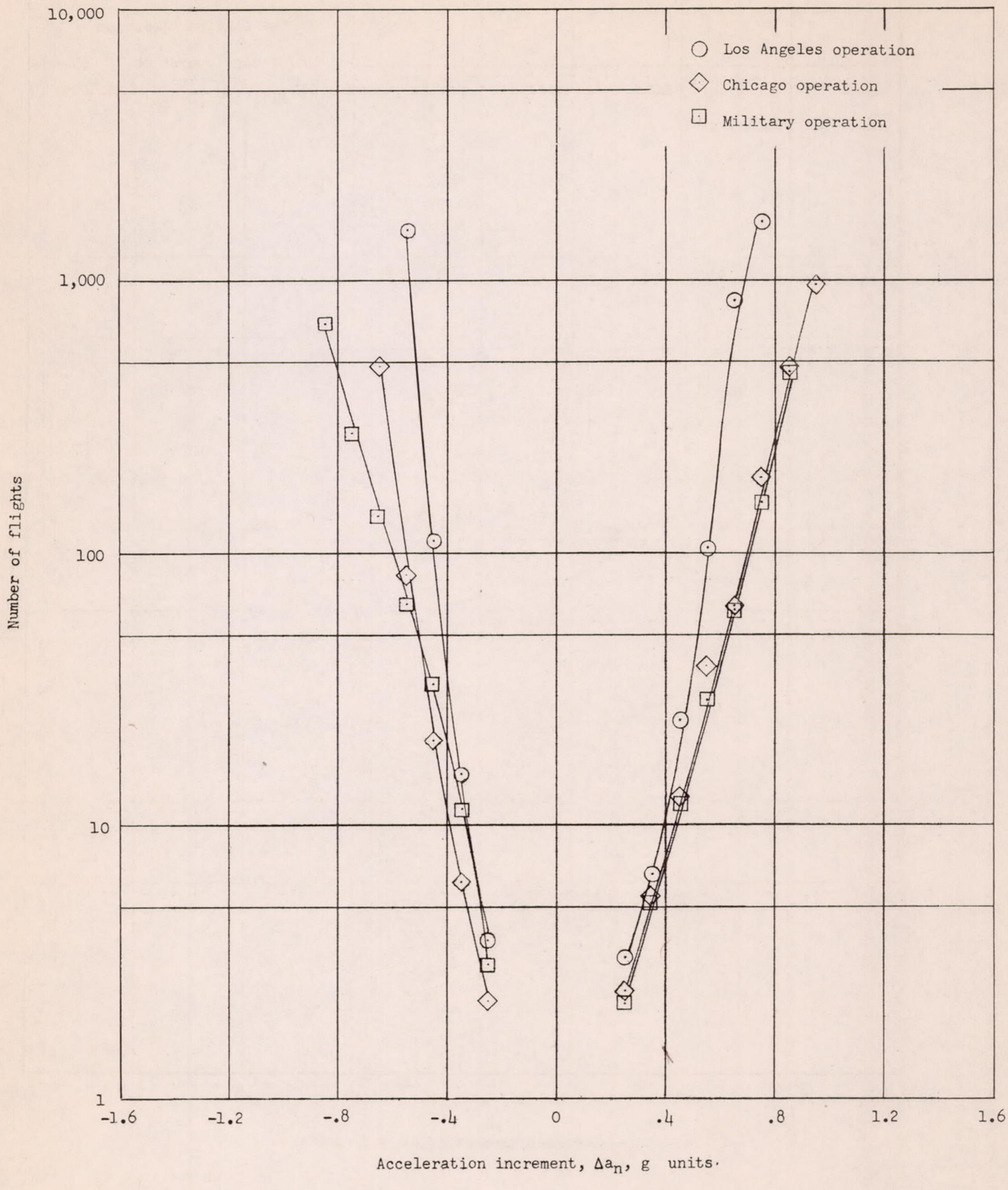
(c) Military pilot-training operation.

Figure 6.- Concluded.



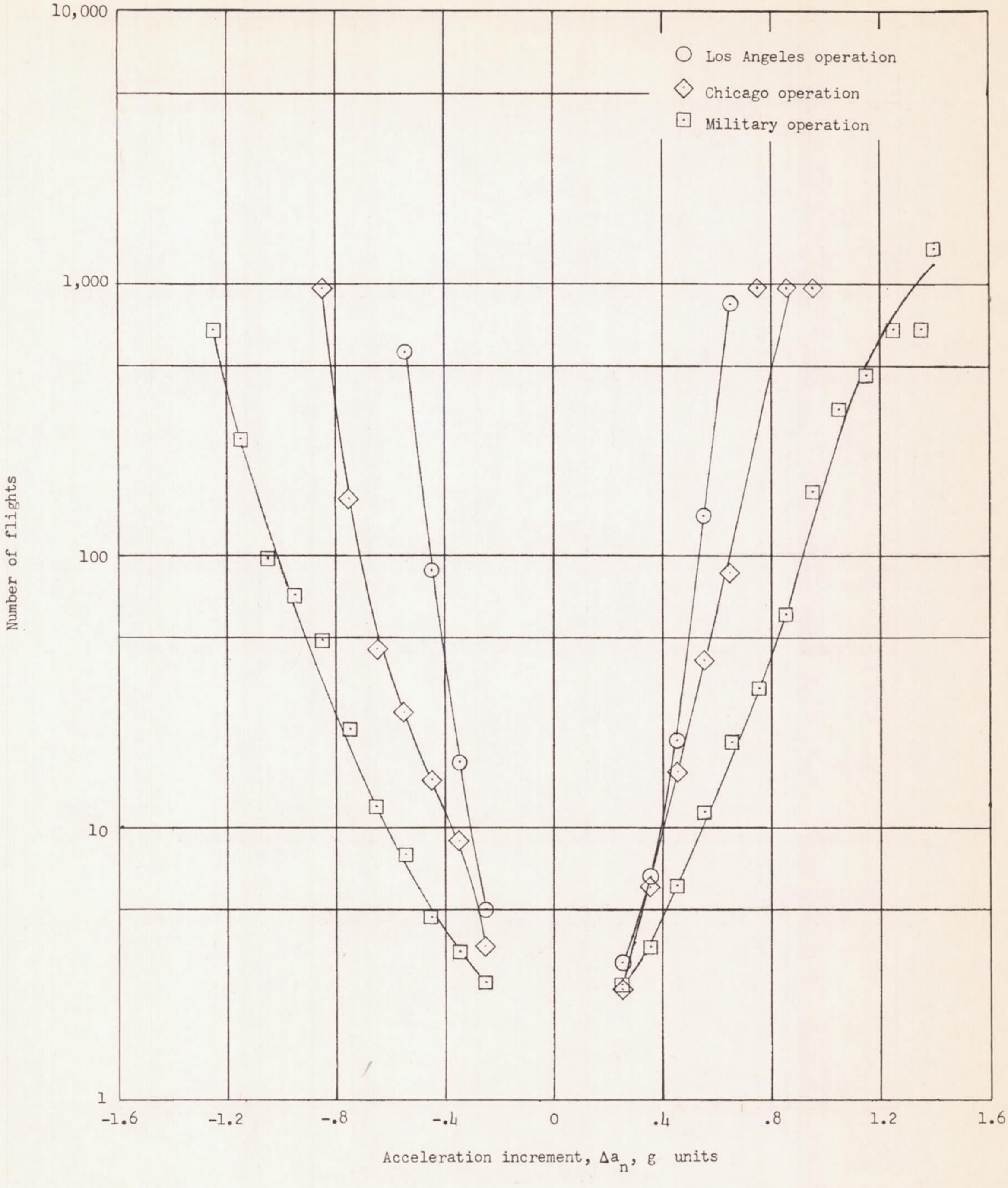
(a) Take-off and climb.

Figure 7.- Comparison of the variation among the three operations, for each flight condition, of the average number of flights required to equal or exceed a given value of acceleration increment.



(b) En route.

Figure 7.- Continued.



(c) Landing approach.

Figure 7.- Concluded.

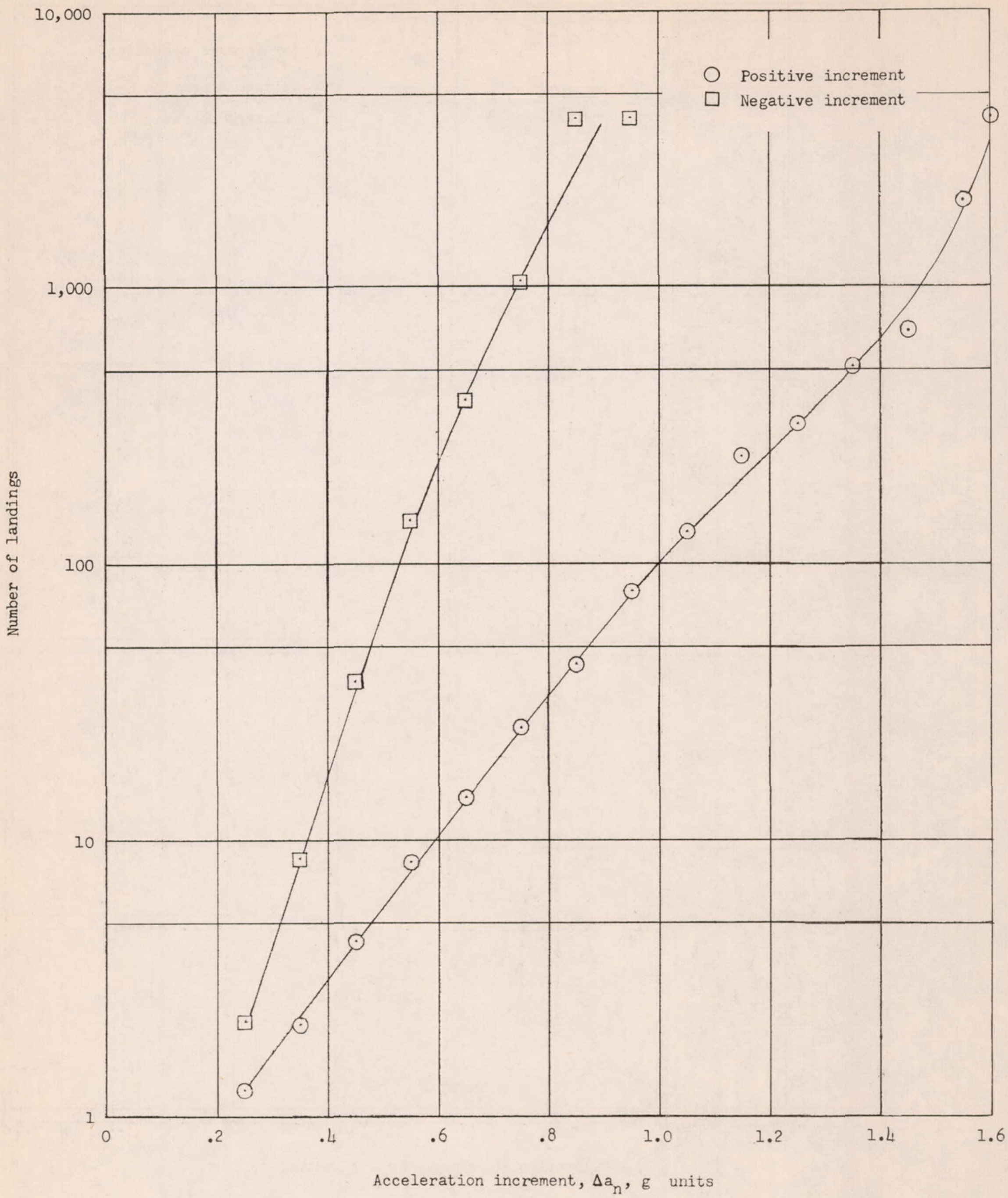


Figure 8.- Summary plot of the number of landings required to equal or exceed a given value of acceleration increment.

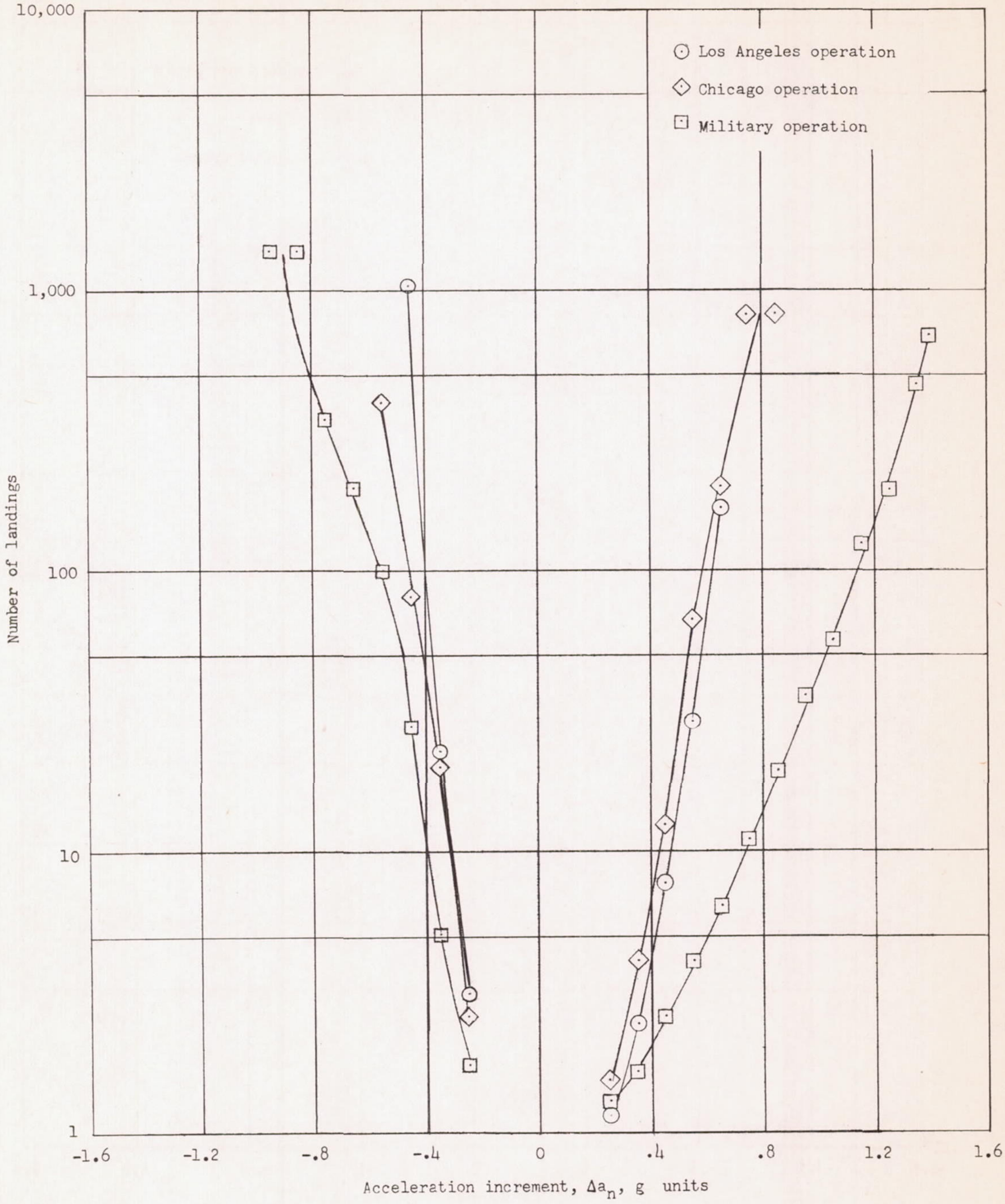
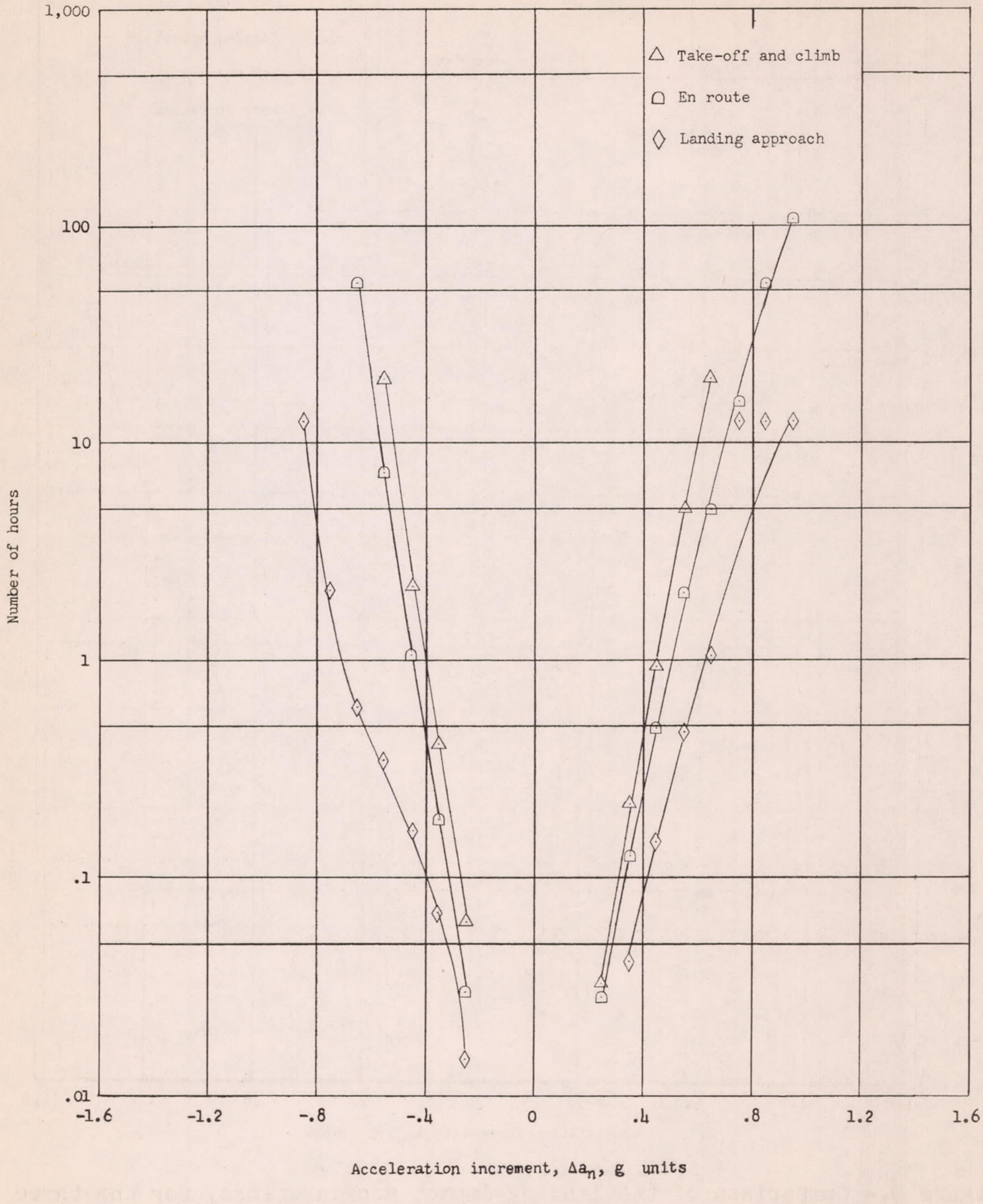
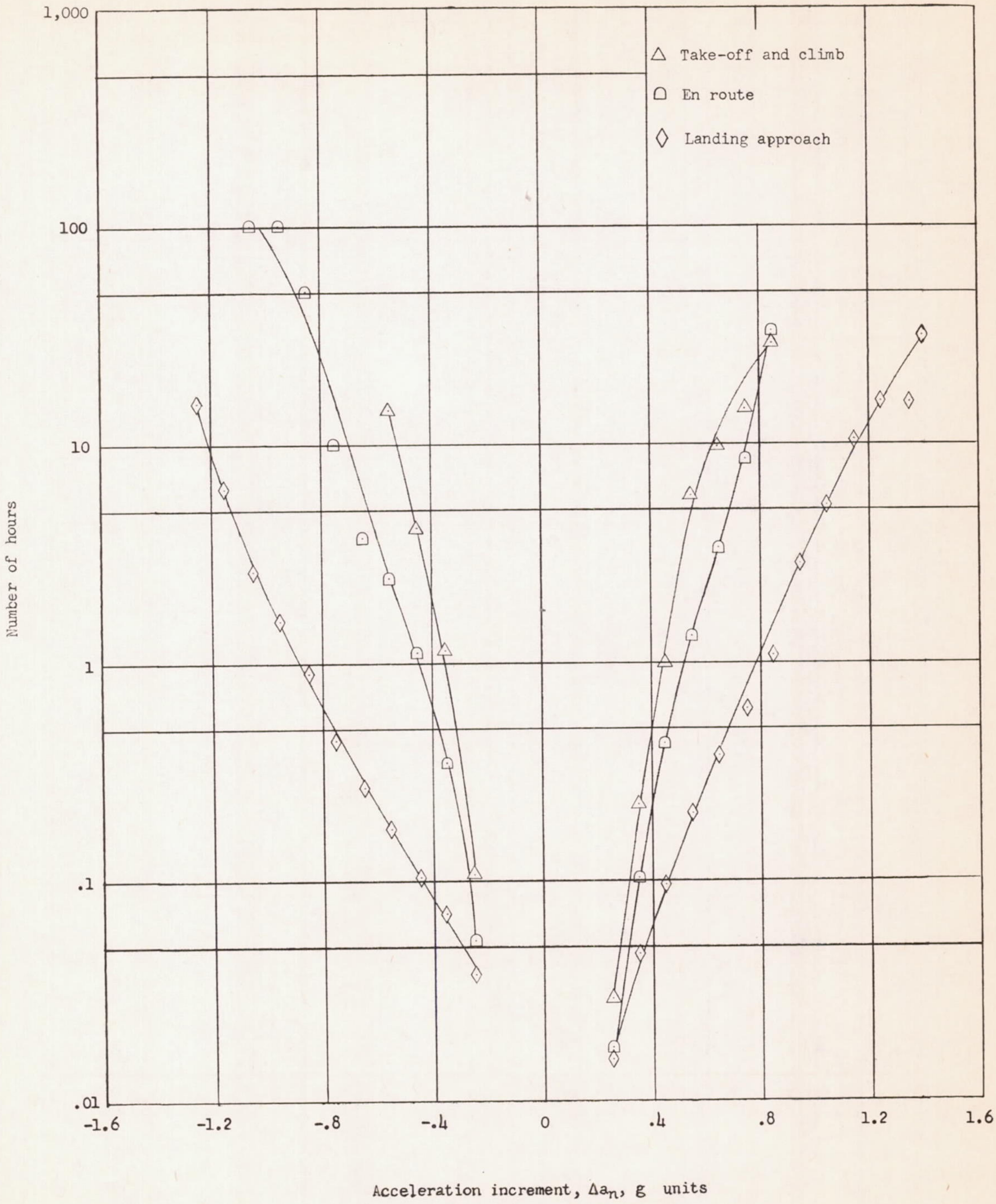


Figure 9.- Comparison of the landing-impact accelerations, for the three operators, of the average number of landings required to equal or exceed a given value of acceleration increment.



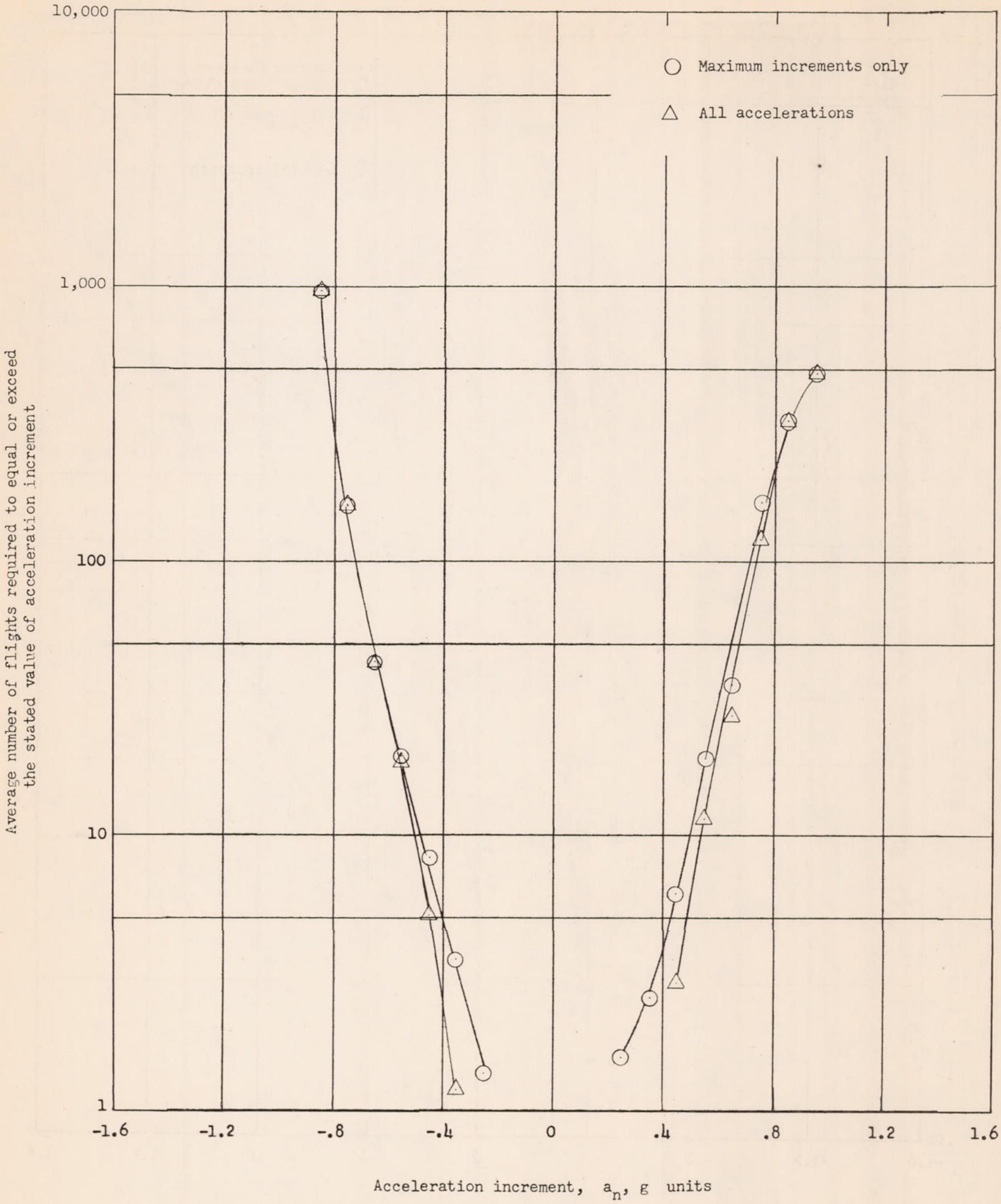
(a) Chicago operation.

Figure 10.- Comparison of the average number of flying hours required in each flight condition to equal or exceed the given value of acceleration increment.



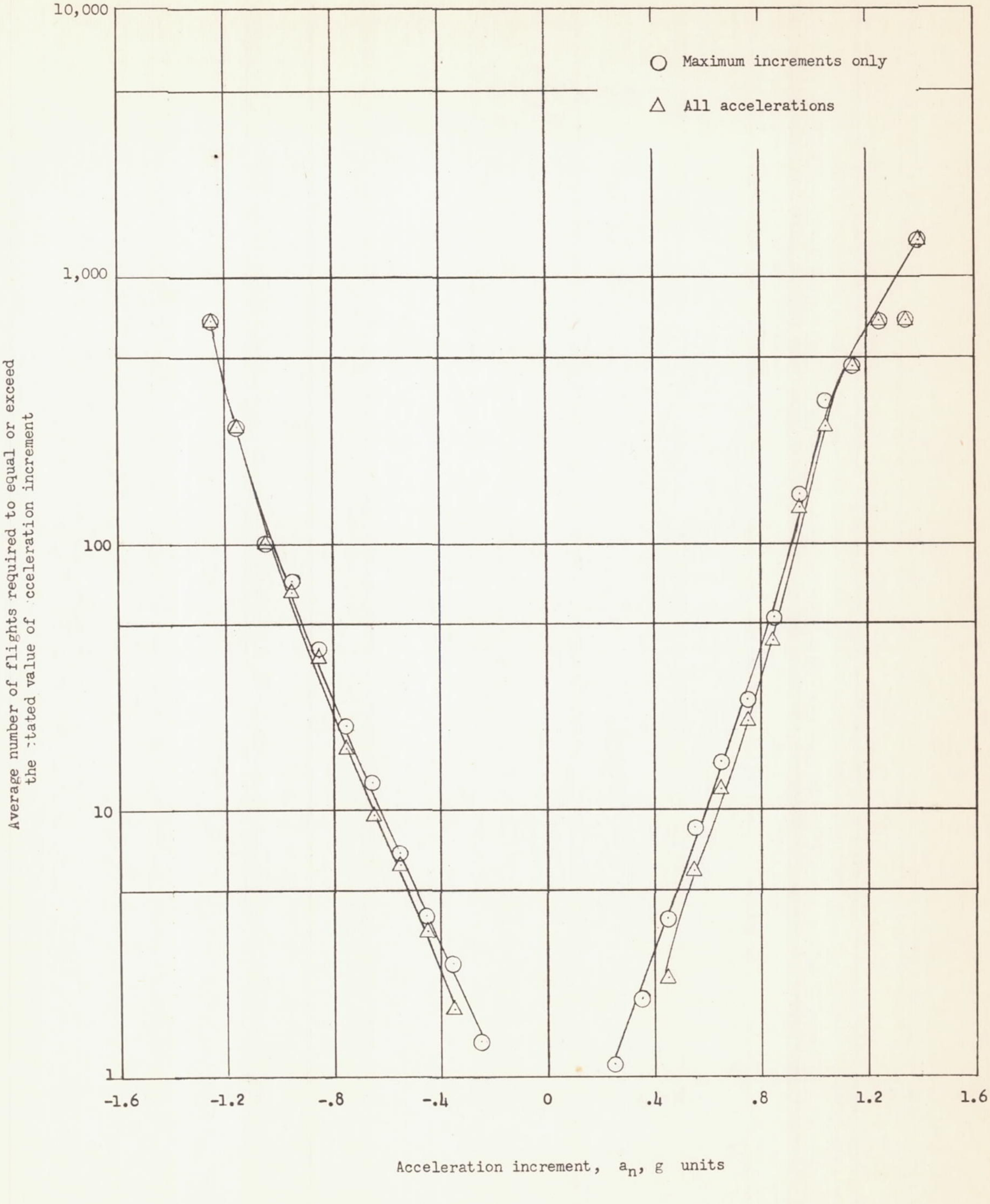
(b) Military pilot-training operation.

Figure 10.- Concluded.



(a) Chicago operation.

Figure 11.- Comparison of plotting all acceleration increments per flight as opposed to use of only the maximum and minimum acceleration increments per flight.



(b) Military pilot-training operation.

Figure 11.- Concluded.

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