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RESEARCH MEMORANDUM

COMPARISON OF NORMAL LOAD FACTORS EXPERIENCED WITH JET FIGHTER AIRPLANES DURING COMBAT OPERATIONS WITH THOSE OF FLIGHT TESTS CONDUCTED BY THE NACA DURING OPERATIONAL TRAINING

7/28/60

By Harold A. Hamer, Carl R. Huss, and John P. Mayer

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RESEARCH MEMORANDUM

COMPARISON OF NORMAL LOAD FACTORS EXPERIENCED WITH JET FIGHTER AIRPLANES DURING COMBAT OPERATIONS WITH THOSE OF FLIGHT TESTS CONDUCTED BY THE NACA DURING OPERATIONAL TRAINING

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SUMMARY

A comparison of normal load factors measured during combat operations with those measured during an NACA flight program conducted with fully instrumented service airplanes in operational training is presented. Results are shown in the form of plots of measured normal load factors against indicated airspeed, probability of occurrence, and average flight time required for exceeding a given positive or negative load factor.

The results indicate that, for an equal number of maneuvers, normal load factors obtained from the limited NACA flight program as well as those obtained during other training operations are somewhat greater than those obtained during combat when based on the service-limit load factor. When the data are compared on a time-to-exceed basis, it is indicated that the average flight time required to exceed a given load factor for the NACA flight program is less than that for normal operational training or combat data. For normal operational training and combat, the differences in the time-to-exceed values are small. This result is different from the results obtained for airplanes during World War II where it was determined that, for the same flight time, training operations resulted in larger normal load factors than combat operations.

INTRODUCTION

The National Advisory Committee for Aeronautics with the cooperation of the Air Force and Bureau of Aeronautics, Department of the Navy, has been conducting a flight program with several jet-propelled fighter-type airplanes in order to obtain information on the airplane response

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and the actual amounts and rates of control motion used by service pilots in performing their regular operational training missions. The airplanes were instrumented by the NACA and were flown by regular service pilots. Preliminary data for each of the airplanes tested in this program: the North American F-86A, McDonnell F2H-2, Republic F-84G, and Lockheed F-94B airplanes have been presented in references 1 to 5. In addition, a summary of references 1 to 5 and a brief statistical analysis of these data are given in reference 6. Since information of this type may be useful for the determination of more realistic design load criteria, questions have arisen as to whether the data recorded in these limited tests are representative of the values which are experienced in combat operations.

This paper, which is considered supplementary to reference 6, presents a comparison between the available normal-load-factor data which have been obtained on F-86, F-84, and F-94 airplanes in combat operations (refs. 7 to 9) and the normal-load-factor data obtained during the shorter NACA flight program conducted with service airplanes in operational training. Other training data (refs. 10 to 12) which involve many more hours of flight time are also included in this paper. Airplane normal load factor is the only quantity compared because it is the only quantity other than airspeed and altitude which was measured in combat operations. Although only normal-load-factor data have been compared, it is possible that similar comparisons may be expected for the other quantities defining the control motions and airplane response given in reference 6.

SYMBOLS

N	total number of load-factor peaks
$\bar{n}_v$	average value of normal load factor frequency distribution
n_v	measured normal load factor
n_{v_s}	service-limit positive normal load factor
P	probability
T	total number of hours represented by data
t	average flight time required to exceed a given normal load factor, hr
V_i	indicated airspeed, knots

α_3 coefficient of skewness of frequency distribution, $\frac{1}{\sigma^3}\frac{\sum(n_v - \bar{n}_v)^3}{N}$

α_4 coefficient of kurtosis of frequency distribution, $\frac{1}{\sigma^4}\frac{\sum(n_v - \bar{n}_v)^4}{N}$

σ standard deviation of frequency distribution, $\left[\frac{\sum(n_v - \bar{n}_v)^2}{N}\right]^{1/2}$

SCOPE OF DATA

This paper includes comparisons of two sets of normal-load-factor data for combat and two sets of normal-load-factor data for training. One set of training data was obtained by the NACA on fully instrumented North American F-86A, Republic F-84G, Lockheed F-94B, and McDonnel F2H-2 airplanes during regular squadron operational training. Data were recorded, however, only during those flights in which the primary mission was acrobatics, ground gunnery, aerial gunnery, or dive bombing. (See refs. 1 to 5.) The normal load factors presented for these airplanes were measured with standard NACA air-damped recording accelerometers. The other set of training data was obtained by the U. S. Air Force on North American F-86A airplanes (ref. 10), Lockheed F-80A and F-80B airplanes (ref. 11), and on F-80A, F-80B, and F-80C airplanes (ref. 12) during operational training in this country. These data were recorded with USAF flight analyzers.

The two sets of combat data are designated as "combat operations" and "enemy engagements." The combat-operations data were recorded on F-86E, F-86F, F-84E, F-84G, and F-94B airplanes in Korea with USAF flight analyzers. (See refs. 7 to 9.) Enemy-engagement data include all the normal-load-factor values for any flight where actual contact was made with the enemy. The enemy-engagement flights cover a total flight time of 231 hours and are taken from 1577 hours of combat operations with F-86E and F-86F airplanes. Combat-operations data include the load-factor values for all combat missions and contain enemy-engagement data.

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The scope of the four sets of data is summarized in the following table:

Airplane		Training				Combat			
		NACA flight program		USAF		Combat operations (includes enemy engagements)		Enemy engagement (from 1577 hours of combat operations)	
Type	Model	Hours	Flights	Hours	Flights	Hours	Flights	Hours	Flights
F-86	A	14.3	24	1150	--------				
	E and F					1265	1080	231	179
F-84	G	19.6	20						
	E and G					489	348		
F-94	B	7.9	18			255	186		
F2H	2	17.8	18						
F-80	A and B			1212	1274				
	A, B, and C			1044	1172				

AIRPLANES

The F-86A, F-86E, and F-86F airplanes have the same dimensions and the same physical characteristics, except for the horizontal tail. The F-86A airplane has a conventional horizontal tail (with adjustable stabilizer) whereas the F-86E and F-86F airplanes have the action of the elevator and stabilizer combined into one unit, known as the controllable "flying tail." The F-86F airplane is also equipped with a 6-inch—3-inch extended leading edge. The dimensions and physical characteristics are the same for the F-84E and F-84G airplanes. Dimensions and physical characteristics of the F-86A, F-84G, and F-94B airplanes are given in reference 6.

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RESULTS AND DISCUSSION

The results presented in this paper are in the form of V-n envelopes and probability curves. The probability curves are given in two forms: the probability of exceeding a given normal load factor and the average flight time required to exceed a given normal load factor.

The frequency distributions of normal load factors and some of the statistical parameters representing the data are given in tables I to III for the F-86, F-84, and F-94 airplanes, respectively. The load-factor data given in the tables represent peak values greater than 2 and less than 0. For the data of the NACA flight program, load-factor peaks were counted by using method B of reference 6.

V-n envelopes.- In order to compare the load factors reached during combat and training, the maximum positive and negative normal load factors and the corresponding indicated airspeeds for the combat and training data are shown in figures 1, 2, and 3 for the F-86, F-84, and F-94 airplanes, respectively. Only those points necessary to define the envelope for each of the sets of data are plotted. The V-n diagrams are included in these figures for a comparison of the test results with the service limits of the corresponding airplane. The V-n diagrams shown in the figures are for sea-level conditions and for about the average in-flight gross weight of each airplane.

It may be seen in figures 1 to 3 that the service-limit positive normal load factor was exceeded by an appreciable amount with the F-86 airplanes and was reached with the F-84 and F-94 airplanes. Below the service-limit load factor, it may be seen that the training and combat data are quite similar as to the magnitude of normal load factor reached at a given indicated airspeed, except for the F-94B airplane. In this case, the lack of large positive normal load factors at the higher airspeeds during combat operations is probably due to the fact that, as stated in reference 7, the F-94B had seen only limited action as an interceptor and therefore the data may not be representative of what is to be expected under normal combat operation. Negative normal load factors obtained during both training and combat were generally small; however, three load factors greater than -2 were measured on the F-86E and F-86F airplanes during combat.

Probability of exceeding a given positive normal load factor.- The probability of exceeding any positive normal load factor greater than 2 for each of the four sets of F-86 data is given in figure 4. The experimental probabilities were calculated by dividing the summation of the number of load-factor peaks above any given load-factor level by the total number of load-factor peaks under consideration. The probability was also calculated by fitting a Pearson type III curve through the data.

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(See ref. 13.) The probability curves fit the experimental points reasonably well, except for the very large load-factor values of the USAF training data. These large load-factor values are probably associated with an emergency or inadvertency type of load-factor frequency distribution which cannot be predicted on the basis of frequency distributions obtained at load factors below the limit load factor. (See ref. 6.) The four plots show that the Pearson type III curve is adequate for predicting the probability of exceeding any load factor up to about the positive design limit of the F-86 airplanes.

For comparsion of the four sets of data, the probability curves from figure 4 are shown in figure 5. It may be noted that the spread in the probability values is small throughout the load-factor range for the four sets of F-86 data with the spread between all the curves, at a load factor of 6, being only of the order of about 2 to 1. The probabilities for the NACA flight program and enemy-engagement data are the same and those of the USAF training and combat-operations data are about the same. The NACA flight program and enemy-engagement data appear to be somewhat more severe than the USAF training and combat-operations data.

Since the service-limit normal load factor for the F-86A is different from that of the F-86E and F-86F airplanes, the curves for the four sets of data are shown in figure 6 as probability against the load-factor ratio $n_V - 2/n_{V_S} - 2$. The curves are plotted in this way since it is indicated in reference 6 that the manner in which a pilot controls an airplane is influenced by the magnitude of the service-limit load factor. In figure 6 the value for the service-limit normal load factor for the F-86A is taken as 6 and that for the F-86E and F-86F airplanes is taken as 7 (see fig. 1) even though the service-limit normal load factor is 6 for all of the F-86 airplanes at altitudes above 15,000 feet. The F-86E and F-86F service-limit normal-load-factor value of 7 is used because in the combat data of reference 8 the majority of normal load factors that were measured above 6 for the F-86E and F-86F airplanes were recorded at altitudes below 15,000 feet. It may be seen in figure 6 that, although the spread between all the probability curves is greater than when plotted against load factor, the probability of exceeding a given percentage of the limit load factor for the two sets of training data is somewhat higher than that for the two sets of combat data. Although not shown, the probability curves for the F-84 and F-94 airplanes have similar comparisons between the NACA flight-program data and the combat-operations data.

In reference 6 the data from about 3500 hours of training with jet fighter airplanes were used to obtain a tentative standard probability curve for training operations in terms of the load factor ratio $n_V - 2/n_{V_S} - 2$. The data and the standard training curve from reference 6 are shown in figure 7. The experimental probabilities for the combat data of the F-86, F-84, and F-94 airplanes are compared with this standard training curve in figure 8. It may be seen that the probability values for the combat operations data of the F-86 and the F-84 airplanes are about the same whereas the values for the F-94 airplane are considerably smaller. (As noted previously, the combat data for the F-94B may not be representative of normal combat operation.) The probability values for the enemy-engagement data appear to be slightly higher than the combat-operations data. The standard training curve from reference 6 falls above the combat data so that, for an equal number of maneuvers, normal load factors obtaned in training operations are somewhat greater than those obtained during combat when based on the load-factor ratio $n_v - 2/n_{v_s} - 2$.

Average flight time required to exceed a given positive normal load factor.- A probability curve such as shown in figure 8 is one method of characterizing the manner in which an airplane is utilized. Since it indicates the proportion of all load-factor peaks which exceed a given level, it may be thought of as a measure of the severity of the operations. Another measure of the manner in which the airplane is utilized is the ratio N/T, the average number of load-factor peaks per hour, which is a measure of the activity of the operations. Time-to-exceed curves are a joint measure of both severity and activity, because the probability curve determines the shape and the average number of peaks per hour determines the level. The value of the ratio N/T is influenced greatly by the type and length of mission flown. For example, in reference 12, the number of load-factor peaks per hour greater than 2 varied from 17 in transition and proficiency training to 69 in low-angle-bombing training. This result would mean that, if the probability curves are similar, the average time to exceed a given load factor in transition and proficiency training would be four times that obtained in low-angle-bombing training. On the other hand, if the missions of two similar airplanes are the same but the distances to the target are different, the time-to-exceed values would be directly proportional to the distance to the target plus the time spent in maneuvering at the target.

It may be noted that, although probabilities of exceeding a given load-factor ratio may be higher in training than in combat for an equal number of maneuvers, many more maneuvers per hour of flight time might be obtained in combat. Thus, on a time-to-exceed basis, the flight time required to exceed a given load factor might be less for combat than for training. In figure 9, time-to-exceed values for the four sets of F-86 data are plotted against normal load factor. The flight time required to exceed a given normal load factor was calculated by dividing the total number of hours represented by the data by the product of the probability determined from the Pearson type III curve and the total number of measured load-factor peaks. It can be seen that the time-to-exceed values for the 1265 hours of combat operations are somewhat less than those for the 1150 hours of USAF training operations. The average flight time required to exceed a given load factor in the USAF training operations is about twice that required during combat operations.[1] This trend is different from that obtained for World War II airplanes where, on the basis of normal load factor, it was determined that training operations resulted in larger normal load factors than combat operations for the same flight time. (See ref. 14.) One contributing reason for this result may be that the speeds of present-day fighters are much greater and therefore the time spent in traveling to and from the target is much less than that for World War II fighters. The average time required to exceed a given load factor for the NACA flight program is slightly less than that obtained in enemy engagements, about one-quarter of that obtained in normal operational training, and about one-half of that obtained in overall combat operations.

The time-to-exceed curves for the F-84 and F-94 as well as the F-86 airplanes during combat and training are compared on the basis of the service-limit normal load factor in figure 10. It can be seen that the time-to-exceed values for the airplanes of the NACA flight program are less than those of combat or the USAF training, a reflection of the high values of the frequency ratio N/T (32 to 73) for the NACA flight program as compared with those for the combat and USAF training operations (12 to 24).

Probability curves for negative normal load factor.- Because of the relatively small number of negative normal load factors obtained, as detailed a comparison as that for positive load factors is not possible. A Pearson type III curve was calculated for the set of data for the F-86E and F-86F airplanes during combat operations and is shown in figure 11 along with the experimental points for probability of exceeding a given negative load factor. Also shown in the figure are the experimental points for the enemy-engagement data and the F-84 data of the NACA flight program. Although the data for the two latter cases are very limited, it is seen that the probability of exceeding a given negative normal load factor for these two cases is approximately the same as that of combat operations.

In figure 12 it may be seen that the average flight time required to exceed a given negative normal load factor for the F-86 combat-operations data or enemy-engagement data is from 4 to 5 times greater than that for the F-84 airplane of the NACA flight program. This difference in time is indicative of the greater activity for the F-84 airplane for which the number of negative load-factor peaks per hour is 1.48 as compared to about 0.30 for the F-86 airplanes during combat operations and enemy engagements. The experimental points shown in figure 12 were obtained by dividing the total number of hours represented by the data by the summation of the number of load-factor peaks above any given load-factor level.

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[1]Although not shown in figure 9, the time-to-exceed curve for the F-84 combat-operations data is practically coincident with that for the F-86 combat-operations data.

CONCLUDING REMARKS

Probability curves have been compared for normal-load-factor data obtained during combat and training operations with jet-fighter-type airplanes. From the results presented in this paper it has been shown that, for an equal number of maneuvers, noraml load factors obtained from training operations are slightly greater than those obtained during combat when based on the service-limit load factor. Therefore, the tentative standard probability curve for jet-fighter-airplane training presented in reference 6 appears to be applicable to combat conditions. Although only normal-load-factor data have been compared, it is probable that similar comparisons may be expected for the other quantities defining the control motions and airplane response given in NACA RM L53L28.

When the data are compared on a time-to-exceed basis, it is shown that the average flight time required to exceed a given load factor for normal operational training or combat is from 4 to 10 times that required for the limited NACA flight program. It is indicated that time-to-exceed values may be considerably influenced by the type and length of mission. The differences between the average flight time required to exceed a given load factor in normal operational training and in combat operations are small. This result is not the same as that obtained for airplanes during World War II where it was determined that, for the same flight time, training operations resulted in larger normal load factors than combat operations.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 6, 1954.

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TABLE I.- FREQUENCY DISTRIBUTION OF NORMAL LOAD FACTOR FOR F-86 AIRPLANES

(a) Positive normal load factor

Load factor	Combat operations	Enemy engagement
2.0 to 2.39	7,666	1,554
2.4 to 2.79	5,705	1,272
2.8 to 3.19	3,719	921
3.2 to 3.59	2,452	651
3.6 to 3.99	1,623	500
4.0 to 4.39	877	243
4.4 to 4.79	536	155
4.8 to 5.19	384	104
5.2 to 5.59	220	72
5.6 to 5.99	126	46
6.0 to 6.39	52	26
6.4 to 6.79	20	12
6.8 to 7.19	11	1
7.2 to 7.59	4	1
7.6 to 7.99	2	0
8.0 to 8.39	1	2
8.4 to 8.79	0	0
8.8 to 9.19	0	0
9.2 to 9.59	1	1
N	23,399	5,561
T	1,265	231
$\bar{n}_v$	2.898	3.020
σ	0.792	0.860
α_3	1.527	1.464
α_4	5.828	5.723
N/T	18.5	24.1

Load factor	USAF training	NACA flight program
2.0 to 2.49	5,557	190
2.5 to 2.99	4,157	96
3.0 to 3.49	2,530	71
3.5 to 3.99	1,618	41
4.0 to 4.49	760	34
4.5 to 4.99	330	9
5.0 to 5.49	139	12
5.5 to 5.99	57	8
6.0 to 6.49	19	2
6.5 to 6.99	7	
7.0 to 7.49	3	
7.5 to 7.99	1	
8.0 to 8.49	0	
8.5 to 8.99	1	
9.0 to 9.49	1	
9.5 to 9.99	0	
10.0 to 10.49	0	
10.5 to 10.99	0	
11.0 to 11.49	0	
11.5 to 11.99	0	
12.0 to 12.49	2	
N	15,182	463
T	1,150	14.3
$\bar{n}_v$	2.919	2.981
σ	0.740	0.875
α_3	1.584	1.378
α_4	8.613	4.548
N/T	13.2	32.4

(b) Negative normal load factor

Load factor	Combat operations	Enemy engagement
0 to -0.199	182	20
-0.2 to -0.399	93	15
-0.4 to -0.599	72	15
-0.6 to -0.799	33	8
-0.8 to -0.999	10	1
-1.0 to -1.199	5	1
-1.2 to -1.399	7	1
-1.4 to -1.599	2	0
-1.6 to -1.799	0	0
-1.8 to -1.999	0	0
-2.0 to -2.199	1	0
-2.2 to -2.399	0	0
-2.4 to -2.599	1	1
-2.6 to -2.799	1	
N	407	62
T	1,265	231
$\bar{n}_v$	-0.342	----
σ	0.333	----
α_3	2.718	----
α_4	15.008	----
N/T	0.32	0.27

[redacted]

TABLE II.- FREQUENCY DISTRIBUTION OF NORMAL
LOAD FACTOR FOR F-84 AIRPLANES

Load factor	Combat operations	Load factor	NACA flight program	Load factor	NACA flight program
2.0 to 2.39	1,575	2.0 to 2.49	306	0 to -0.099	16
2.4 to 2.79	1,440	2.5 to 2.99	204	-0.1 to -0.199	4
2.8 to 3.19	1,041	3.0 to 3.49	179	-0.2 to -0.299	2
3.2 to 3.59	644	3.5 to 3.99	150	-0.3 to -0.399	1
3.6 to 3.99	471	4.0 to 4.49	110	-0.4 to -0.499	1
4.0 to 4.39	386	4.5 to 4.99	74	-0.5 to -0.599	1
4.4 to 4.79	242	5.0 to 5.49	28	-0.6 to -0.699	0
4.8 to 5.19	123	5.5 to 5.99	15	-0.7 to -0.799	1
5.2 to 5.59	71	6.0 to 6.49	12	-0.8 to -0.899	1
5.6 to 5.99	40	6.5 to 6.99	3	-0.9 to -0.999	1
6.0 to 6.39	19	7.0 to 7.49	3	-1.0 to -1.099	0
6.4 to 6.79	5			-1.1 to -1.199	1
6.8 to 7.19	5				
7.2 to 7.59	3				
N	6,065	N	1,084	N	29
T	489	T	19.6	T	19.6
$\bar{n}_v$	3.045	$\bar{n}_v$	3.287	$\bar{n}_v$	----
σ	0.853	σ	0.993	σ	----
α_3	1.252	α_3	0.973	α_3	----
α_4	4.478	α_4	3.683	α_4	----
N/T	12.4	N/T	55.3	N/T	1.48

TABLE III.- FREQUENCY DISTRIBUTION OF NORMAL

LOAD FACTOR FOR F-94 AIRPLANES

Load factor	Combat operations	Load factor	NACA flight program
2.0 to 2.39	816	2.0 to 2.49	158
2.4 to 2.79	806	2.5 to 2.99	116
2.8 to 3.19	553	3.0 to 3.49	100
3.2 to 3.59	370	3.5 to 3.99	77
3.6 to 3.99	261	4.0 to 4.49	51
4.0 to 4.39	142	4.5 to 4.99	35
4.4 to 4.79	73	5.0 to 5.49	17
4.8 to 5.19	23	5.5 to 5.99	12
5.2 to 5.59	12	6.0 to 6.49	5
5.6 to 5.99	3	6.5 to 6.99	4
6.0 to 6.39	0	7.0 to 7.49	3
6.4 to 6.79	0		
6.8 to 7.19	1		
7.2 to 7.59	1		
N	3,061	N	578
T	255	T	7.9
$\bar{n}_v$	2.913	$\bar{n}_v$	3.304
σ	0.693	σ	1.035
α_3	1.065	α_3	1.136
α_4	4.411	α_4	4.137
N/T	12.0	N/T	73.2

[redacted]

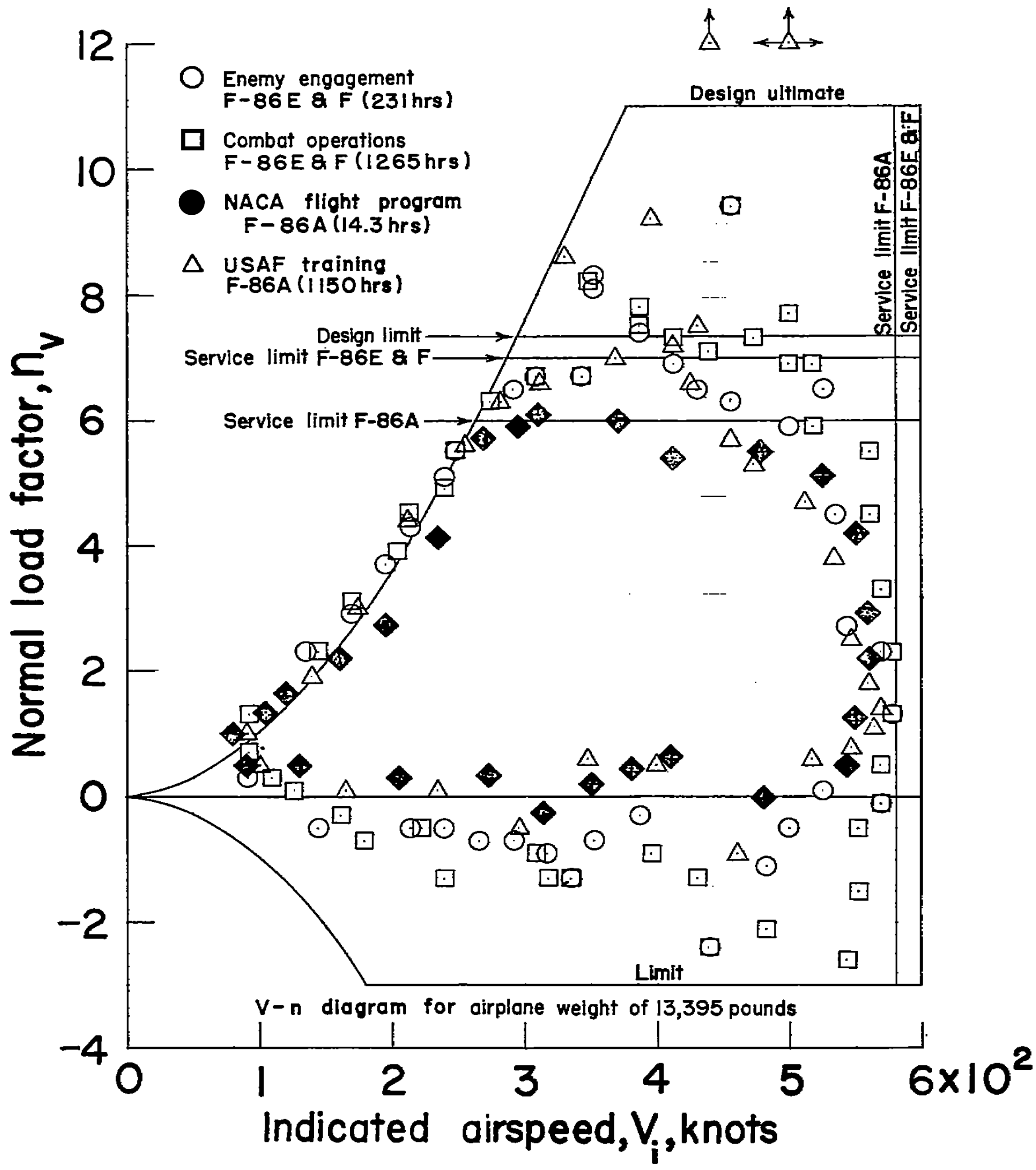

Figure 1.- Comparison of measured normal load factors obtained during combat and training with F-86 airplanes.

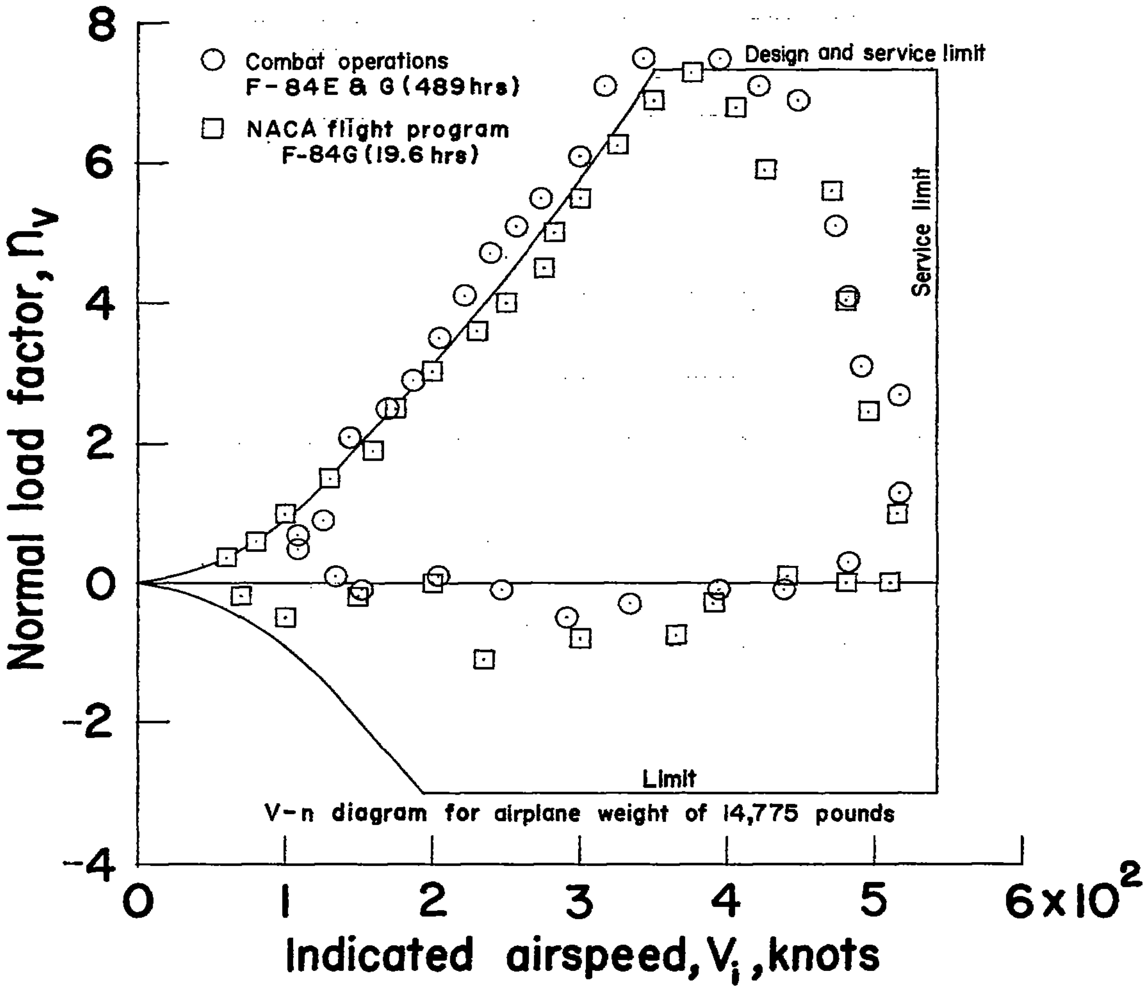

Figure 2.- Comparison of measured normal load factors obtained during combat and training with F-84 airplanes.

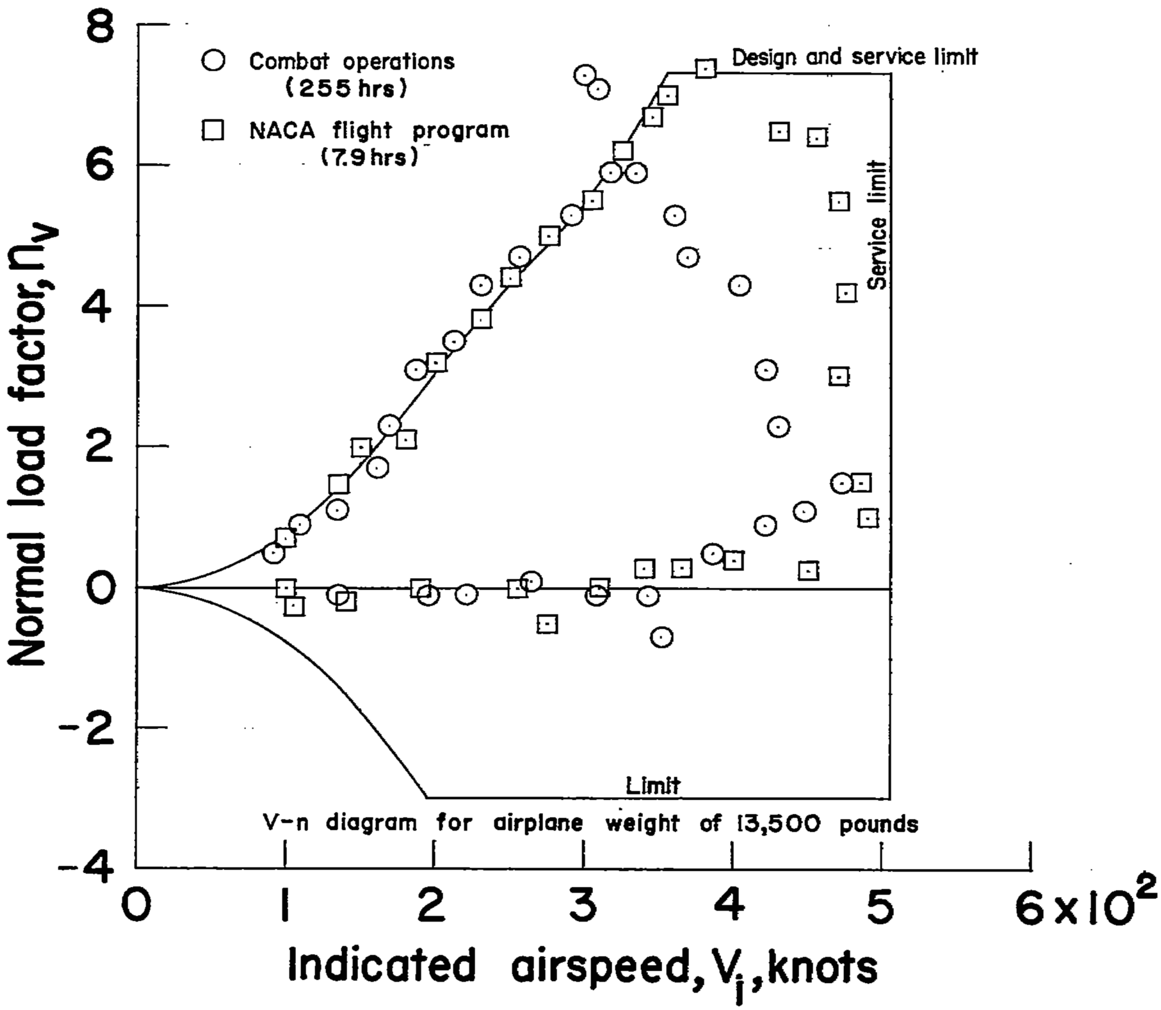

Figure 3.- Comparison of measured normal load factors obtained during combat and training with F-94B airplanes.

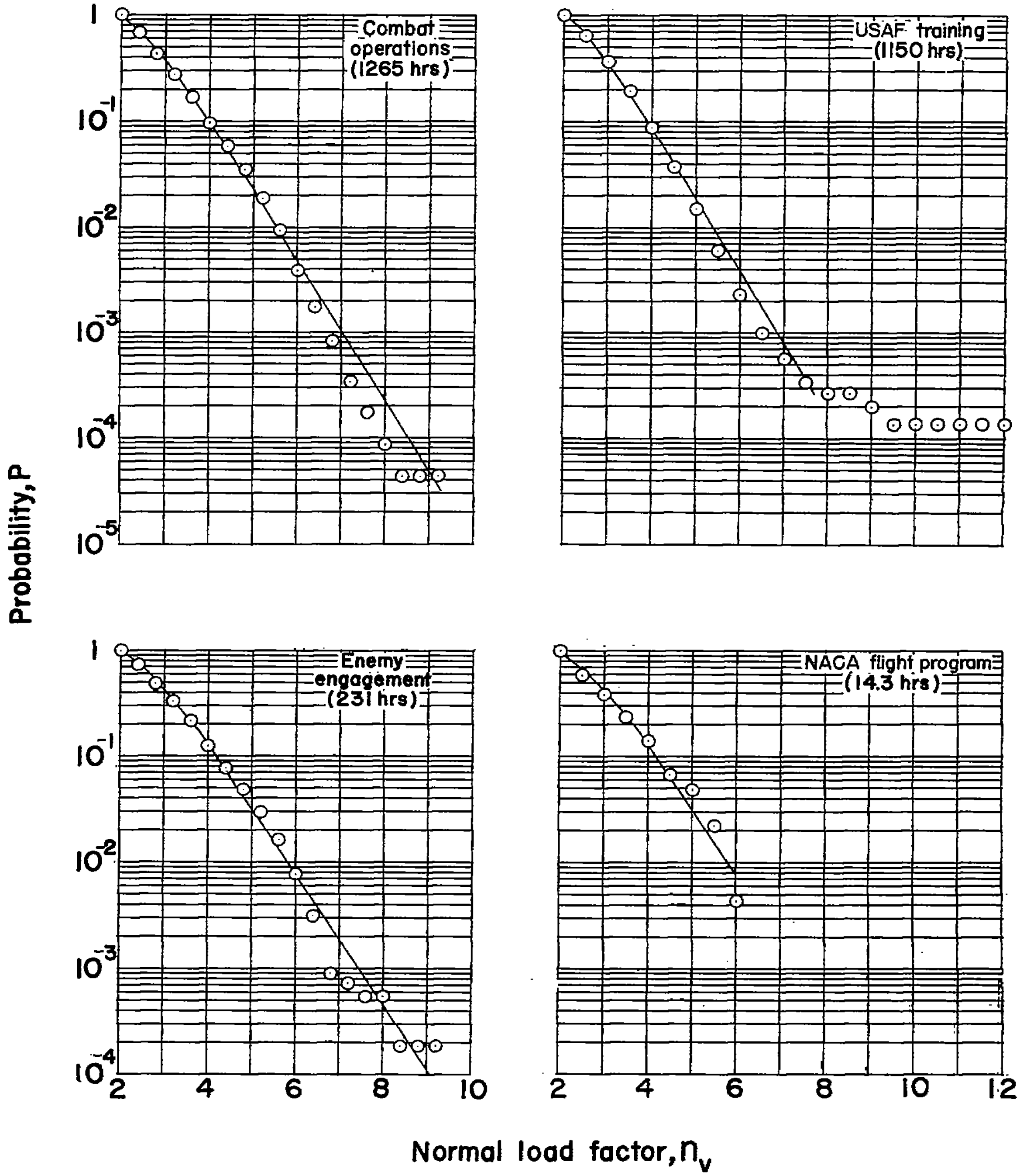

Figure 4.- Comparison of the F-86 test data with the fitted Pearson type III curve for probability of exceeding a given normal load factor.

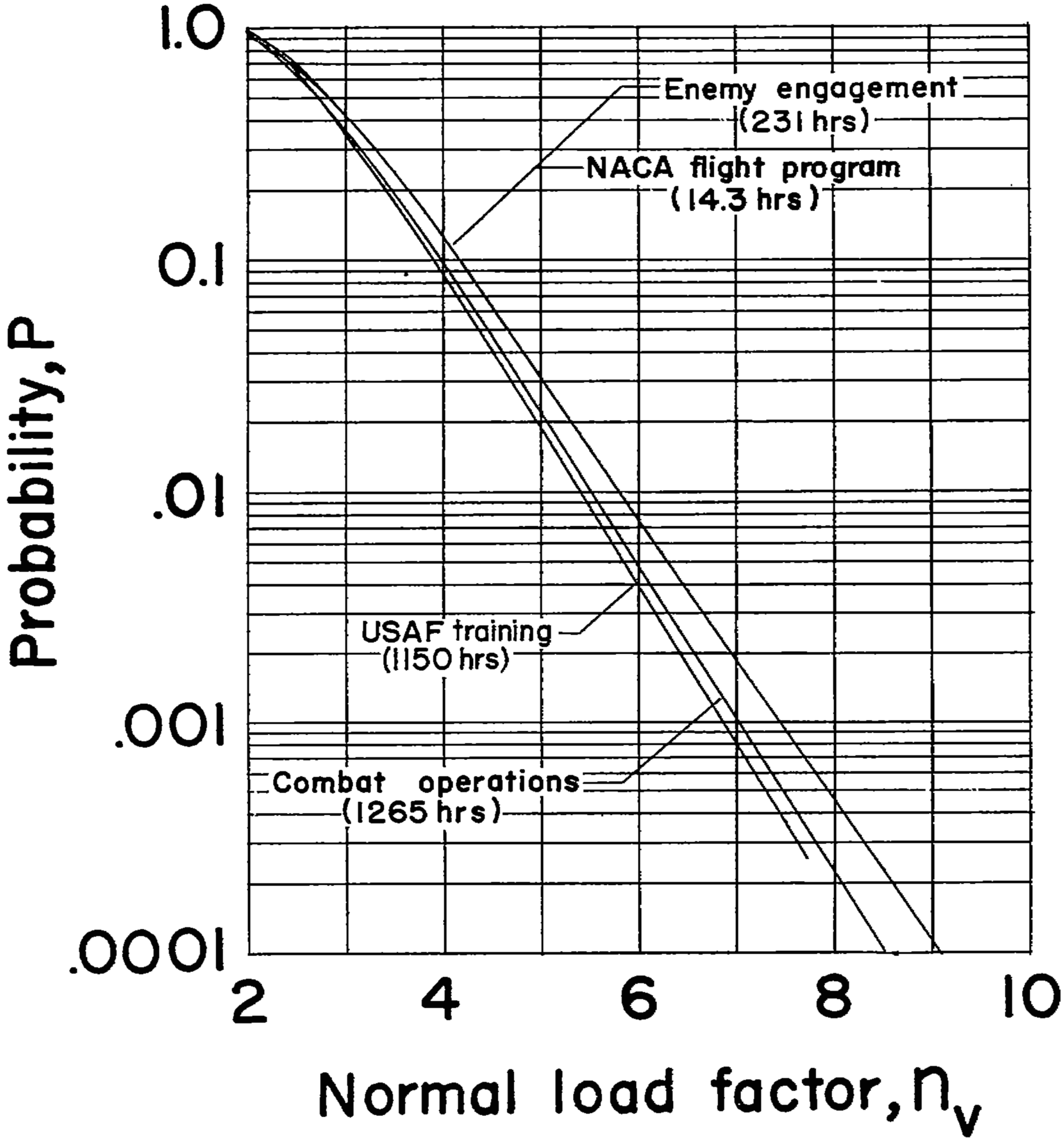

Figure 5.- Comparison of probabilities of exceeding a given normal load factor for F-86 airplanes during combat and training.

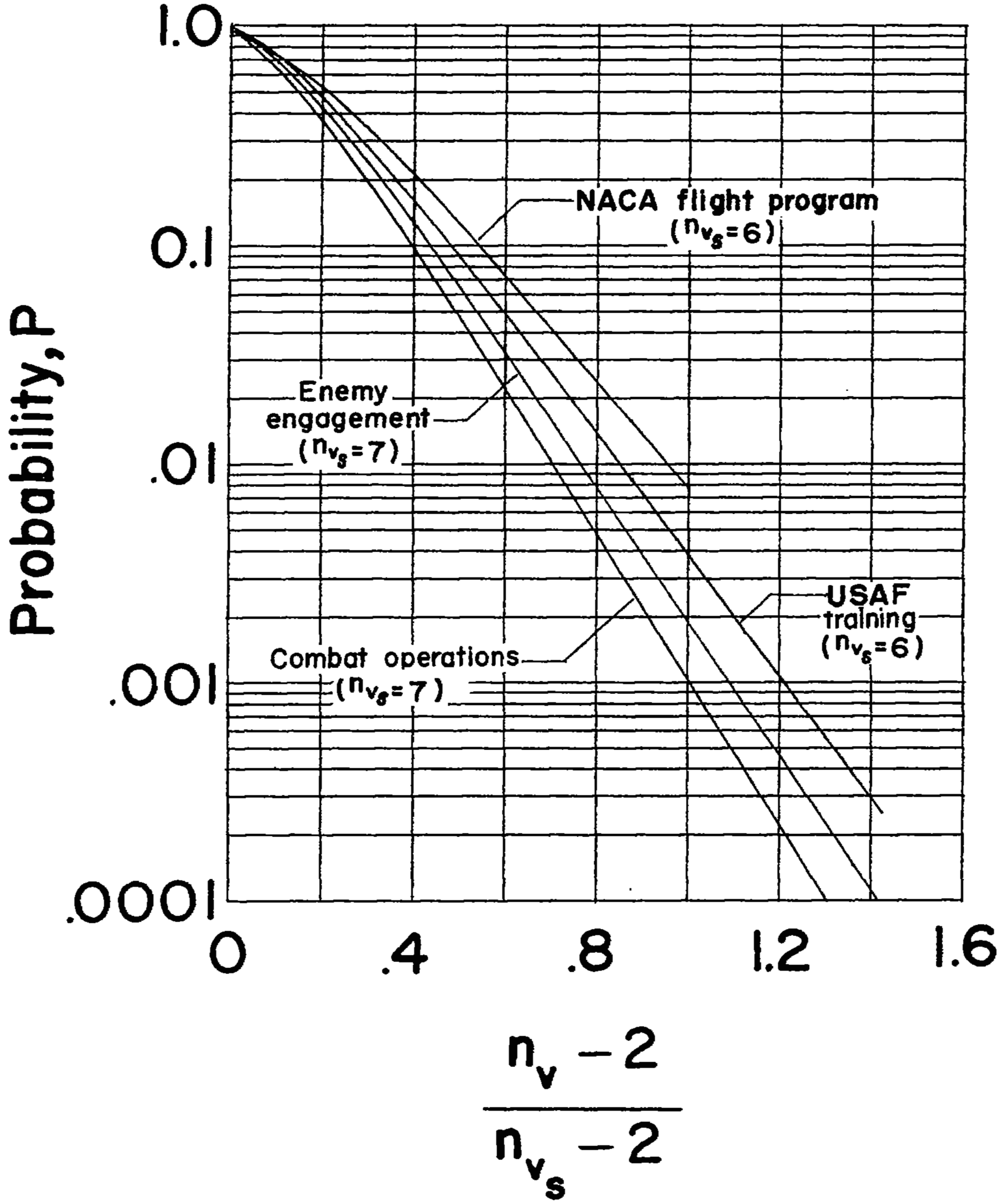

Figure 6.- Comparison of probabilities of exceeding a given fraction of the service-limit positive normal load factor for F-86 airplanes during combat and training.

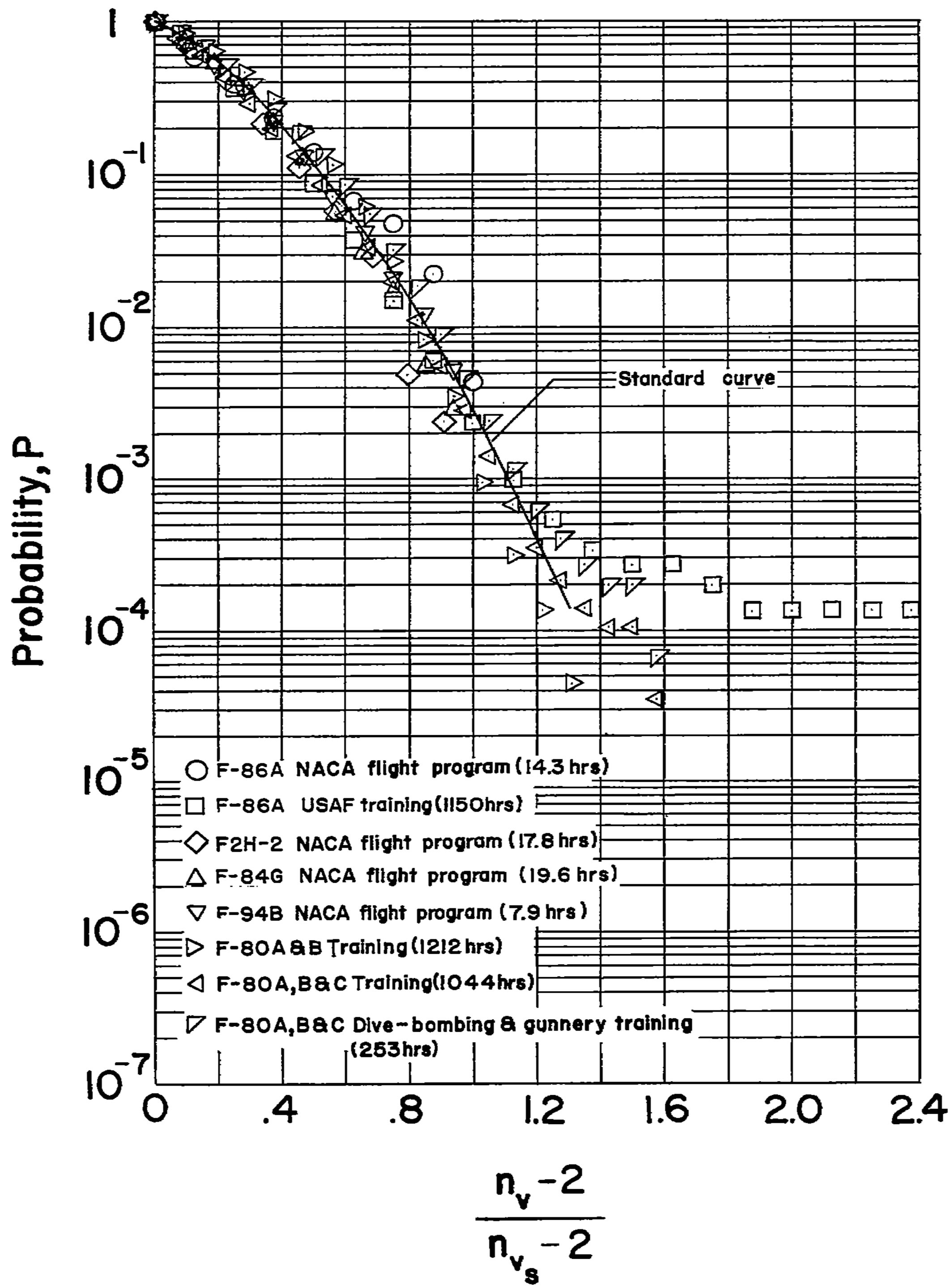

Figure 7.- Probability of exceeding a given fraction of the service-limit positive normal load factor for training operations.

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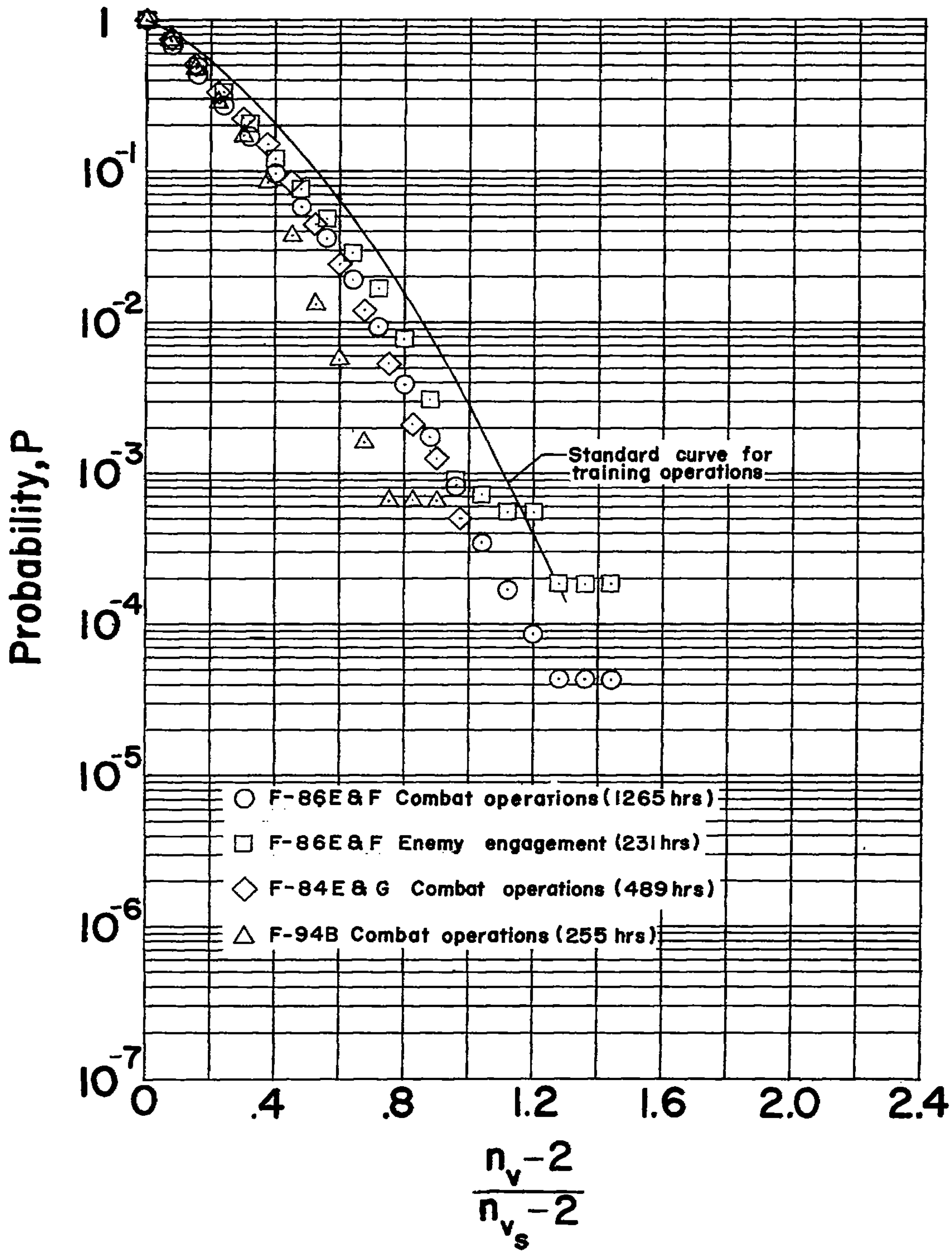

Figure 8.- Comparison of probability values obtained during combat with the standard probability curve for training operations.

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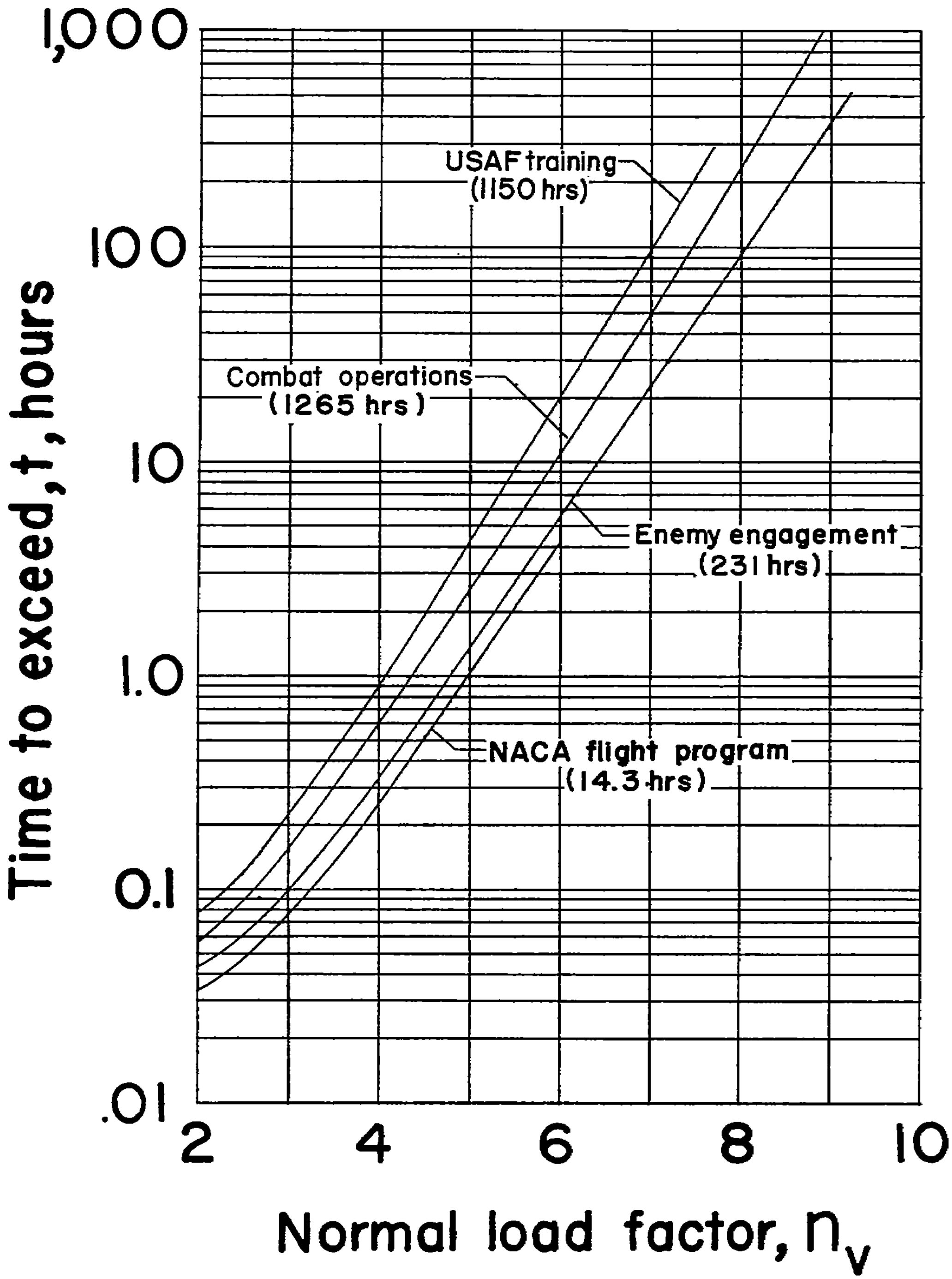

Figure 9.- Comparison of average flight times required to exceed a given normal load factor for F-86 airplanes during combat and training.

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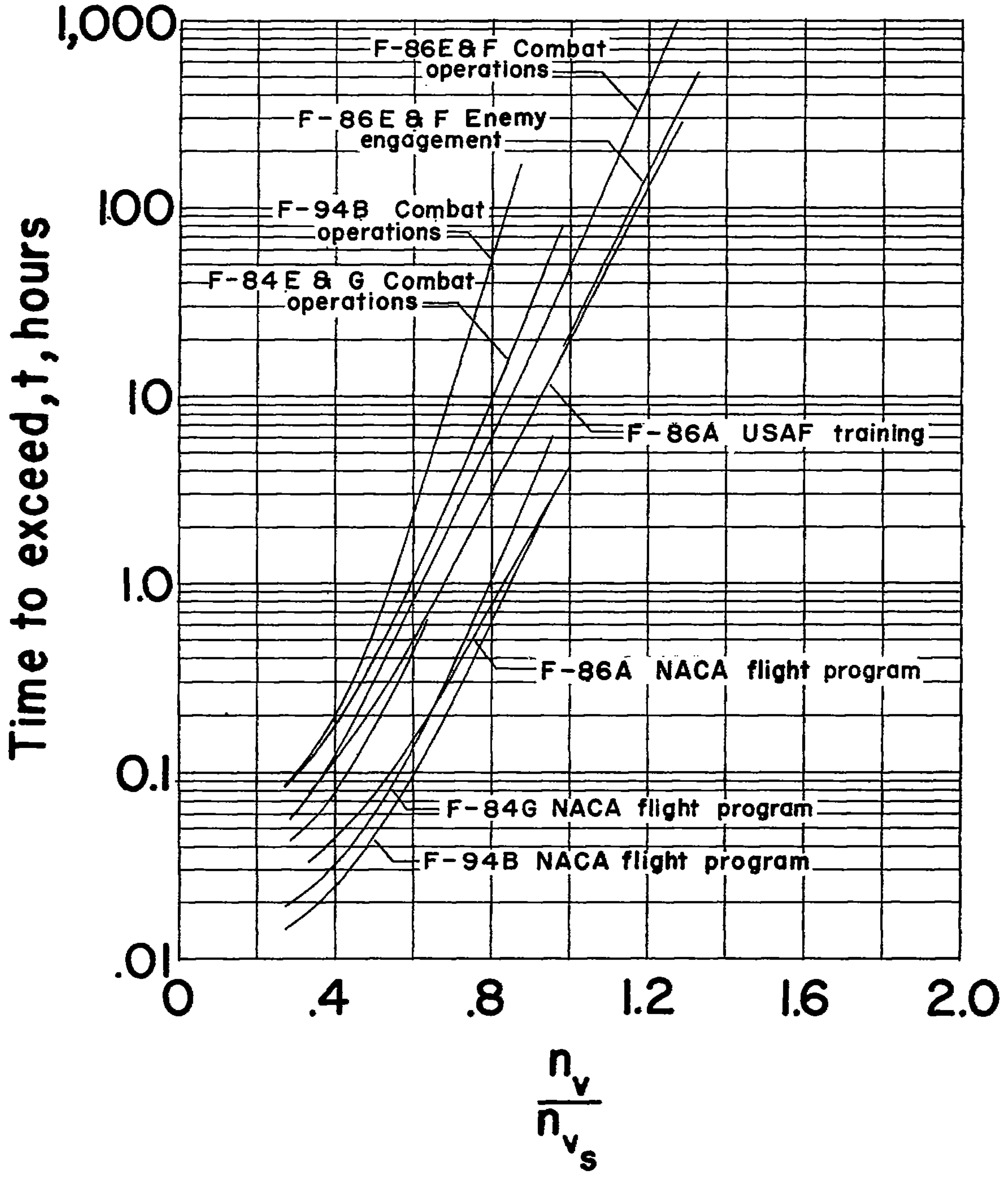

Figure 10.- Comparison of average flight times required to exceed a given fraction of the service-limit positive normal load factor during combat and training.

[redacted]

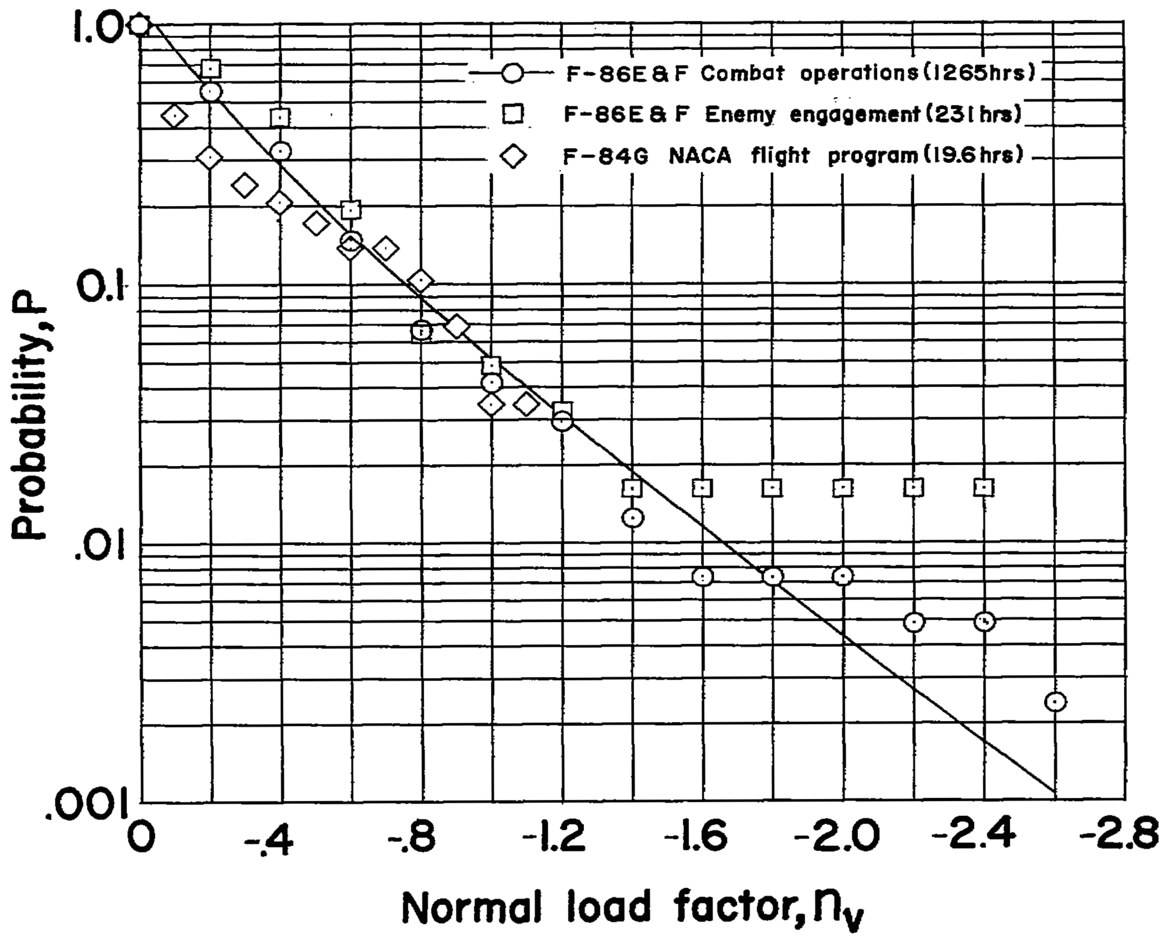

Figure 11.- Comparison of probabilities of exceeding a given negative normal load factor during combat and training.

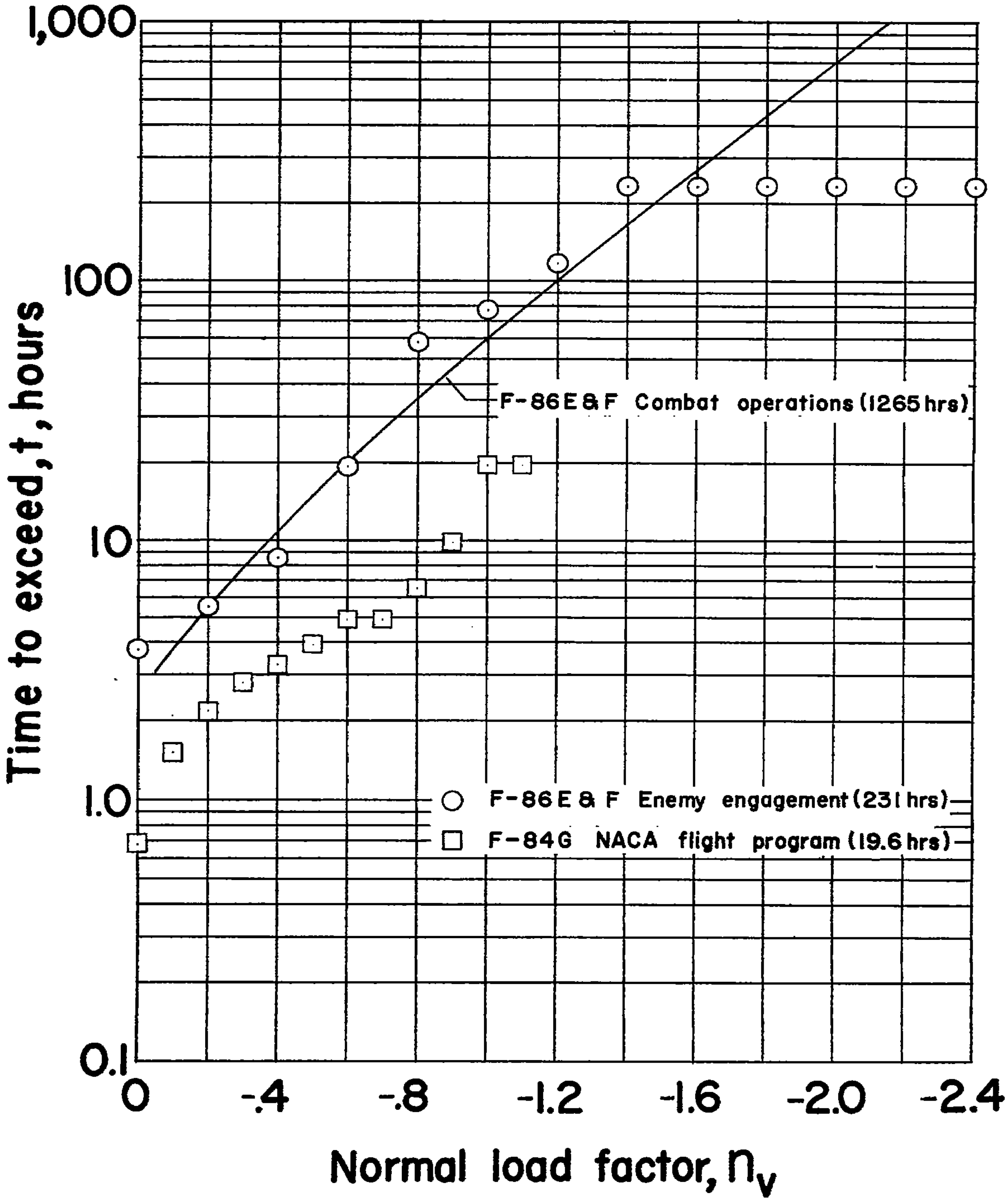

Figure 12.- Comparison of average flight times required to exceed a given negative normal load factor during combat and training.

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