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**USAAVLABS TECHNICAL REPORT 69-79**

**CORRELATION AND EVALUATION OF CH-47A  
FLIGHT SPECTRA DATA FROM COMBAT  
OPERATIONS IN VIETNAM**

By

**John D. Porterfield  
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**November 1969**

**U. S. ARMY AVIATION MATERIEL LABORATORIES  
FORT EUSTIS, VIRGINIA**

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CORRELATION AND EVALUATION OF CH-47A  
FLIGHT SPECTRA DATA FROM COMBAT  
OPERATIONS IN VIETNAM

Kaman Aerospace Report Number R-812

By

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Prepared by

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Bloomfield, Connecticut

for

U. S. ARMY AVIATION MATERIEL LABORATORIES  
FORT EUSTIS, VIRGINIA

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## SUMMARY

This report evaluates flight spectra data for three different mission assignments flown by CH-47A helicopters. Two of these missions were flown in Southeast Asia under actual combat conditions: one as an armed/armored helicopter, Reference 1, and one as a cargo/transport helicopter, Reference 2. The third mission was flown as a cargo/transport helicopter during simulated maneuvers in the United States, Reference 3. The CH-47A flight spectra data for the various missions are compared to each other; to flight spectra data obtained for other helicopters, Reference 4; to the spectrum shown in Appendix A of Civil Aeronautics Manual 6, Reference 5; and to one of the assumed fatigue substantiation spectra used initially to establish component fatigue lives for the CH-47A, Reference 6. Evaluations and correlations of these spectra are presented; and where variations occur, their probable cause and possible effects on fatigue life are discussed.

## FOREWORD

This report, "Correlation and Evaluation of CH-47A Flight Spectra Data From Combat Operations in Vietnam", was prepared by Kaman Aerospace Corporation of Bloomfield, Connecticut, for the U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, under Contract DAAJ02-68-C-0102, Task 1F162204A14601. Mr. William Alexander was the contract monitor.

Past flight spectra surveys have indicated that the mission assigned to a helicopter is one of the major factors influencing the frequency of occurrence of flight loads experienced by the helicopter during its lifetime. Flight spectra data for two CH-47A combat mission assignments as flown in the Army environment of Southeast Asia have recently become available. These data, along with previous flight spectra data obtained for the CH-47A, permit a closer evaluation of the mission assignment-frequency of occurrence relationship. In addition, data for the CH-47A helicopter are compared with the flight spectra data obtained for other helicopters, and with empirical flight spectra used to establish preliminary component fatigue or service lives.

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TABLE OF CONTENTS

	<u>Page</u>
SUMMARY . . . . .	iii
FOREWORD . . . . .	v
LIST OF ILLUSTRATIONS . . . . .	viii
INTRODUCTION . . . . .	1
PROGRAM OBJECTIVES . . . . .	2
HELICOPTER CHARACTERISTICS AND OPERATION . . . . .	3
MISSION SEGMENTS . . . . .	5
AIRSPEED . . . . .	8
GROSS WEIGHT . . . . .	12
ALTITUDE . . . . .	14
RATE OF CLIMB . . . . .	15
VERTICAL LOAD FACTORS . . . . .	17
VERTICAL LOAD FACTORS BY AIRSPEED . . . . .	21
ESTABLISHING A FLIGHT SPECTRUM . . . . .	24
CONCLUSIONS . . . . .	25
RECOMMENDATIONS . . . . .	26
LITERATURE CITED . . . . .	69
DISTRIBUTION . . . . .	70

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Comparison of Flight-Measured Mission Segments for Three CH-47A Mission Assignments With CAM-6, Fatigue, and Flight-Measured Spectra Obtained for Other Helicopters . . . . .	27
2	Three-Segment Mission Breakdown for CH-47A Mission Assignments Compared to Flight-Measured Data Obtained for Other Helicopters . . . . .	28
3	Cumulative Airspeed Frequency Distributions for Three CH-47A Mission Assignments Compared to CAM-6 and Fatigue Spectra . . . . .	29
4	Cumulative Airspeed Frequency Distributions for Three CH-47A Mission Assignments Compared to Flight-Measured Spectra Obtained for Other Helicopters . . . . .	30
5	Cumulative Airspeed Frequency Distributions by Mission Segment for the CH-47A Helicopters Operating in Southeast Asia . . . . .	31
6	Cumulative Airspeed Frequency Distributions by Gross Weight for CH-47A Helicopters. . . . .	33
7	Cumulative Airspeed Frequency Distributions by Altitude for CH-47A Helicopters. . . . .	36
8	Cumulative Gross Weight Frequency Distributions for Three CH-47A Mission Assignments Compared to Other Turbine-Powered Helicopters Having a Design Normal Gross Weight of Greater Than 15,000 Pounds . . . . .	39
9	Cumulative Altitude Frequency Distributions for Three CH-47A Mission Assignments . . . . .	40

<u>Figure</u>		<u>Page</u>
10	Cumulative Rate-of-Climb Frequency Distributions for Three CH-47A Mission Assignments . . . . .	41
11	Cumulative Rate-of-Climb Frequency Distributions for Three CH-47A Mission Assignments Compared to Other Data . . . . .	42
12	Cumulative Total Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments Compared to Those Obtained From Other Helicopters . . . . .	43
13	Cumulative Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Mission Segment . . . . .	44
14	Cumulative Maneuver-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments Compared to Those Obtained From Other Helicopters . . . . .	48
15	Cumulative Maneuver-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Mission Segment . . . . .	49
16	Cumulative Gust-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments Compared to Those Obtained From Other Helicopters . . . . .	53
17	Cumulative Gust-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Mission Segment . . . . .	54
18	Cumulative Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Airspeed . . . . .	58
19	Composite of Cumulative Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Airspeed . . . . .	61

## INTRODUCTION

The importance of helicopter flight spectrum definition in the determination of component fatigue lives can vary significantly from helicopter to helicopter or from component to component, depending on the appropriate load-strength relationship associated with the particular helicopter or component. If, for example, high frequencies of occurrence are combined with cyclic loads that are considerably above the component endurance limit, fatigue damage may be such that the component fatigue life would be relatively low. If, on the other hand, these same frequencies of occurrence were associated with lower loads that were close to or below the endurance limit, the cumulative fatigue damage for this condition could possibly have only a minor effect on the resulting component fatigue life. Thus, it is imperative that the frequency of occurrence for helicopter flight loads (flight loads spectra) be defined as accurately as possible if meaningful predictions of fatigue lives are to be realized.

In the past, flight spectra used in fatigue life calculations were derived from empirical spectra such as that suggested by Appendix A of Civil Aeronautics 6 (CAM-6), Reference 5, or from a contractor's previous experience with similar type helicopters. Recent flight spectra studies, summarized in Reference 4, have shown that the CAM-6 spectrum agrees fairly well with flight spectra data obtained from helicopters flying utility-type missions but differs considerably from data obtained from special-purpose helicopters. It has been generally concluded in the foregoing studies that the mission assigned to a helicopter has a substantial effect on the flight spectrum experienced. Additional CH-47A flight spectra data for armed/armored missions and for cargo/transport missions, References 1 and 2, were obtained during actual combat flights in Southeast Asia. These combat data, along with CH-47A data obtained during simulated cargo/transport combat flights during maneuvers in the United States, Reference 3, permit a more realistic evaluation of the effects that mission assignments have on the resulting flight spectra. This report compares the CH-47A combat flight spectra data with CH-47A simulated combat flight spectra data; with flight spectra data previously obtained for other helicopters; with the flight spectrum proposed in Appendix A of Civil Aeronautics Manual 6; and with the flight spectrum used to establish preliminary component fatigue lives for the CH-47A helicopter. These data are presented in seven sections, namely, mission segments, airspeed, gross weight, altitude, rate of climb, vertical load factors, and vertical load factors by airspeed, to permit a systematic comparison of parameters that have been shown to have an effect on fatigue lives.

## PROGRAM OBJECTIVES

The purpose of this program was to evaluate and correlate flight spectra data acquired during combat operations in CH-47A helicopters in Southeast Asia, to establish the actual flight loading spectra, to compare them to prior data obtained for the CH-47A helicopter as well as for other helicopters. Further, to compare these data to empirical spectra such as the spectrum found in Appendix A of Civil Aeronautics Manual 6 and that used to establish preliminary CH-47A component fatigue lives. The significance of variations in spectra as they occur is discussed, with the probable effect on component fatigue lives being the primary consideration.

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## HELICOPTER CHARACTERISTICS AND OPERATION

The CH-47A is a twin-turbine, tandem-rotor helicopter designed primarily as a cargo/transport. Data obtained from the pilot's handbook or operator's manual for the CH-47A helicopter define the pertinent characteristics and operational limitations used in this report as:

1. Maximum attainable level flight velocity,  $V_A = 130$  knots at sea level.
2. Design normal gross weight = 28,500 pounds.
3. Maximum design alternate gross weight = 33,000 pounds.
4. Usable power = 4940 hp.
5. Maximum rotor speed (power on) = 230 rpm.
6. Altitude limitation = 15,500 feet.
7. Acceleration limitations = 2.9 g's positive and .5 g negative.

The CH-47A cargo/transport helicopter flown in the United States in the vicinity of Fort Benning, Georgia (USA), and the cargo/transport helicopter flown in Southeast Asia (SEA) had similar operational capabilities and basic mission assignments, whereas the armed/armored ship flown in Southeast Asia was modified for its specialized mission. As described in Reference 1:

'The armed and armored CH-47A is a special-purpose helicopter whose payload capability is used to mount extensive armaments for aerial fire support and armor to protect the crew and the helicopter. Specifically, this helicopter has five gunnery stations, two on each side and one aft; each is equipped with either a 7.62-mm or a .50-caliber machine gun. Fixed pylons on either side support 20-mm guns and either 2.75-inch rocket pods or 7.62-mm minigun pods. Extensive armor protects the crew and vital aircraft components.

'These helicopters have the mission of providing aerial fire support while escorting airmobile formations; of performing reconnaissance and security operations; and of supporting other offensive, defensive, and retrograde actions as a part of a highly mobile arms team. Deployment

is generally as a team to ensure mutual support and to decrease vulnerability of the aircraft as well as to increase rapidity and ease of target acquisition."

The depth of the data base for each mission assignment in terms of hours of flight, number of flights, hours per flight, and number of engine starts is tabulated below:

<u>Mission Assignment</u>	<u>Hours Flown</u>	<u>Number of Flights</u>	<u>Hours Per Flight</u>	<u>Engine Starts</u>
USA cargo/transport	165	769	.21	230
SEA cargo/transport	235.76	1081	.22	395
SEA armed/armored	207	564	.37	266

As shown, the average flight durations for the two cargo/transport helicopters are approximately equal (.21 and .22 hour). Comparable data for the armed/armored helicopter show that the average flight duration is .37 hour, or 72% longer than that for the cargo/transport aircraft.

If the armed/armored helicopter were used to escort the cargo/transport helicopter on a particular strike, it would be expected to spend more time in the air to provide aerial fire support while the cargo/transport ship is unloading supplies or troops or picking up wounded, particularly when enemy resistance is being experienced.

## MISSION SEGMENTS

The mission segment data obtained from References 1, 2, and 3 are presented in four segments: (1) takeoff and ascent; (2) maneuvering; (3) descent, flare, and landing; and (4) steady state.

As stated in Reference 3, the definitions of these segments are:

"During the first three mission segments, which comprise the transient part of flight, the stick position traces show no steady values about which the stick traces seem to deviate, while the air-speed and altitude traces manifest frequent changes. Mission Segment 1 (takeoff and ascent) includes not only the takeoff and climb to the initial steady-flight altitude but also unsteady ascents to other steady-flight altitudes. Mission Segment 2 (maneuvering) consists of any transient parts of flight which are not characteristic of Mission Segments 1 and 3. During maneuvering, the normal acceleration trace is usually very active. In addition to the unsteady part of flare and landing, Mission Segment 3 (descent, flare, and landing) includes the unsteady part of any descent whether intended for a new steady-flight altitude or for landing. Mission Segment 4 (steady state) includes those parts of the flight where the stick traces are relatively steady and where the air-speed and altitude traces are steady or changing smoothly. Such characteristics prevailed during cruise, hover, and steady ascent and descent."

To facilitate comparison of the data obtained from References 1, 2, and 3 with data obtained from other helicopters in Reference 4, the four-segment mission data were also converted to the three-segment mission by use of a rate-of-climb criterion: i.e., percentages of time spent at positive rates of climb of 300 feet per minute or greater are considered to be the percentages of time spent in ascent; percentages of time spent at rates of descent of 300 feet per minute or greater are considered to be the percentages of time spent in descent; and percentages of time spent at rates of climb/descent between +300 feet per minute and -300 feet per minute are considered to be the percentages of time spent in the enroute segment.

Figure 1 presents both the three-segment and the four-segment mission data for the three CH-47A mission assignments being

considered. Also shown are the three- and four-segment breakdowns derived from the CAM-6 Spectrum, Reference 5, and the mission segment breakdowns obtained from one of the fatigue spectra used to establish preliminary fatigue lives for CH-47A components, Reference 6. In addition, the three-segment mission averages for climb, enroute, and descent obtained for other helicopters, Reference 4, are presented.

Comparing the four-segment mission breakdown presented in Figure 1, it is noted that, in general, the data obtained for the two cargo/transport helicopters are fairly similar. Variations in the maneuver and descent segments occurring may be due to the normal scatter that can be expected with this type of data or could possibly be due to variations in factors associated with operating in friendly and hostile environments.

Four-segment mission data obtained for the armed/armored CH-47A operating in Southeast Asia vary considerably from those obtained for the cargo/transport helicopters. In the four-segment breakdown, the maneuver segment is essentially unsteady forward flight at fairly constant altitudes. The high percentage of the total time spent in this segment reflects the unsteady nature of the gun ship's mission assignment in supporting ground operations. As cyclic loads are generally higher for unsteady flight conditions than they are for steady conditions, it is reasonable to assume that some of the service lives of the armed/armored helicopter components will be reduced from those determined for the cargo/transport helicopter.

If the four-segment mission breakdowns derived from CAM-6 and the earlier fatigue spectra are compared with the flight measured data, considerable variation is noted. Both empirical spectra predict higher steady-state percentages of time than are revealed by the flight-measured data. Of the two, the breakdown derived from the CAM-6 spectrum is in closer agreement with the flight-measured data than is the fatigue spectrum. The effect of these spectra variations on the calculated fatigue life for a given component is difficult to ascertain without additional knowledge of the fatigue loads and fatigue strength of the component being considered. It is fairly safe to conclude that the use of CAM-6 or fatigue spectrum for predicting lives of the armed/armored helicopter components would result in unconservative fatigue life estimates.

If the flight-measured three-segment mission data are compared, a surprisingly close correlation is revealed. The enroute times for these three sets of data are essentially the same. Slight variations in ascent and descent time are noted, but these variations are much less than those associated with the four-segment mission data.

Comparing the four-segment and the three-segment mission breakdowns for the armed/armored helicopter, it can be concluded that the method used to reduce flight-measured data could have a considerable effect on the interpretation of these data. As previously mentioned, cyclic loads associated with unsteady flight are usually higher than those associated with steady-state flight for most components. In the four-segment mission breakdown, the unsteady ascent, descent, and maneuver segments are unsteady-state conditions. Steady-state ascent, descent, and forward flight are included in the steady-state segment of the four-segment mission. In the three-segment, no distinction is made between steady or unsteady mission segments; thus, the flight spectra breakdown for the three-segment mission may overlook some of the higher cyclic load frequencies of occurrence and thus present an unconservative basis for fatigue life determination.

Figure 2 compares the three-segment mission breakdown for the three CH-47A mission assignments with the  $+1\sigma$  scatter bands of flight-measured data obtained from the helicopters reported in Reference 4. The percentages of time experienced by the CH-47A helicopters in the ascent, enroute, and descent segments are plotted as a function of the design normal gross weight to usable power ratio. As stated in Reference 4, the standard mission is tentatively defined as a mission in which 65% or more of the total time is spent in the enroute segment, whereas a nonstandard mission would be one in which less than 65% is spent in the enroute segment. Percentages of enroute time experienced by the three CH-47A helicopters are: 63.5% for the USA cargo/transport, 63.6% for the SEA cargo/transport, and 62.5% for the SEA armed/armored ships. As shown in the upper portion of Figure 2, these percentages of enroute time fall within the  $\pm 1\sigma$  scatter band established in Reference 4 for the nonstandard mission.

## AIRSPPEED

Airspeed frequency distributions, presented in the form of histograms and bivariate tables in References 1, 2, and 3, for the three CH-47A mission assignments, were converted to cumulative airspeed frequency distributions to facilitate comparisons with similar data presented in Reference 4. In addition, the airspeed values, expressed as knots, were converted to the nondimensional parameter  $\% V_A$ , where  $V_A$  is defined as the maximum attainable level-flight velocity considering gross weight, usable power, blade stall, and structural limitations. This airspeed conversion was made to permit comparisons with helicopters having different airspeed capabilities.

Figure 3 compares the cumulative airspeed frequency distributions obtained for the three CH-47A mission assignments with each other as well as with the empirical flight loads spectra derived from Appendix A of CAM-6, Reference 5, and the spectrum derived from one of the earlier fatigue spectra used to establish component failure lives for the CH-47A helicopter, Reference 6.

It should be noted that only steady-state airspeed frequency data were available for the USA cargo/transport helicopter. Because the mission assignments for the USA and SEA cargo/transport aircraft are similar, an initial comparison of airspeed frequency distributions based on total time and on steady-state time was made for the SEA cargo/transport helicopter. The study showed that results were virtually unaffected if the steady-state time data (apportioned such that the total of the steady-state time equaled 100%) were used in lieu of the total time data for this mission assignment. Therefore, the steady-state airspeed frequency distribution for the USA cargo/transport was considered to be proportional to the total time for the purpose of comparing mission assignment trends.

Comparing the cumulative airspeed frequency distributions obtained for the three CH-47A mission assignments shown in Figure 3, several general trends are noted:

1. The SEA armed/armored and the USA cargo/transport helicopters spent greater percentages of time at the higher airspeeds than did the SEA cargo/transport helicopter. The variations between the USA and the SEA cargo/transport aircraft may be influenced by geographic and climatic conditions as well as by the change from a friendly to a hostile environment.

2. The cargo/transport helicopters spent more time at the lower airspeeds than did the SEA armed/armored helicopter.
3. The maximum airspeed attained by the SEA armed/armored helicopter was higher than that attained by either of the cargo/transport helicopters. In either case, the percentage of time spent at airspeeds in excess of 100%  $V_A$  was relatively small.

A comparison of the flight-measured airspeed spectra for the three CH-47A mission assignments with the airspeed portion of the CAM-6 spectrum reveals that the CAM-6 spectrum is in fairly close agreement with the data for the USA cargo/transport and the SEA armed/armored helicopters but is probably conservative for the SEA cargo/transport helicopter. The fatigue spectrum, on the other hand, is not in very good agreement with flight-measured data obtained for the three CH-47A mission assignments except in the vicinity of 70%  $V_A$  for the USA cargo/transport and the SEA armed/armored helicopters. It is difficult to ascertain whether these variations are conservative or nonconservative without additional information defining the fatigue strength and the fatigue loads action on a particular component. If it is assumed that the majority of the component fatigue damage occurs at the higher airspeeds, both of the empirical spectra would probably be conservative, as they both predict higher percentages of time at the high airspeed values than are shown by the flight-measured data.

Figure 4 presents a comparison of the cumulative airspeed frequency distributions obtained for the three CH-47A mission assignments with flight-measured airspeed data previously obtained for other helicopters (Reference 4). To simplify this comparison, only the  $\pm 1\sigma$  scatter band curves, obtained by statistical analysis for two groupings of these data, are presented. One set of curves was obtained by considering only those data available for turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds. The other set of curves was determined by including all available helicopter airspeed frequency data, regardless of the type of power plant installed or the design normal gross weight, in the statistical analysis used for establishing the  $\pm 1\sigma$  scatter band curves.

Comparing the three CH-47A mission assignments with the  $\pm 1\sigma$  scatter band curves obtained for turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds, only the low airspeed data and data at airspeeds in excess of 100%  $V_A$  fall within these scatter band limits. The remaining data fall below the  $-1\sigma$  bound, as did the basic

CH-47A data in the Reference 4 study. It now appears that the CH-47A generally spends more time at lower percentages of its  $V_A$  than do other helicopters of that general classification.

A much closer agreement is obtained if all available airspeed data are included in establishing the  $\pm 1\sigma$  scatter band limits. In this case, the data for the three CH-47A mission assignments generally fall within the scatter band - either near the center or near the low ( $-1\sigma$ ) limit. Thus, the CH-47A airspeed data for the three mission assignments are in agreement with the airspeed data obtained for all helicopters; but when considered in the classification or groupings established in Reference 4, the correlation is poor.

Figure 5 presents the cumulative airspeed frequency distributions by mission segment for the SEA cargo/transport and the SEA armed/armored CH-47A helicopters. No similar data were available for the USA cargo/transport, as only steady-state airspeed distributions were presented in Reference 3.

Figure 5a presents the airspeed-mission segment cumulative frequency distributions for the SEA cargo/transport. The percentages of time spent at the various airspeed values experienced in the ascent mission segment are fairly uniformly distributed up to approximately 65%  $V_A$ . Above this airspeed, only small percentages of time are encountered. In the descent mission segment, the airspeed range is greater than it was for the ascent mission segment, extending approximately to 82%  $V_A$  before the percentages of time spent at the higher airspeeds become very small. Percentages of time spent at the various airspeed values encountered in the maneuver mission segment are uniformly distributed over the entire airspeed range (30 to 97%  $V_A$ ). The frequency of airspeed occurrences in the steady-state mission segment approximately establishes the curve shape for the total airspeed frequency distribution, with the majority of the time being spent at airspeeds up to approximately 85%  $V_A$ .

Figure 5b presents the cumulative airspeed frequency distributions by mission segment for the SEA armed/armored CH-47A helicopter. The airspeed frequency distributions experienced in the maneuver and steady-state mission segments establish the character of the total airspeed distribution curve, with the majority of the time being spent at airspeeds below 90%  $V_A$ . The airspeed frequency distributions occurring in the ascent and descent mission segments are more uniformly distributed over the total airspeed ranges experienced: 30 to 93%  $V_A$  for ascent and 30 to 85%  $V_A$  for descent.

Figures 6a, b, and c present the cumulative airspeed frequency distribution by gross weight for the SEA cargo/

transport, SEA armed/armored, and USA cargo/transport helicopters respectively. In general, these three sets of curves are fairly similar in shape, varying only in magnitude. This trend indicates that based on average values, gross weight was not too influential in establishing the airspeeds at which each helicopter was flown. If flight-by-flight data reduction had been available, this conclusion may have been altered, for it is reasonable to assume that there should be some reduction in airspeed at the higher gross weight values.

Figures 7a, b, and c present the cumulative airspeed frequency distributions by altitude for the three CH-47A mission assignments. As with the airspeed-gross weight data, the curves are similar in shape, varying only in magnitude, thus signifying a lack of airspeed dependency on altitude. As the performance capabilities of this aircraft do vary with altitude, it is reasonable to assume that airspeed would also vary somewhat with altitude, particularly at the higher airspeed-altitude values.

It will be noted that the two SEA studies report more time at higher altitudes than does the USA study. Since it is density altitude that is reported, the apparent differences may be ascribed to geographic and climatic conditions in the locale as well as to variations in operating technique.

## GROSS WEIGHT

The cumulative gross weight frequency distributions for the three CH-47A mission assignments are shown in Figure 8. These distributions are plotted as a function of both the operating gross weight to design normal gross weight ratio and the operating gross weight to maximum design alternate gross weight ratio. Also included is the  $\pm 1\sigma$  scatter band, obtained from Reference 4, for turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds.

Little similarity is noted in the cumulative gross weight frequency distributions for the three CH-47A mission assignments, particularly between the cargo/transport and the armed/armored helicopters. The SEA armed/armored helicopter spent 90% of the total time at gross weights in excess of the 28,500 design normal gross weight, whereas the SEA cargo/transport helicopter spent only 10% and the USA cargo/transport helicopter spent only 7% of the total time above this value. The specialized nature of the SEA armed/armored helicopter's mission requires it to carry a considerable amount of attached armament and armor to and from the target area. The weight variations occurring during the mission would be due only to the fuel, oil, and ammunition expended. The cargo/transport helicopter, on the other hand, would be loaded with troops or cargo either on its way to the target area or on its way back from the target area, but usually not in both directions. Thus, the percentages of time spent by the cargo/transport ships at the heavier gross weights should be considerably less than those spent by the armed/armored ship.

Differences in the cumulative gross weight frequency distributions experienced by the two cargo/transport aircraft may be due, in part, to factors associated with the nature of the environment that each was operating in. It is reasonable to assume that operations in a friendly environment would not be as efficiently performed as they would in an unfriendly environment, or the need to carry higher payloads in the USA cargo/transport helicopter would not be as urgent as it would in the SEA cargo/transport helicopter.

Comparing the gross weight frequency distributions for the three CH-47A mission assignments with the  $\pm 1\sigma$  scatter bands obtained in Reference 4 for turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds, it is noted that, in general, the data for the two cargo/transport helicopters fall within the scatter band limits but that data for the armed/armored helicopter fall a considerable distance outside of these limits. This further

points out the uniqueness of the SEA armed/armored ship's mission assignment and the effect that mission assignment can have on the character of the flight loads spectrum. Based on these data, it must be concluded that components on the armed/armored helicopter would have a significantly shorter fatigue life than identical components on the cargo helicopters. This would be true for those components whose vibratory loads vary with rotor thrust or gross weight.

## ALTITUDE

The cumulative altitude frequency distributions for the three CH-47A mission assignments are shown in Figure 9. Both the distributions based on total time and those based on steady-state time (apportioned such that the total of steady-state time percentages equals 100%) are presented. As noted, only steady-state time percentages were available for the USA cargo/transport helicopter.

The two helicopters operating in Southeast Asia generally flew at higher density altitudes than did the cargo/transport helicopter operating in the United States. This is primarily due to the higher elevations of the flight terrain and the relatively higher temperatures prevalent in the areas of operation in Southeast Asia. Figure 9 shows that the USA cargo/transport helicopter spent the total steady-state time at altitudes of 5,000 feet and under, whereas the SEA cargo/transport spent the total time at 15,000 feet or under and the SEA armed/armored ship spent the total time at 10,000 feet or under. It should be noted that the maximum altitude restriction of 15,000 feet was not exceeded during any of the three mission assignments.

The use of steady-state altitude data in lieu of total data for the USA cargo/transport appears to be slightly conservative, assuming that fatigue damage varies directly with altitude. This conclusion is reached after comparing the steady-state frequency distribution curves obtained for the SEA cargo/transport and the SEA armed/armored helicopters. In each case, the steady-state time curves show higher altitudes experienced at a given cumulative percentage of time than do the total time curves.

It is conjectured that perhaps differences in environment experienced by the helicopter flying in the United States and the two flying in the Southeast Asia area may have also contributed to the differences in the resulting altitude frequency distributions. Normally, helicopters flying over terrain where enemy ground fire may be expected would fly at higher altitudes to avoid this danger than would a helicopter engaged in maneuvers with only friendly troops.

## RATE OF CLIMB

Rate-of-climb frequency data, previously reported in References 1, 2, and 3, were converted to cumulative rate-of-climb frequency distributions for the three CH-47A mission assignments being compared in this report. Figure 10 presents the rate-of-climb data for these three mission assignments plotted as the "or more" type of cumulative frequency distribution, where percentages of time spent at the various rates of climb or descent were cumulatively summed starting with the largest positive rate of climb or the largest negative rate of climb (rate of descent). As only the steady-state rate-of-climb frequency data were available for the USA cargo/transport helicopter, it was assumed that these data were proportional to the total time data. Therefore, the steady-state data for the USA cargo/transport were apportioned such that the sum of the individual percentages would equal 100%.

A comparison of the resulting cumulative rate-of-climb frequency distributions for the three CH-47A mission assignments presented in Figure 10 shows a relatively close agreement between these three mission assignments, particularly at the lower rates of climb. Rates of descent for the two cargo/transport helicopters are also fairly similar, but the cumulative rate of descent frequency distribution for the SEA armed/armored helicopter varies appreciably from those of the cargo/transport helicopters, particularly at the higher rates of descent.

It would be expected that the armed/armored ship would experience higher rates of climb and descent than would the two cargo/transport ships due to the differences in mission assignment. The armed ship, engaged in searching out hostile troops and suppressing enemy ground fire, would be changing altitude fairly frequently and rapidly. This assumption is borne out by the rate-of-descent frequency distributions but not by the rate-of-climb frequency distributions, in that the rate-of-climb distribution for the armed/armored ship is very similar to the distributions for the cargo/transport ships. This discrepancy may be due, in part, to the high gross weight at which the gun ship normally flies, which may limit its rate-of-climb capacity but not its rate-of-descent capability.

Figure 11 further points out the dissimilarity of the rate-of-descent frequency distribution, at the higher rates of descent, obtained for the armed/armored helicopter when it is compared either to helicopters of its own class or to all helicopters in general. The rate-of-climb  $\pm 1\sigma$  scatter band curves established in Reference 4 for turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds and the rate-of-climb  $\pm 1\sigma$  scatter band curves

obtained by considering the cumulative rate-of-climb frequency distributions for all helicopters for which applicable data were available are shown in Figure 11. The higher rate-of-descent values obtained for the armed/armored helicopter fall outside both sets of these scatter band curves and indicate the uniqueness of the armed/armored ship's mission assignment.

The correlation between the rate-of-climb scatter band of turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds and the scatter band based on all available data appears to be very close. This suggests that rate-of-climb frequency distributions, regardless of helicopter category, class, or mission assignment, are defined by a relatively uniform scatter band.

## VERTICAL LOAD FACTORS

The frequency of occurrence of vertical load factor peaks presented in References 1, 2, and 3 for three CH-47A mission assignments was converted to the "or more" type of cumulative frequency distributions, where the occurrences of vertical load factor peaks were summed cumulatively starting at the largest value of positive vertical load factor and the largest value of negative vertical load factor. In addition, vertical load factor peaks,  $n_z$ , were expressed as incremental vertical load factor peaks,  $\Delta n_z$ , where  $\Delta n_z$  is defined as  $n_z - 1$ .

Figure 12 presents the total vertical load factor experience for the three CH-47A mission assignments; the vertical load factor  $\pm 1\sigma$  scatter bands for turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds, obtained from Reference 4; and the vertical load factor  $\pm 1\sigma$  scatter bands based on all the applicable vertical load factor data presented in Reference 4. Comparing the vertical load factor experience of the three CH-47A mission assignments, it is noted that a degree of variation is exhibited by the positive vertical load factor data, particularly between the two cargo/transport and the armed/armored ships, whereas the negative load factor data are quite uniform. The higher vertical load factors and the higher frequency of occurrence of these load factors experienced by the armed ship are considered to be normal, as it would be expected that this ship would be flown in a more erratic manner than would the cargo ships in carrying out their respective mission assignments. It would also be expected that the frequency of occurrence of the higher negative load factor peaks would be greater for the armed ship than it would be for the cargo ships. This, however, is not evident from the data presently available. It is suspected that factors other than mission assignment account for the similarity of the negative load factor data. In no instances did the vertical load factors experienced by these three ships exceed the acceleration limitations for the CH-47A of positive 2.9 g and negative .5 g. The extreme values experienced were +1.8 g by the armed ship and +.4 g by the USA cargo/transport ship.

A comparison of the vertical load factors experienced by the three CH-47A mission assignments with those experienced by other helicopters of the same class, i.e., turbine-powered helicopters having a design normal gross weight of greater than 15,000 pounds, shows good agreement in Figure 12, as all of the CH-47A data fall within the  $\pm 1\sigma$  scatter band for this class of helicopters. If the CH-47A vertical load factor experience is compared to the  $\pm 1\sigma$  scatter bands based on all of the applicable data of Reference 4, it is noted that

the CH-47A data generally fall near or below the lower scatter band limit. This signifies that the CH-47A helicopters are subjected to less severe vertical accelerations than the average helicopter.

Figure 13 presents the cumulative vertical load factor frequency distributions for the three CH-47A missions by mission segment. The vertical load factors encountered by the armed ship were less than those encountered by either of the cargo ships in the ascent, descent, steady-state, and negative load factor portions of the maneuver mission segment. It is also noted in general that the SEA cargo ship's load factor experience is similar to or less than that for the USA cargo ship for these mission segments. This suggests that perhaps operational gross weight rather than mission assignment is the controlling factor that establishes the character of the load factor frequency distributions for the above-mentioned mission segments. This trend is reversed somewhat in the positive load factor portion of the maneuver segment, in which the maximum load factors experienced by the heavier armed ship are higher than those experienced by either cargo ship; but at incremental load factors lower than .5 g, the frequency of occurrence for given load factors is greater for the SEA cargo/transport helicopter than for the SEA armed/armored ship. It is suggested that additional data are required to resolve these conflicting trends. For the present, it is concluded that, in general, the mission segment data for the three CH-47A mission assignments are fairly similar and that variations that do exist may be due only to the scatter normally expected in this type of data.

Cumulative vertical load frequency distributions experienced during the three CH-47A mission assignments are further analyzed with respect to the source of the acceleration, i.e., maneuver-induced or gust-induced. Figure 14 presents the total maneuver-induced vertical load factor frequency distributions for the three mission assignments and compares them to the maneuver-induced  $\pm 1\sigma$  scatter bands established for other helicopters in Reference 4. The trends noted in Figure 12 for the total vertical load experience hold true, in general, for those associated with the maneuver-induced vertical load factor experience. That is, comparison of the maneuver-induced vertical load factor frequency distributions for the three CH-47A mission assignments with similar data previously reported in Reference 4, indicates that the CH-47A data are in agreement in that they are well distributed throughout the  $\pm 1\sigma$  scatter bands for both positive and negative load factors. Minor variations are due only to the portion of the total load factor experience that was attributed to gust-induced load factors. As will be shown in Figure 16, the gust-induced portion of the vertical load factor experience is a relatively small portion of the total

experience and, as such, would have little effect on the resulting maneuver-induced vertical load factor frequency distributions. In Figure 15, the cumulative maneuver-induced vertical load factor frequency distributions for the three CH-47A mission assignments by mission segments are presented. These frequency distributions are similar to those shown in Figure 13 for the total mission segment frequency distributions with slight differences due to the portion of the total experience attributed to gust-induced load factors.

Figure 16 presents the cumulative gust-induced vertical load factor frequency distributions for the three CH-47A mission assignments and compares them with the  $\pm 1\sigma$  scatter bands established in Reference 4 for gust-induced load factors frequency distributions experienced by other helicopters. It is generally noted that the USA cargo/transport helicopter experienced somewhat higher vertical load factors and load factors of a given value more frequently than did either of the helicopters operating in Southeast Asia. Several possible factors may be involved in producing these variations: differences in prevailing weather conditions and/or terrain over which these ships flew may have produced variations in gust frequencies and magnitude; the lighter of the three ships, the USA cargo/transport, may have sensed higher accelerations for a given gust magnitude; or the scatter noted may be normal for this type of data. At present, there is insufficient data to support any of these possibilities conclusively. A comparison with the  $\pm 1\sigma$  scatter bands previously reported in Reference 4 shows that data for the two ships operating in Southeast Asia fall near or below the lower scatter band limits, whereas data for the USA cargo/transport helicopter lie near the center of these limits. As the data used to establish the scatter band limits in Reference 4 were obtained from helicopters operating under similar conditions in the United States, some support may possibly be given to the premise that prevailing weather and terrain over which the helicopters flew comprise one of the influential factors establishing the character of a gust-induced vertical load factor frequency distribution.

A comparison of the frequency of occurrence of maneuver-induced vertical load factors, Figure 14, with gust-induced vertical load factors, Figure 16, reveals that gust-induced vertical load factors encountered by a helicopter are only a small percentage of the total load factor experience. For example, the number of maneuver-induced vertical load factor peaks experienced per 1000 hours at  $\Delta n_z = .4$  g or greater is approximately 1010 for the SEA armed/armored helicopter. The number of gust-induced vertical load factor peaks experienced at  $\Delta n_z = .4$  g or greater for this helicopter is approximately 4, or  $\approx 39\%$  of the total load factor experience. Similar comparisons can be made for other data points, with similar

percentages resulting. It is therefore concluded that the character of a vertical load factor frequency distribution would be affected only to a very minor degree if the maneuver-induced and gust-induced breakdowns were eliminated during the data reduction process.

Figure 17 presents the cumulative gust-induced vertical load factor frequency distributions for the three CH-47A mission assignments broken down by mission segments. From the very limited data available, it appears that the vertical load factor experience of the three CH-47A helicopters is fairly similar, with perhaps the USA cargo/transport helicopter experiencing a slightly higher frequency of gust-induced vertical accelerations.

## VERTICAL LOAD FACTORS BY AIRSPEED

Frequencies of occurrence of vertical load factors encountered within a given airspeed interval were investigated in an effort to establish the interrelations that may exist between these two parameters. A family of cumulative vertical load factor-airspeed curves was developed from the tabular data presented in References 1, 2, and 3 for the three CH-47A mission assignments. The frequencies of occurrence of vertical load factor peaks were expressed as the cumulative number of load factor peaks per 1000 hours experienced at or below the corresponding airspeed value. Airspeed values were expressed both in knots and as a percentage of the maximum attainable level-flight velocity,  $V_A$ .

The resulting load factor-airspeed distributions for each of the three CH-47A mission assignments are presented in Figure 18. Interpretation of the load factor-airspeed curves presented in Figure 18 can best be accomplished by examples. Thus, for the USA cargo/transport, Figure 18a, it can be stated that at airspeeds of 110 knots or less, approximately 10,000 vertical load factor peaks of  $\Delta n_z = +.2$  g would be experienced in 1000 hours of flight, or, at airspeeds of 60 knots or less, approximately 1000 vertical load factor peaks of  $\Delta n_z = +.2$  g would be experienced in 1000 hours of flight. Frequencies of occurrence of a particular load factor during a given airspeed interval may be estimated by subtracting the cumulative load factor frequencies obtained for the upper and lower limits of the airspeed interval. Thus, using the examples just cited, 9000 vertical load factor peaks of  $\Delta n_z = .2$  g would be experienced between airspeeds of 60 and 110 knots in 1000 hours of flight.

The cumulative load factor curves for the USA cargo/transport helicopter shown in Figure 18a present the relative load factor frequencies of occurrence at a glance by noting the vertical position of each load factor curve. As the load factor value increases, its vertical position becomes lower, signifying that the higher load factor increments are experienced less frequently than are the lower increments. Also, a curve having a uniform slope would signify that the frequency of occurrence for a given load factor value is uniformly distributed throughout the airspeed range. As shown in Figure 18a, the curves for  $\Delta n_z = +.4$  g,  $+ .5$  g, and  $+ .6$  g, and the portion of the  $- .5$  g curve above 85 knots, are approximately uniformly distributed throughout the airspeed range in which they were experienced. The curves for  $\Delta n_z = \pm .2$  g,  $\pm .3$  g, and  $- .4$  g indicate, by the increased slope, that a greater number of load factor peaks were experienced at intermediate values of airspeed. With the exception of the  $\Delta n_z = - .4$  g curve, positive valued load factors are encountered more frequently than

negative valued load factors. It is also noted that the largest negative load factor,  $\Delta n_z = -.6$  g, occurred during this mission assignment in the airspeed interval of 110 to 115 knots.

Figure 18b presents the vertical load factor-airspeed curves for the SEA cargo/transport helicopter. In general, these curves are similar to those shown for the USA cargo/transport helicopter, particularly for the lower values of  $\Delta n_z$ . Comparing the relative vertical positions of the vertical load factor-airspeed curves obtained for the SEA cargo/transport helicopter with those obtained for the USA cargo/transport helicopter, it is noted that a fewer number of load factor peaks were experienced by the SEA cargo/transport helicopter. Load factors were more frequently encountered in the 65- to 100-knot airspeed range than at the lower or higher airspeeds. The highest positive load factor value experienced was  $\Delta n_z = +.6$  g, which occurred within the 90- to 95-knot airspeed interval.

Figure 18c presents the vertical load factor-airspeed curves for the SEA armed/armored mission assignment. The curve shapes for these load factor distributions signify that the majority of load factor peaks lower than  $\Delta n_z = +.7$  g were encountered at airspeeds lower than approximately 90 knots. For  $\Delta n_z = +.7$  and  $+.8$  g, the majority of load factor peaks were encountered in the vicinity of 100 knots.

Vertical load factor-airspeed frequency distributions presented in Figure 18 are repeated in Figure 19 to aid in establishing load factor-airspeed trends with mission assignment. Individual values of  $\Delta n_z$  for the three CH-47A mission assignments are plotted as a composite of cumulative vertical load factor frequency distributions by airspeed in Figures 19a through 19h. It is noted, in general, that the SEA armed/armored helicopter encountered a higher frequency of  $\Delta n_z$  values of .3, .4, .5, .6, .7, and .8 g peaks than did either of the two cargo/transport; also, the  $\Delta n_z = .2$  g frequency distribution curves for the SEA armed/armored ship are almost identical to that for the USA cargo/transport at airspeeds above 70 knots. Below 70 knots, the USA cargo/transport helicopter encountered a higher number of  $\Delta n_z = .2$  g peaks than did the SEA armed/armored ship. In comparison, the USA cargo/transport ship encountered a higher number, and also the highest magnitude, of negative load factor peaks than did the SEA armed/armored or SEA cargo/transport helicopters. The SEA armed/armored helicopter experienced, in general, a slightly higher number of load factor peaks than did the SEA cargo/transport helicopter. The data presented in Figure 19h indicate that the higher load factor values were encountered at airspeeds above 80 knots, that the highest positive load factor peak,  $\Delta n_z = .8$ g, was experienced by the SEA armed/armored

ship, and that the highest negative load factor peak,  $\Delta n_z = -0.6$  g, was experienced by the USA cargo/transport ship.

Interpretation of these data in terms of their impact on component fatigue life is difficult without supplementary information. However, it is apparent that the high frequency of occurrence of positive load factor peaks in the armed/armored helicopter would tend to produce more fatigue damage than the transports in this flight mode. Negative load factor peaks were slightly more frequent in the USA cargo/transport helicopter; however, their general frequency of occurrence is less than positive peaks of corresponding value. Therefore, it is most probable that components of the armed/armored helicopter would have lower fatigue life than the cargo/transport aircraft due to higher incidence of maneuvers and load factor peaks. This conclusion is similar to that reached when considering other flight regimes.

## ESTABLISHING A FLIGHT SPECTRUM

The foregoing frequency distributions may be used to establish the basic characteristics of the flight loads spectra for the three CH-47A mission assignments studied in this report. The data presented herein are the average frequency distributions obtained over a number of flights (50% probability of occurrence). Additional estimates based on the originator's judgment and experience will be required to establish flight loads spectra having probabilities higher than 50%. The task of establishing higher probability frequency distributions would be simplified appreciably if the scatter of the frequency distributions about the mean frequency distribution were known for each parameter of the individual CH-47A mission assignments considered. This scatter of frequency distributions could be obtained from existing flight records by reducing the data on a flight-by-flight basis rather than by considering only the average trends. A statistical analysis could then be made to establish the standard deviation and thus the higher probability frequency distributions.

Figure 1 may be used to estimate the average distribution of the total time spent in either the four-segment mission or the three-segment mission. As the three-segment mission breakdown shows little variation with mission assignment, it is recommended that the four-segment mission percentages be used to establish this portion of the flight spectrum for each mission assignment and that the three-segment mission breakdown be used in developing the rate-of-climb frequency distributions. Considerations affecting the judgement required in establishing a mission segment breakdown having probabilities of higher than 50% should be based on the fatigue load-fatigue life relationship associated with the particular component being investigated. If, for example, the cyclic loads encountered in the ascent segment are found to influence the fatigue life of the component more than those occurring in the other segments, it would be advisable to assign a higher than average percentage of time to the ascent mission segment and adjust the remaining time between the other segments in proportion to their fatigue load-fatigue life sensitivities.

Similar adjustments must be made to the average frequency distributions obtained for airspeed, gross weight, altitude, rate of climb, and vertical load factor to ensure that a conservative flight loads spectrum having probabilities of greater than 50% for its critical elements will be incorporated into the component fatigue life analysis.

## CONCLUSIONS

Based on flight loads spectra data obtained for the three CH-47A mission assignments as well as for other helicopters, it is concluded that:

1. Helicopter flight spectra are influenced by the mission assigned to the helicopter to such a degree that individual flight spectra should be established for each mission assignment.
2. The gross weight at which the helicopter is operating, as well as the mission assigned to it, may affect the frequency distribution of parameters such as rate of climb and vertical load factor.
3. The airspeed portion of CAM-6 appears to agree fairly well with the airspeed frequency distributions obtained for the USA cargo/transport and SEA armed/armored helicopters.
4. Assuming that a particular CH-47A component incurs fatigue damage during the three mission assignments investigated, the components mounted on the SEA armed/armored helicopter will have a shorter fatigue life than the ones mounted on either of the cargo/transport helicopters.

## RECOMMENDATIONS

The following recommendations are based upon a study of the data presented in this report as well as those presented in the referenced reports:

1. Future flight spectra studies should present both the steady and unsteady portions of the ascent, descent, and enroute mission segments to unify data reduction procedures for these parameters.
2. Additional parameters that should be considered in future flight spectra studies are changes and rates of change of directional heading.
3. Flight-by-flight data reduction should be initiated to establish the variability of flight load spectra for a given helicopter flying a given mission assignment and to establish a base for estimating flight spectra having probabilities greater than 50%.

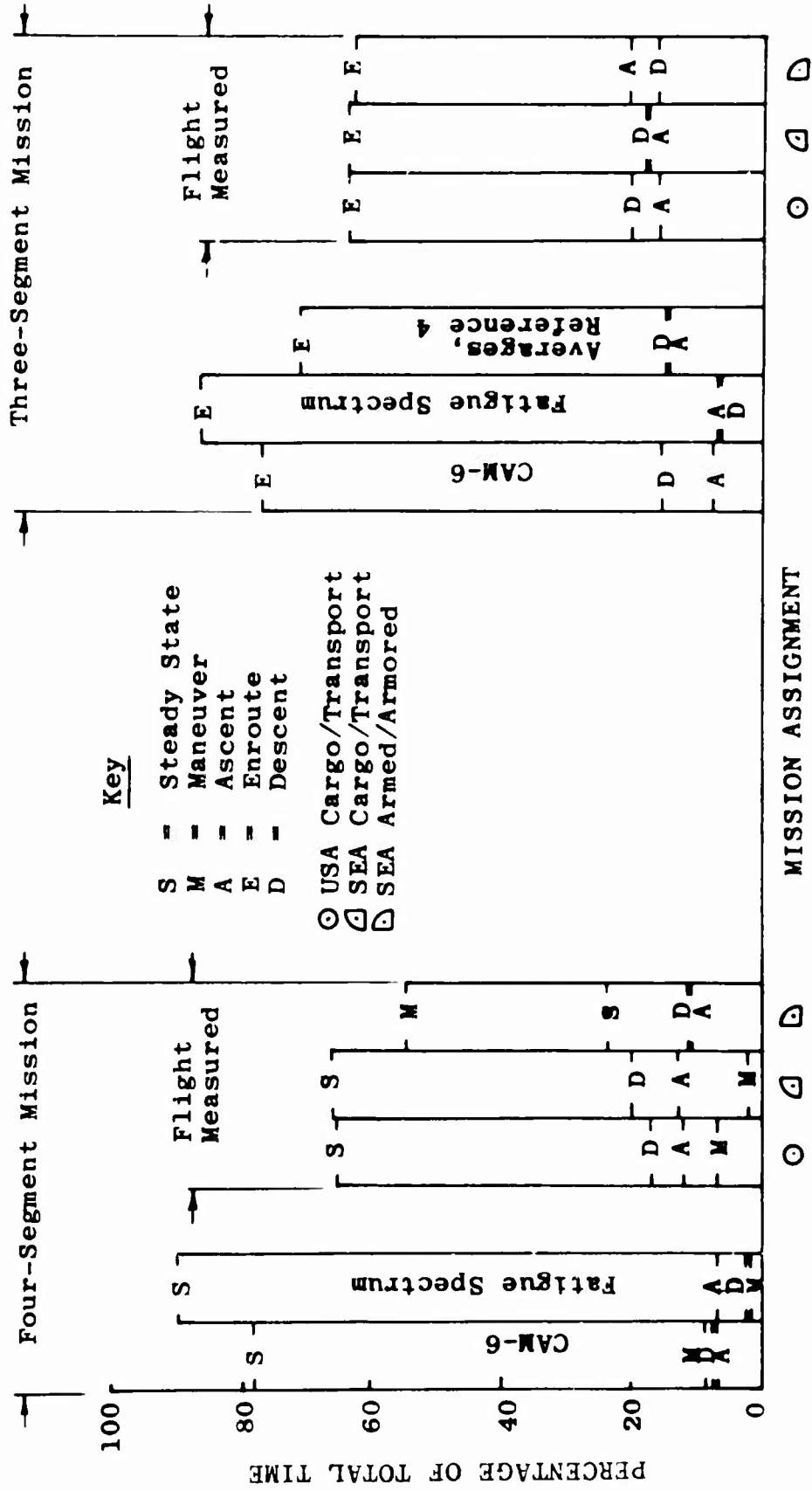


Figure 1. Comparison of Flight-Measured Mission Segments for Three CH-47A Mission Assignments With CAM-6, Fatigue, and Flight-Measured Spectra Obtained for Other Helicopters.

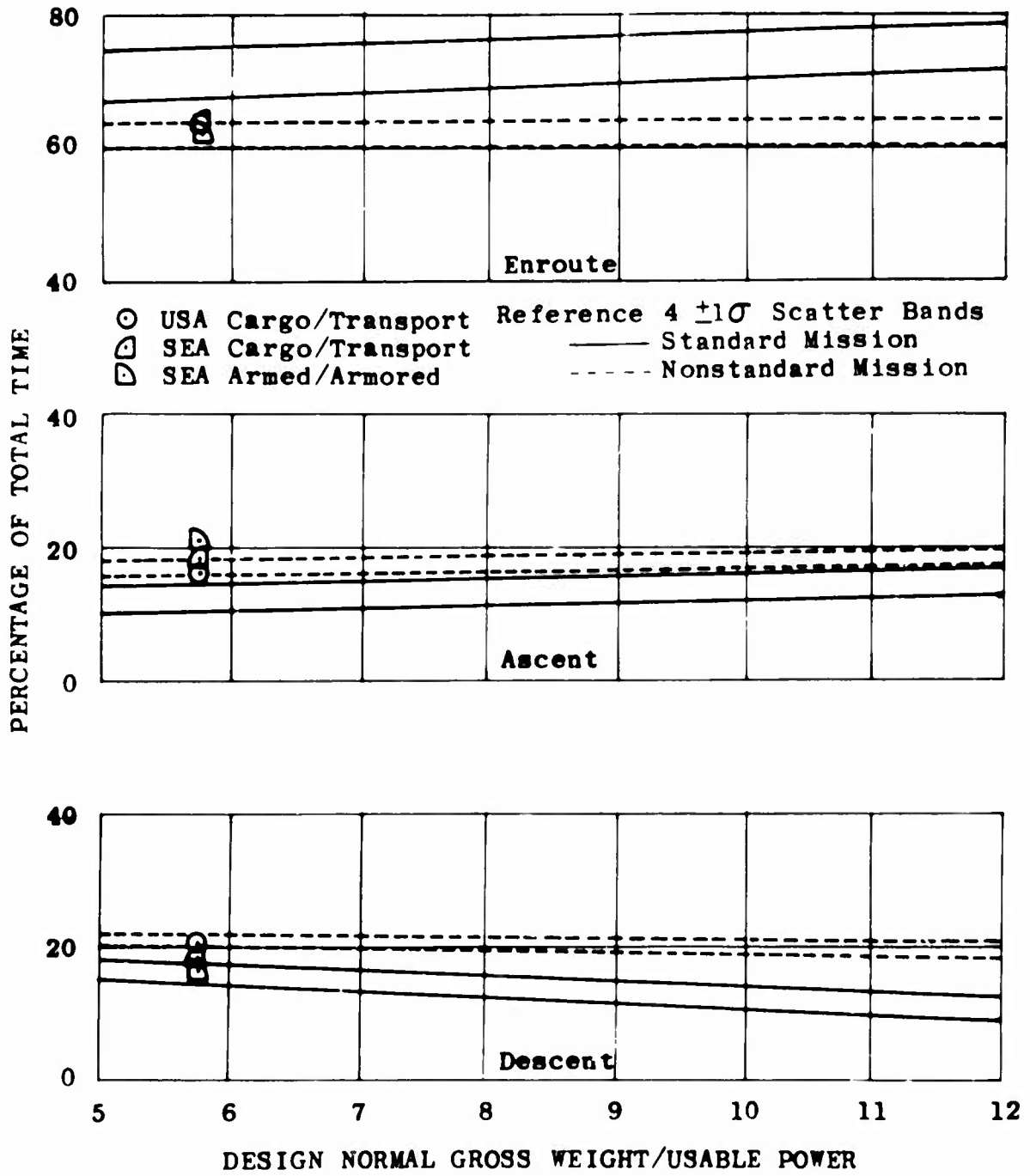


Figure 2. Three-Segment Mission Breakdown for CH-47A Mission Assignments Compared to Flight-Measured Data Obtained for Other Helicopters.

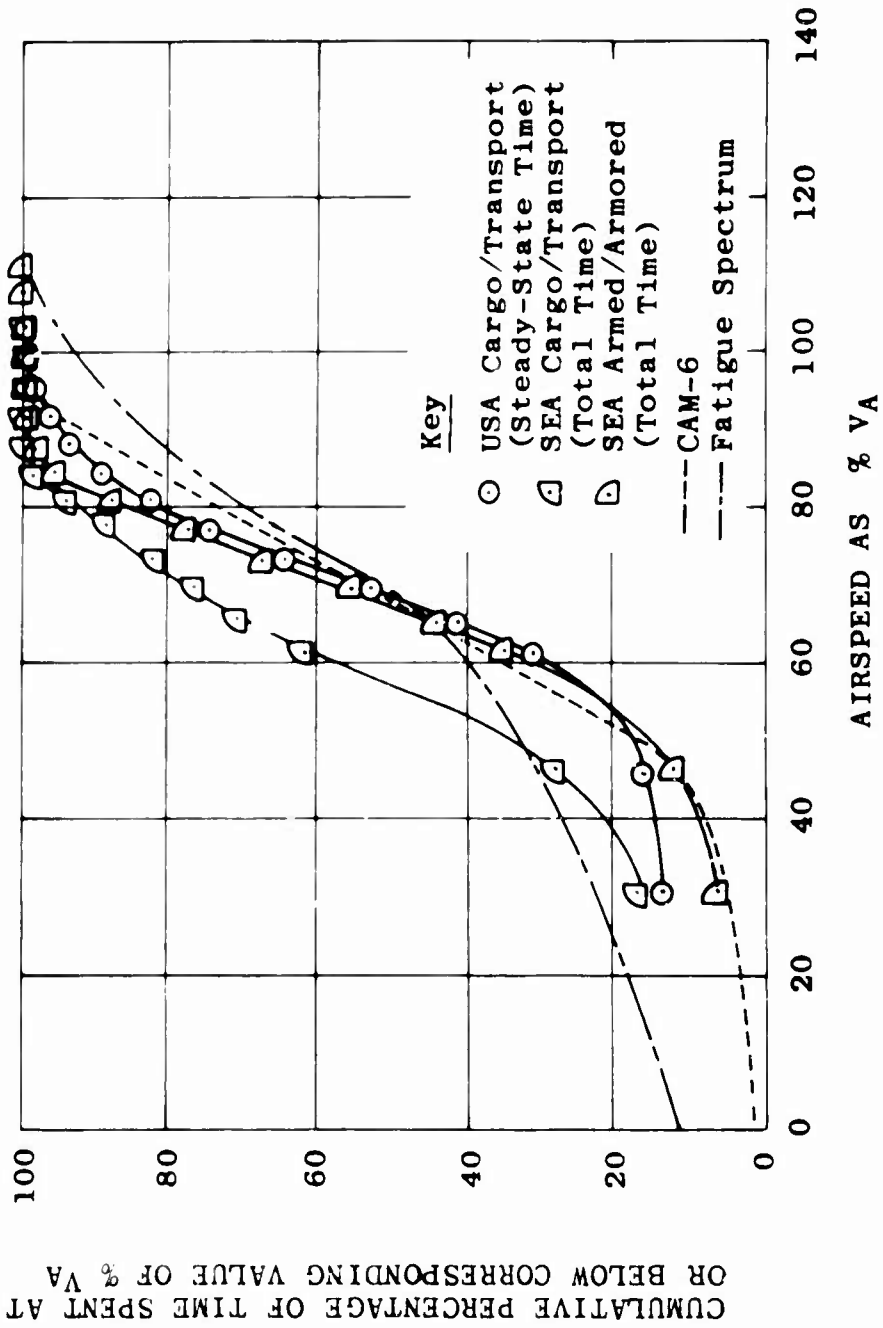


Figure 3. Cumulative Airspeed Frequency Distributions for Three CH-47A Mission Assignments Compared to CAM-6 and Fatigue Spectra.

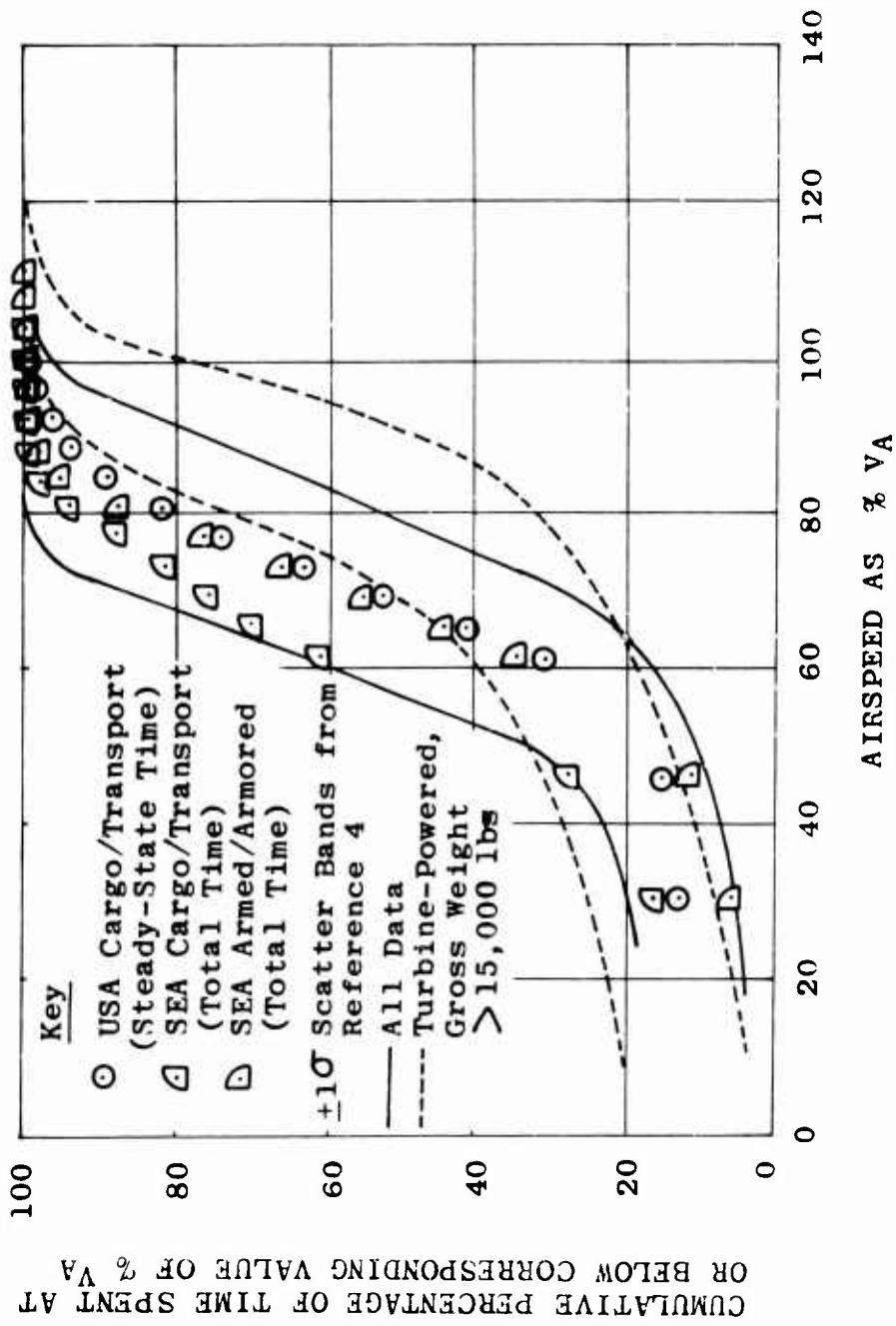
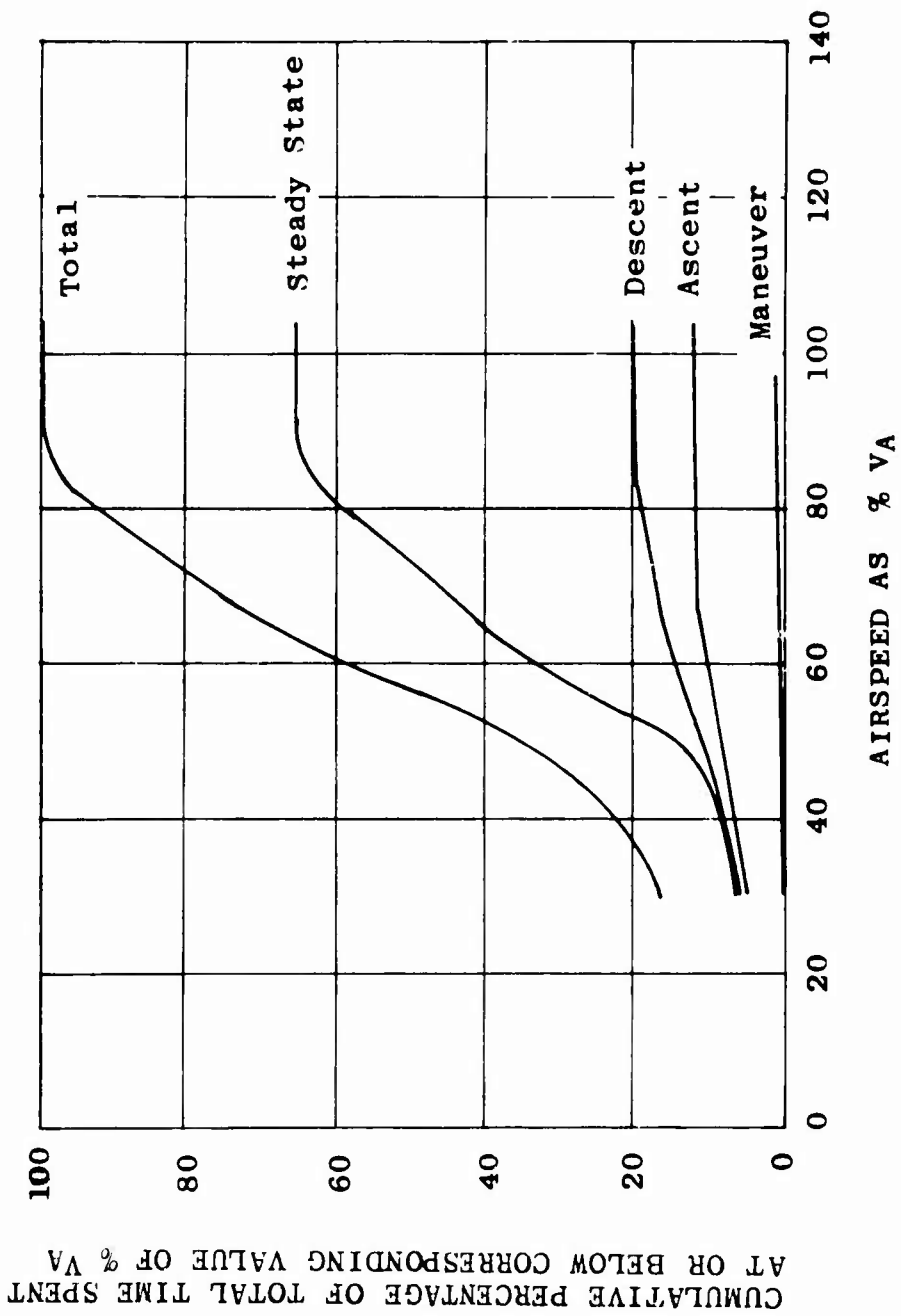
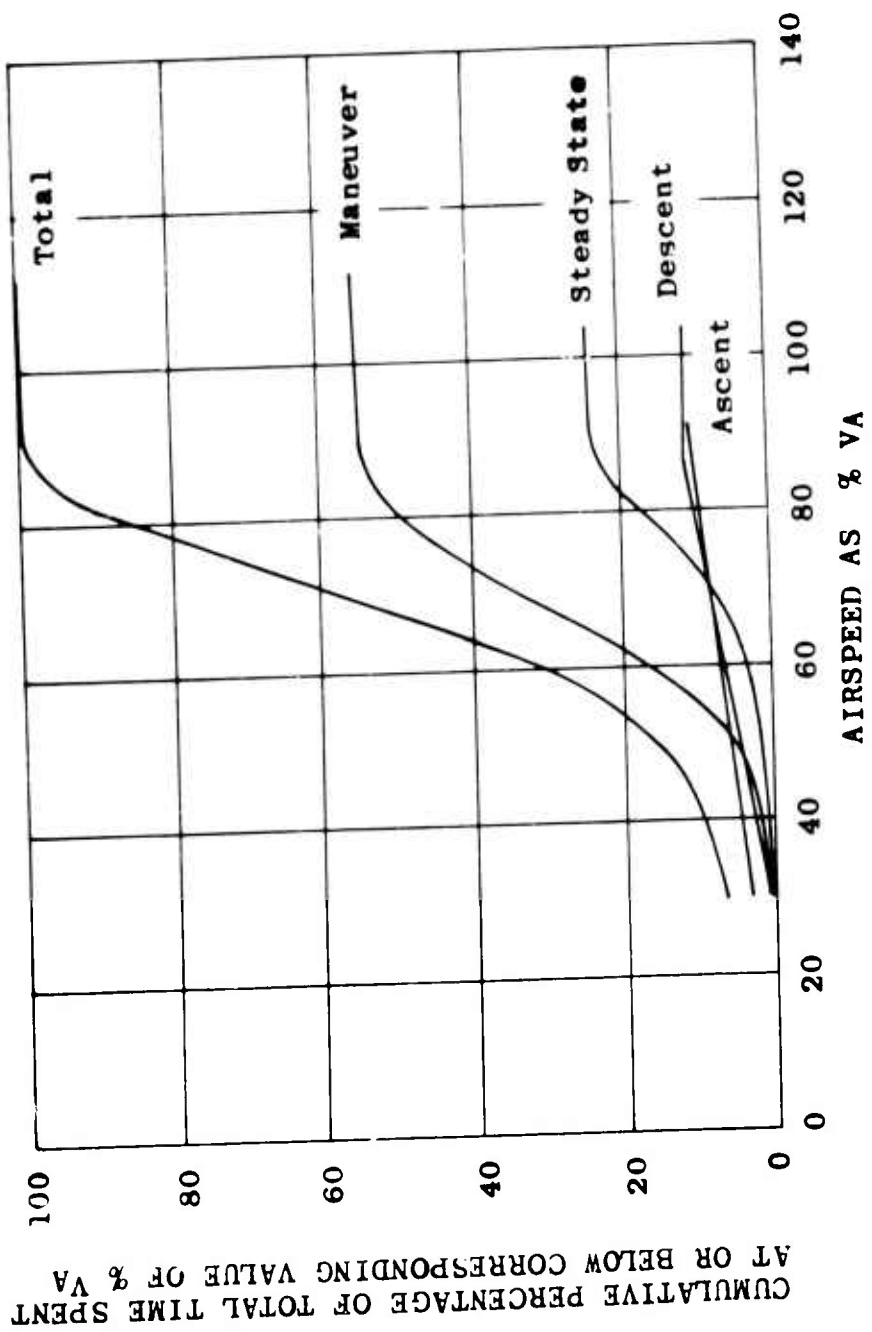


Figure 4. Cumulative Airspeed Frequency Distributions for Three CH-47A Mission Assignments Compared to Flight-Measured Spectra Obtained for Other Helicopters.



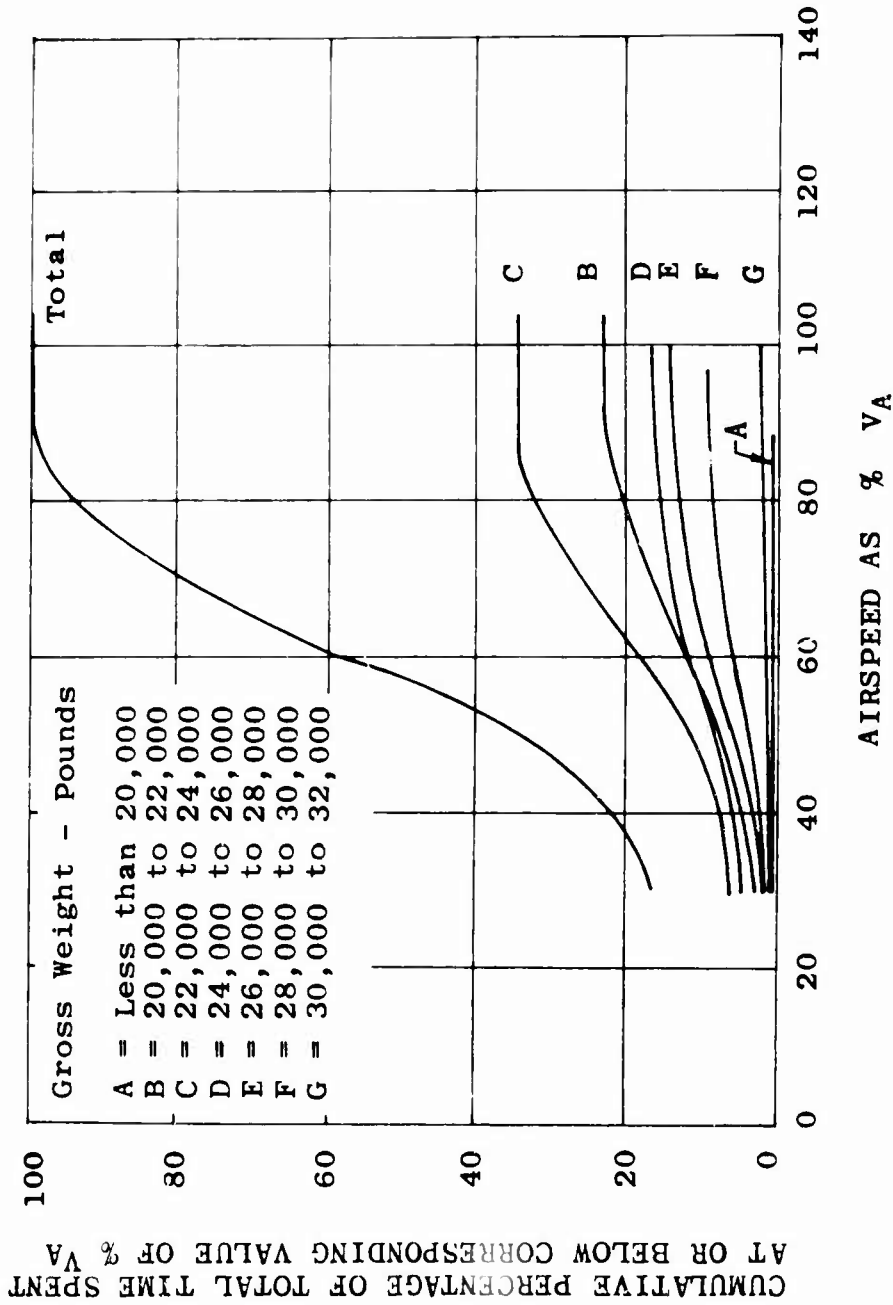
(a) SEA Cargo/Transport.

**Figure 5.** Cumulative Airspeed Frequency Distributions by Mission Segment for the CH-47A Helicopters Operating in Southeast Asia.



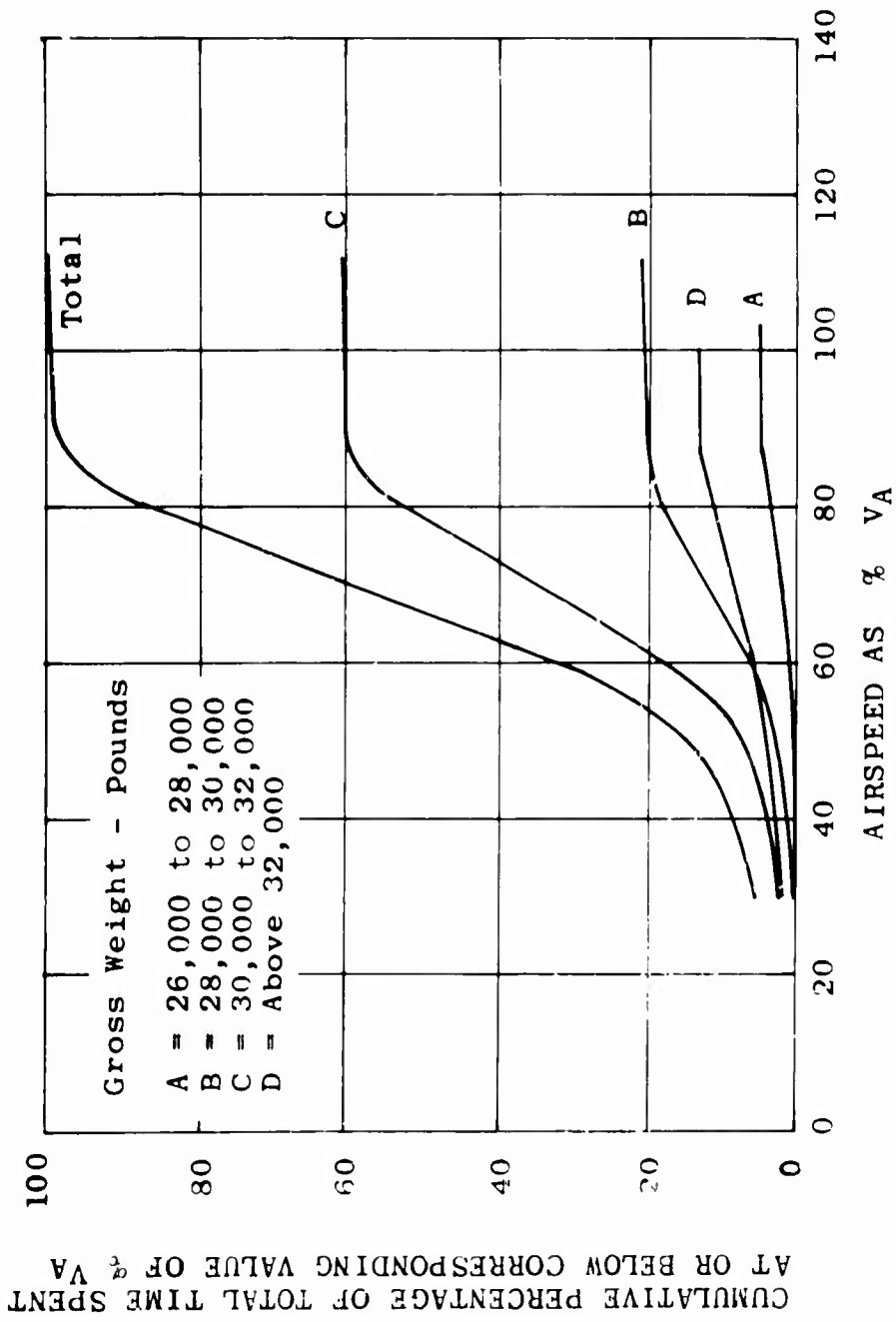
(b) SEA Armed/Armored.

Figure 5 . Continued.



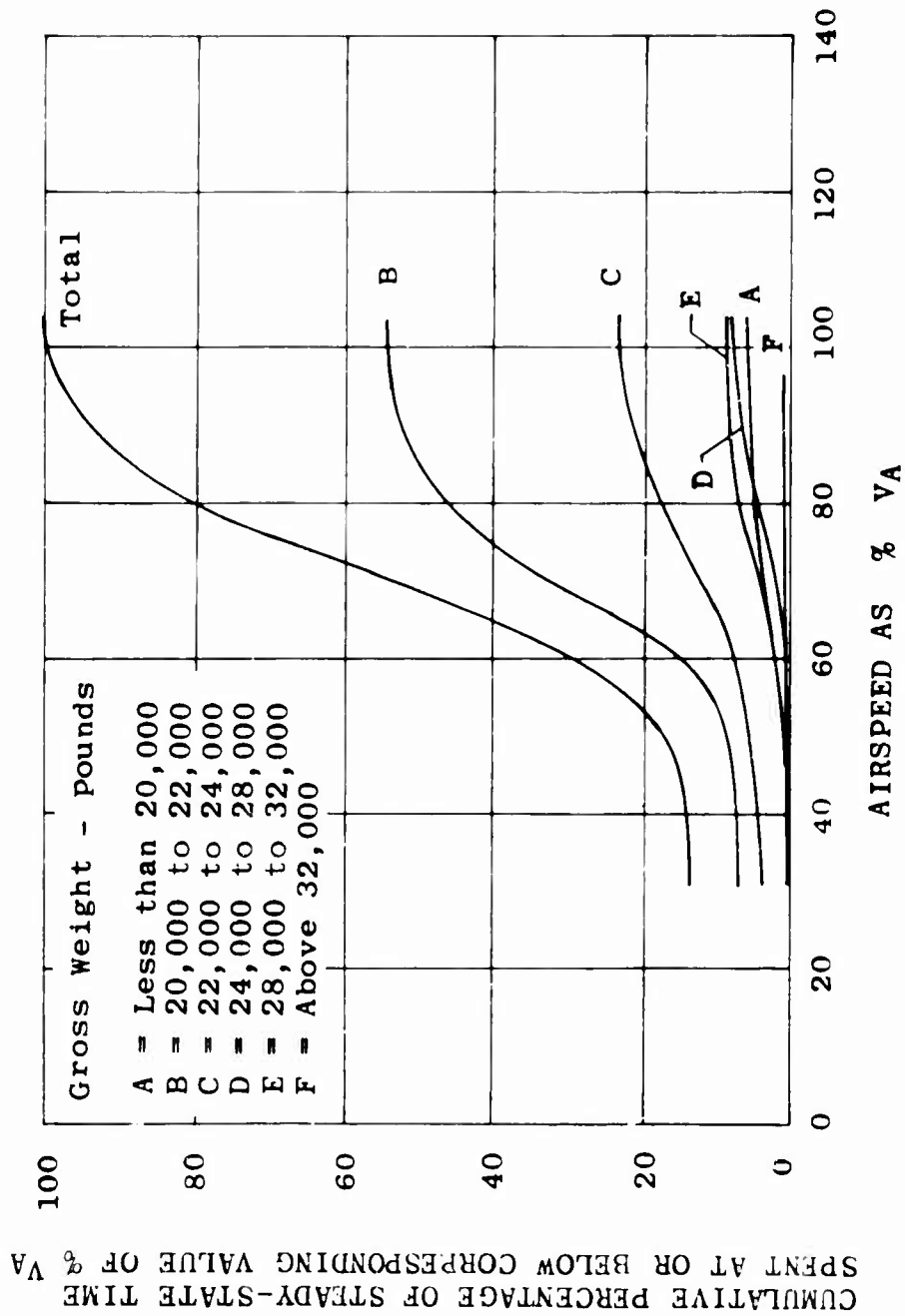
(a) SEA Cargo/Transport.

Figure 6. Cumulative Airspeed Frequency Distributions by Gross Weight for CH-47A Helicopters.



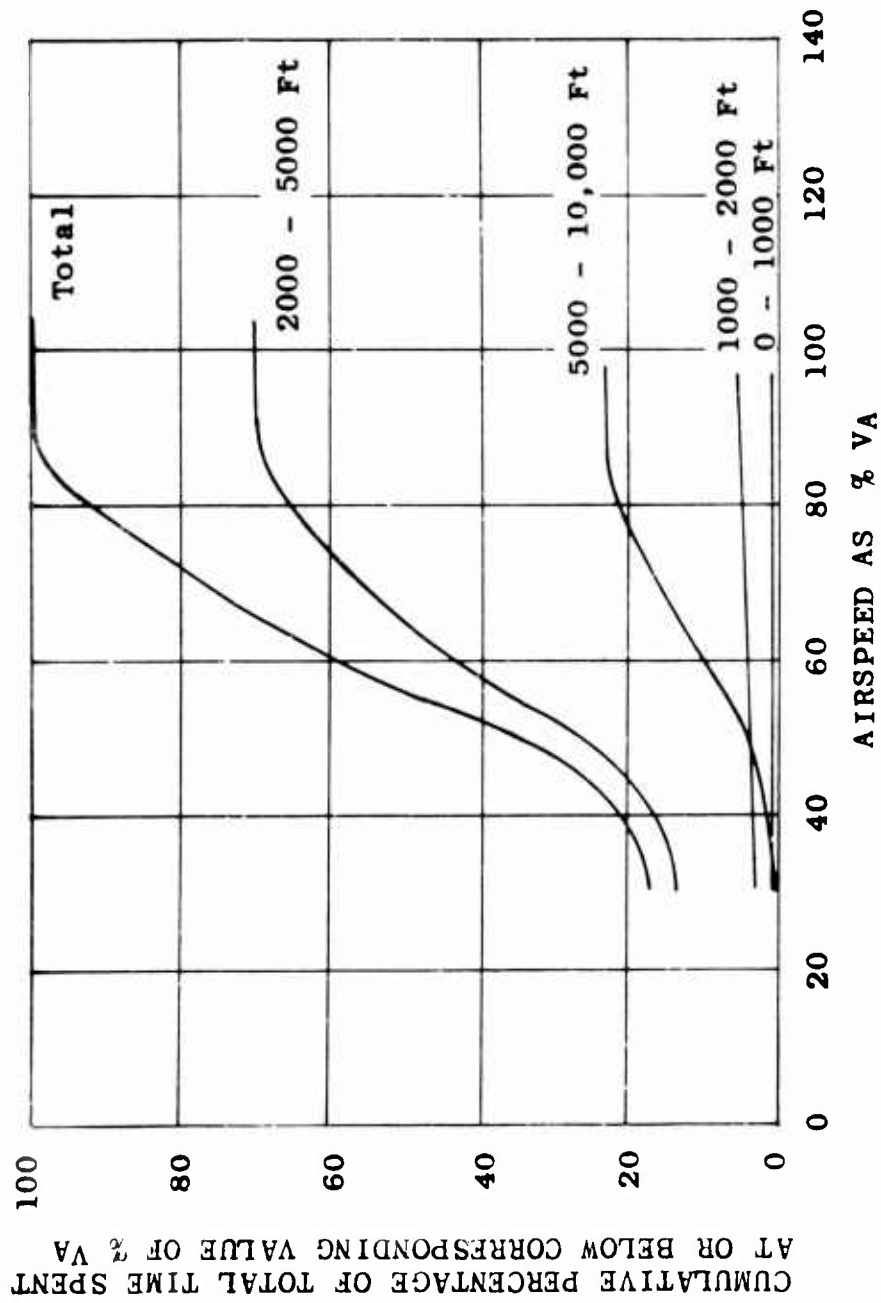
(b) SEA Armed/Armored.

Figure 6 . Continued.

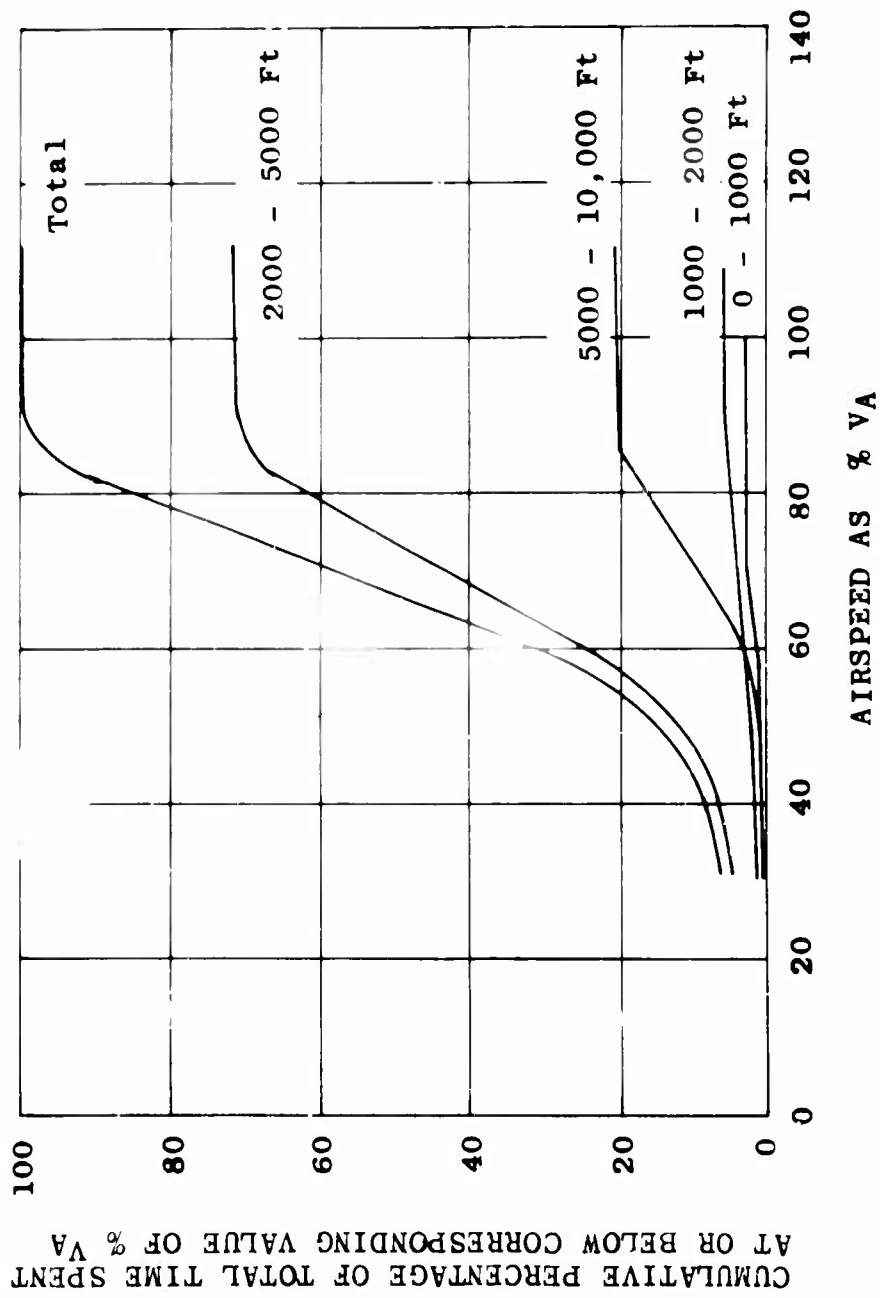


(c) USA Cargo/Transport .

Figure 6 . Continued .

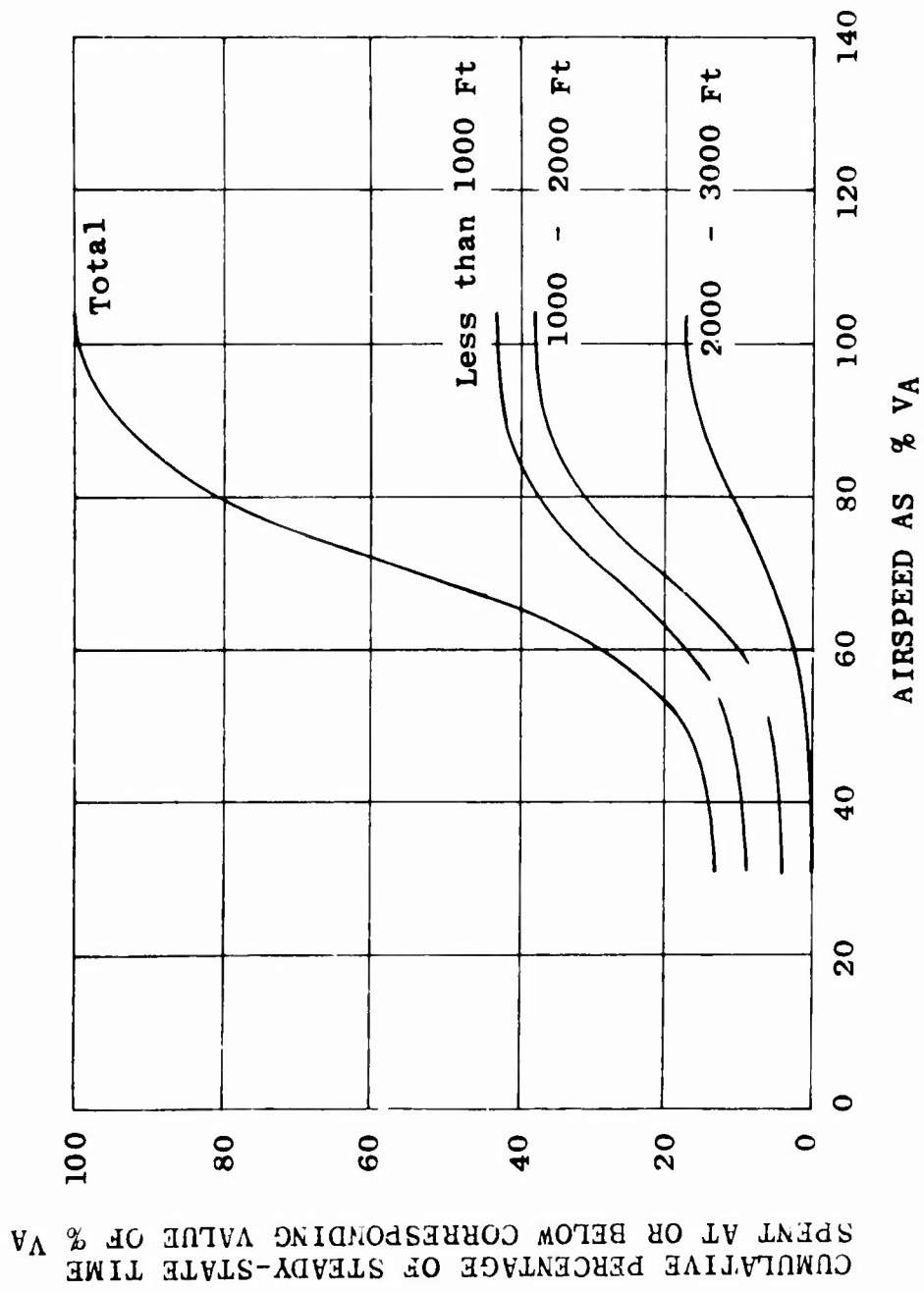


(a) SEA Cargo/Transport.  
 Figure 7. Cumulative Airspeed Frequency Distributions  
 by Altitude for CH-47A Helicopters



(b) SEA Armed/Armored.

Figure 7. Continued.



(c) USA Cargo/Transport.

Figure 7. Continued.

CUMULATIVE PERCENTAGE OF TOTAL TIME SPENT AT  
OR BELOW CORRESPONDING GROSS WEIGHT RATIO

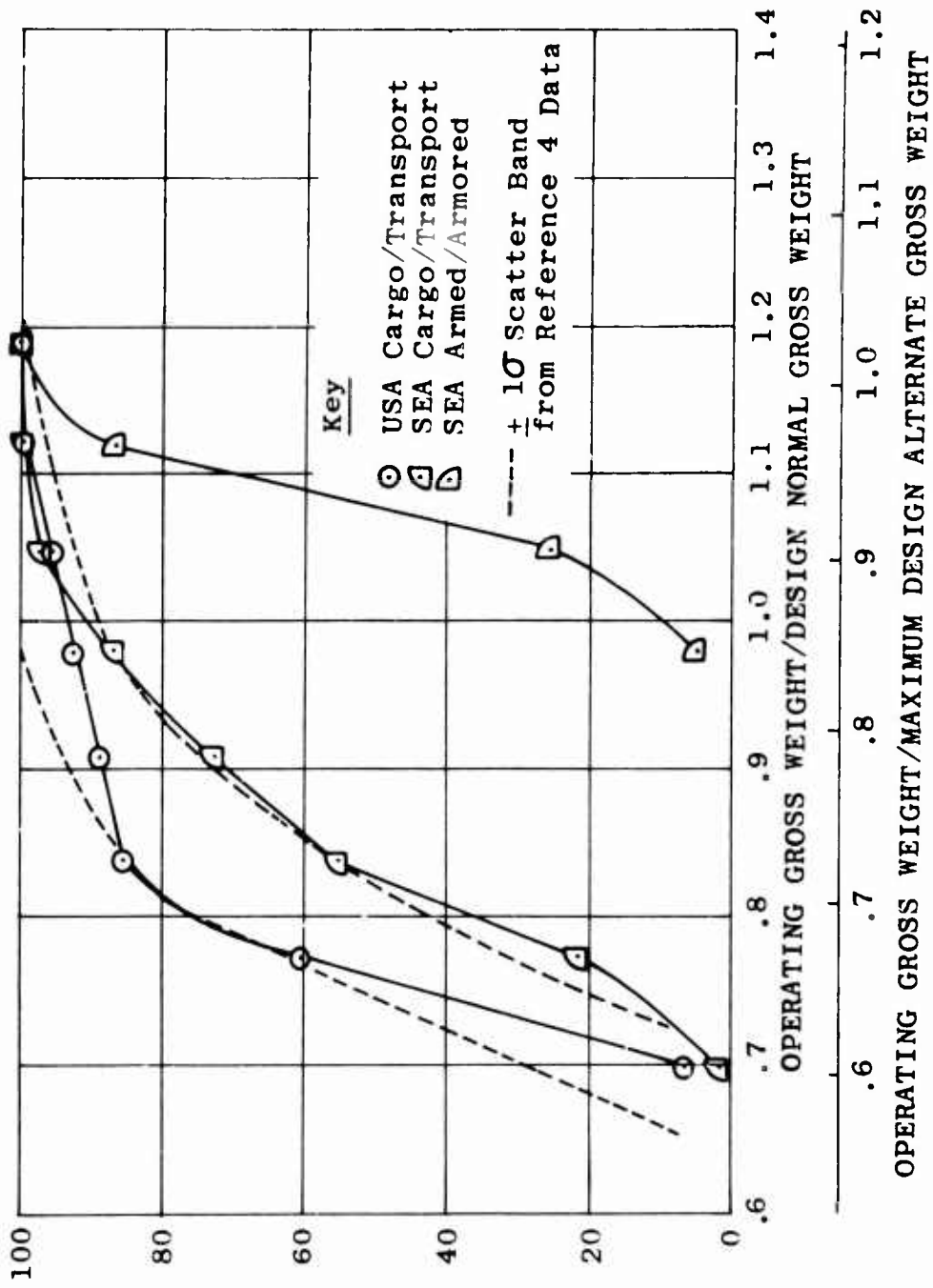


Figure 8. Cumulative Gross Weight Frequency Distributions for Three CH-47A Mission Assignments Compared to Other Turbine-Powered Helicopters Having a Design Normal Gross Weight of Greater Than 15,000 Pounds.

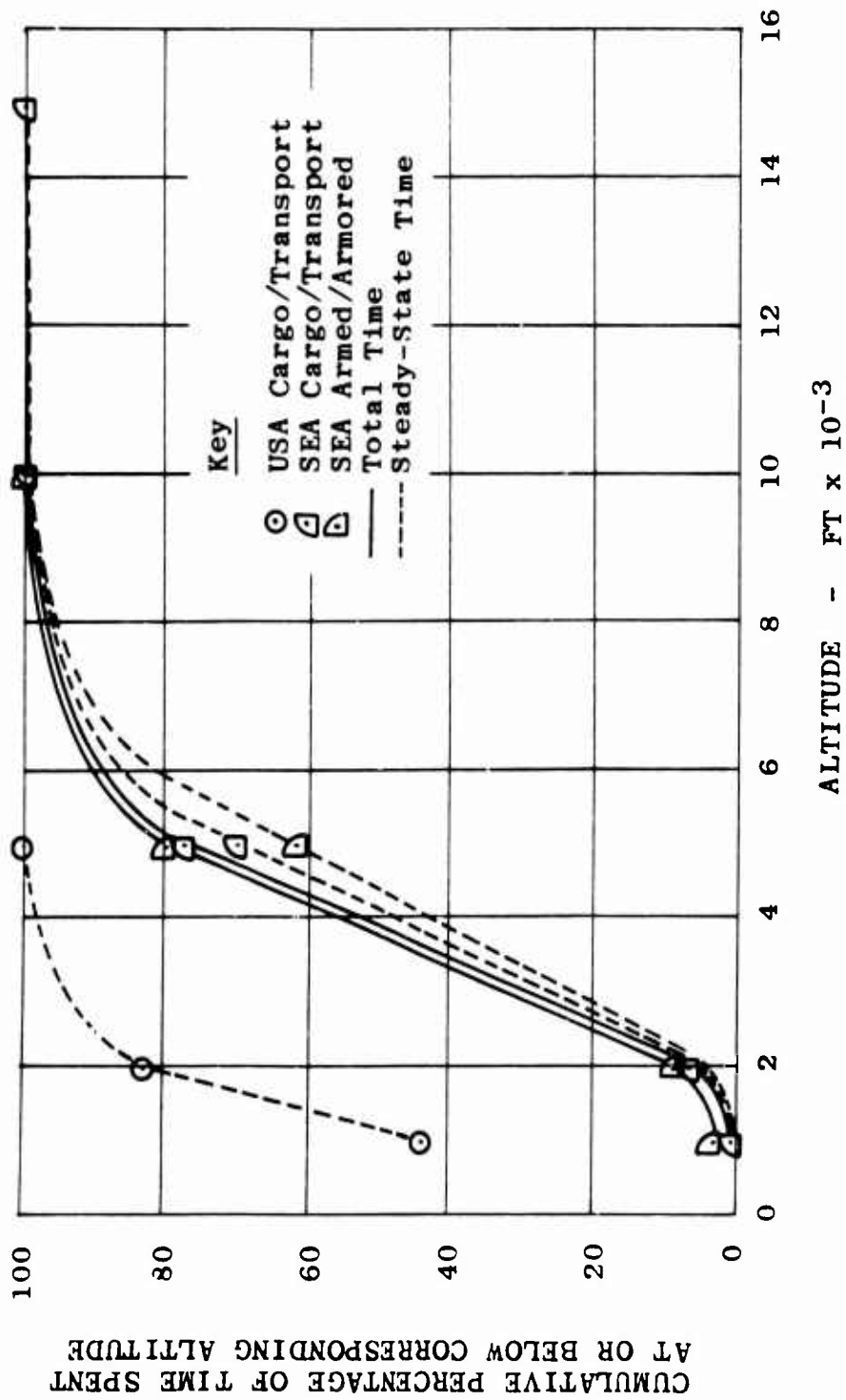


Figure 9. Cumulative Altitude Frequency Distributions for Three CH-47A Mission Assignments.

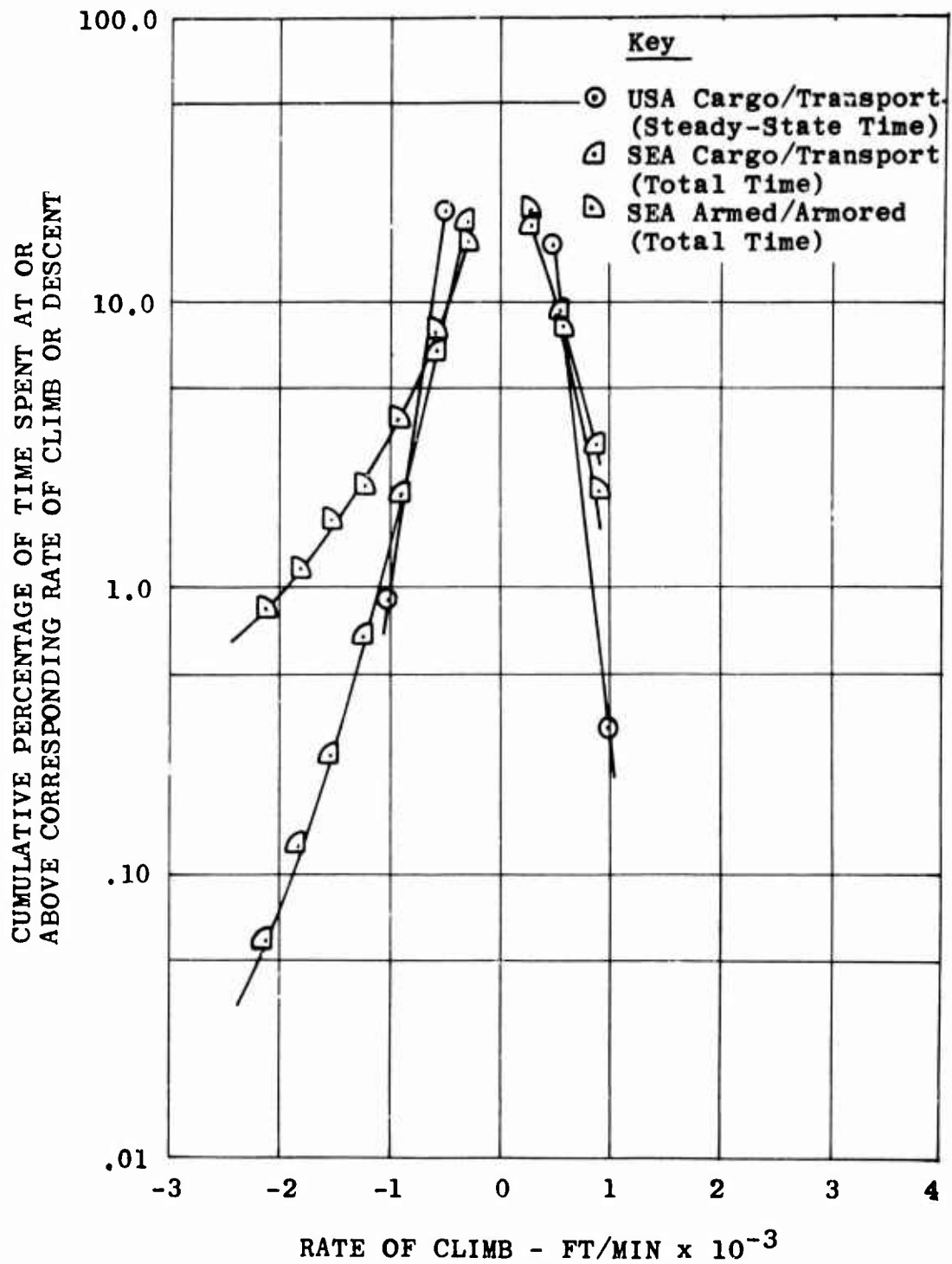


Figure 10. Cumulative Rate-of-Climb Frequency Distributions for Three CH-47A Mission Assignments.

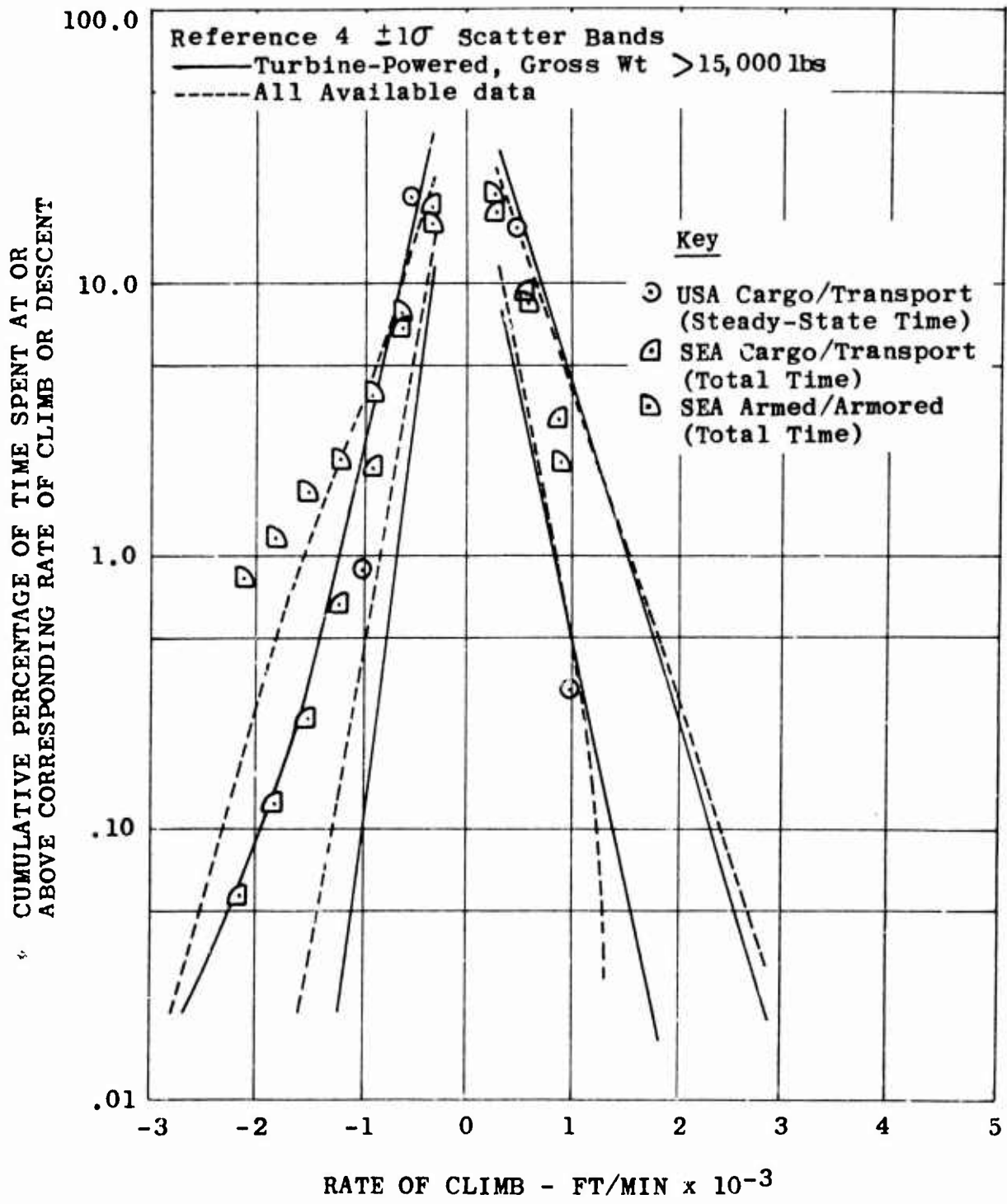


Figure 11. Cumulative Rate-of-Climb Frequency Distributions for Three CH-47A Mission Assignments Compared to Other Data.

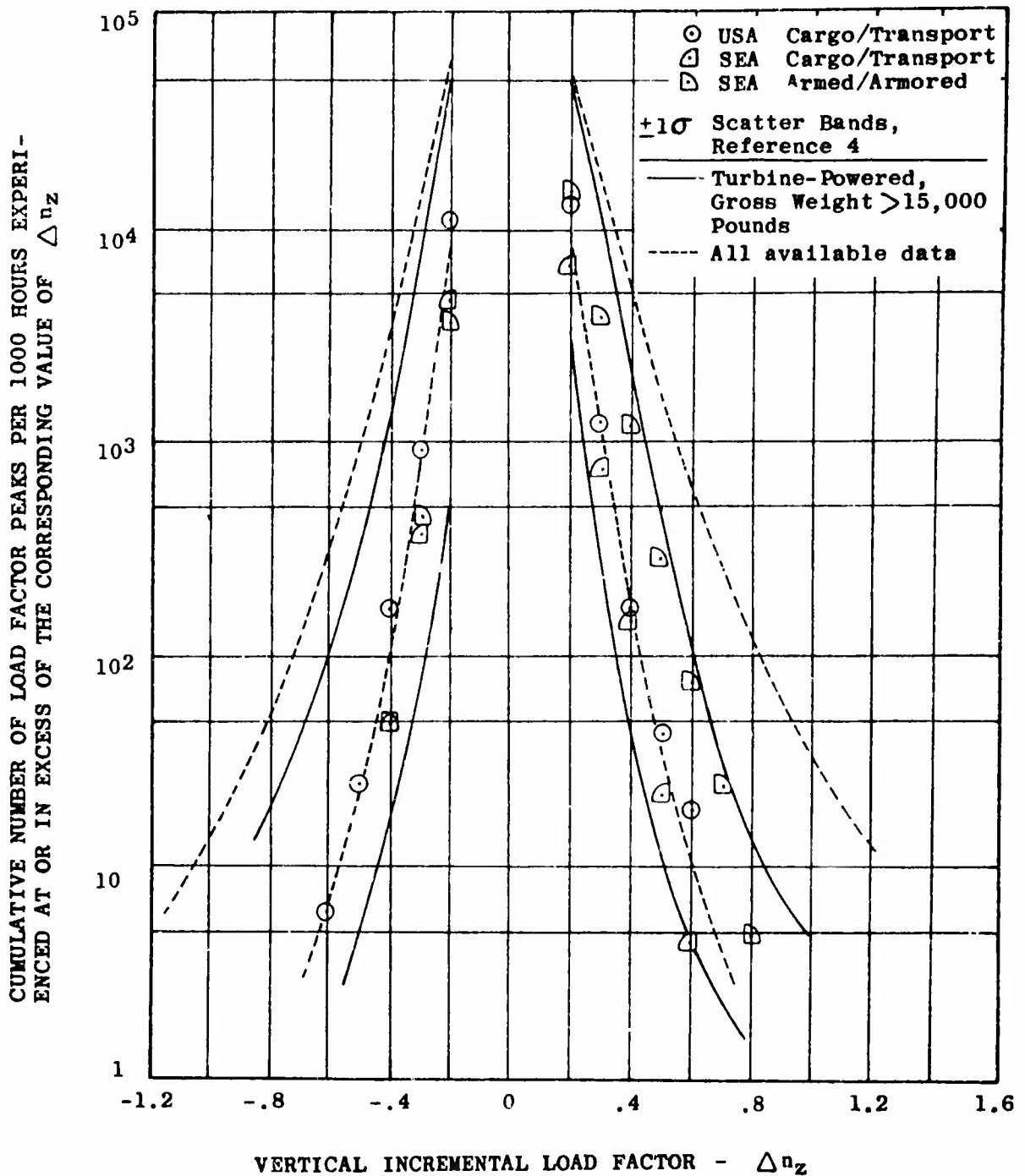
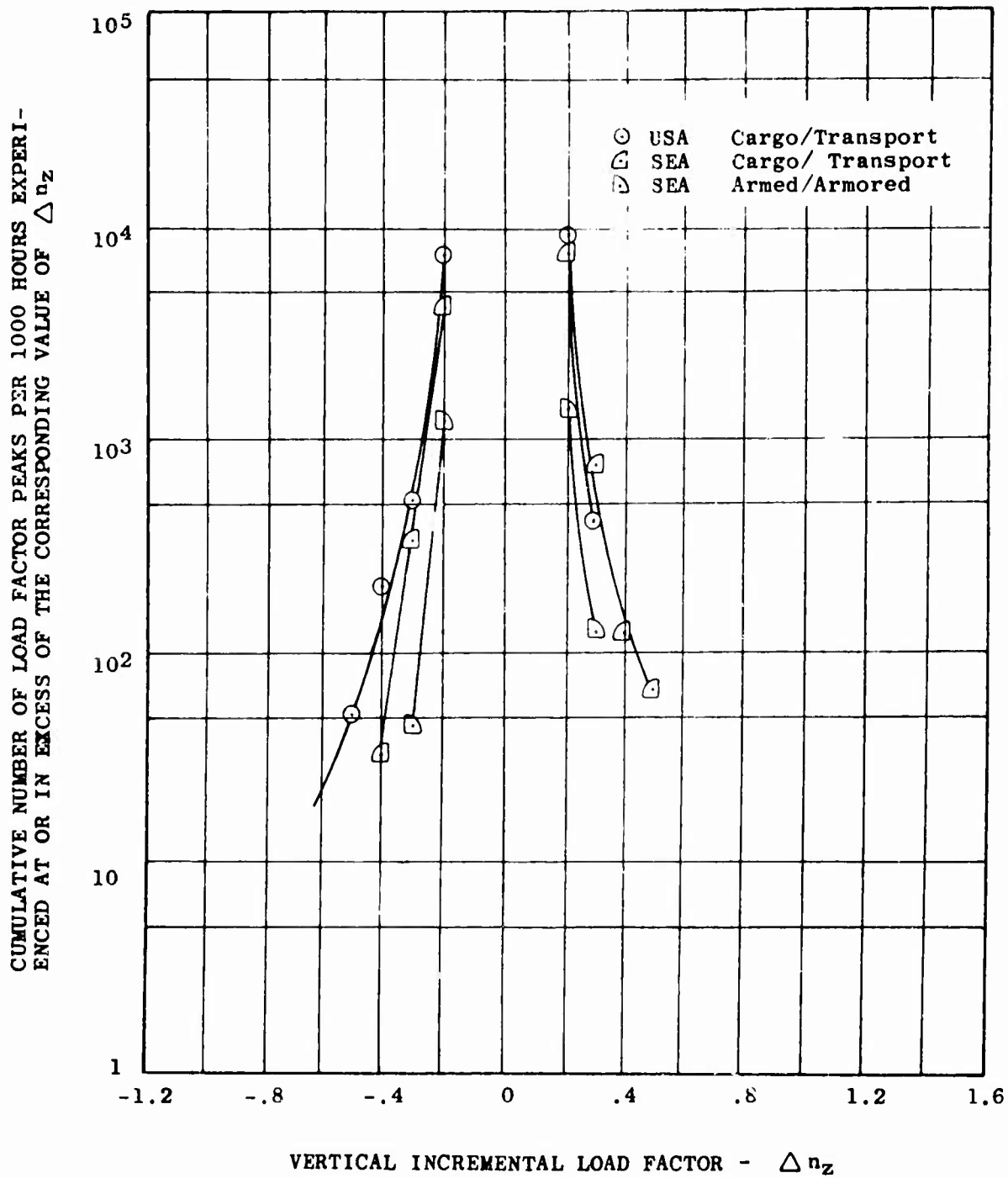
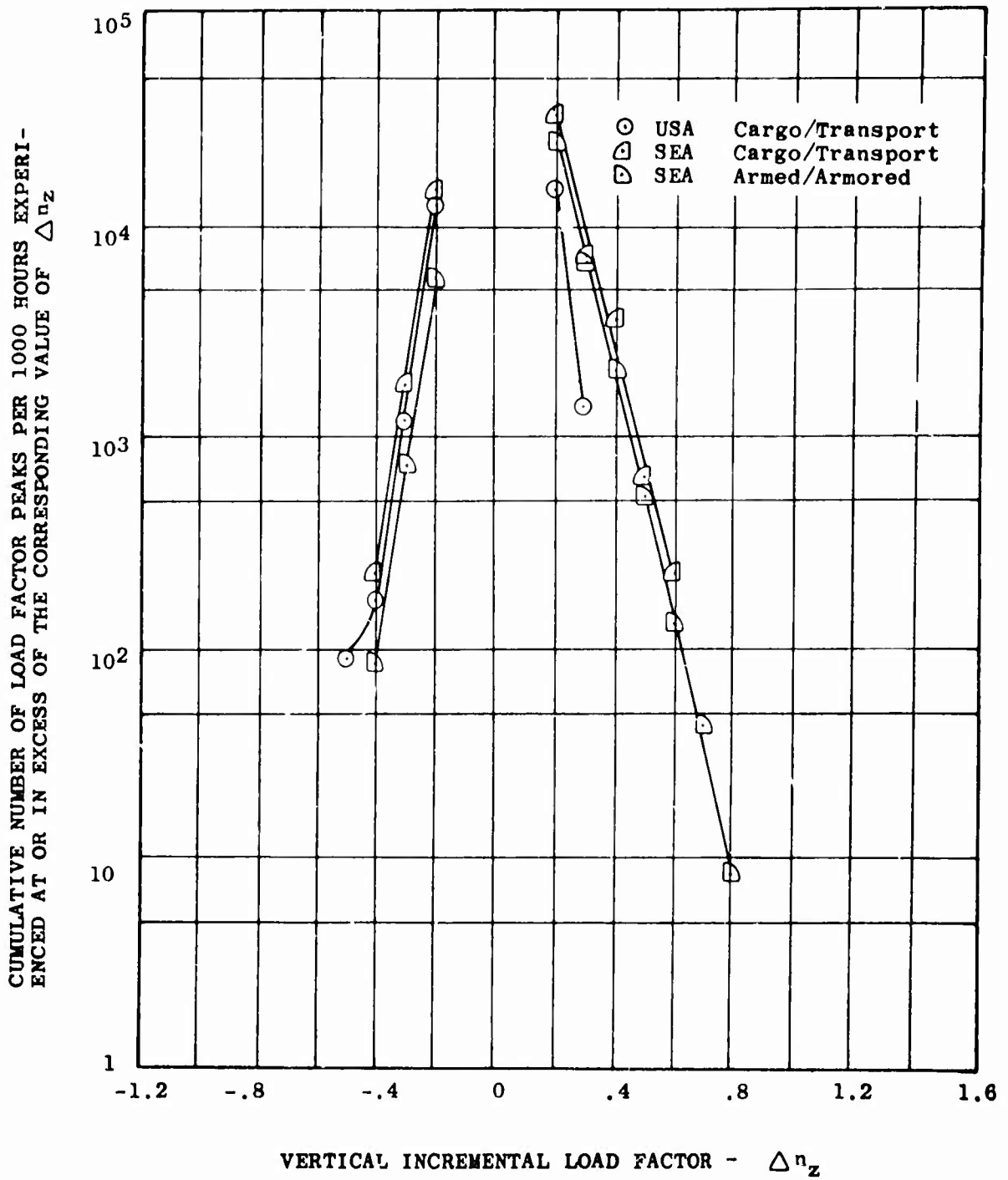


Figure 12. Cumulative Total Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments Compared to Those Obtained From Other Helicopters.



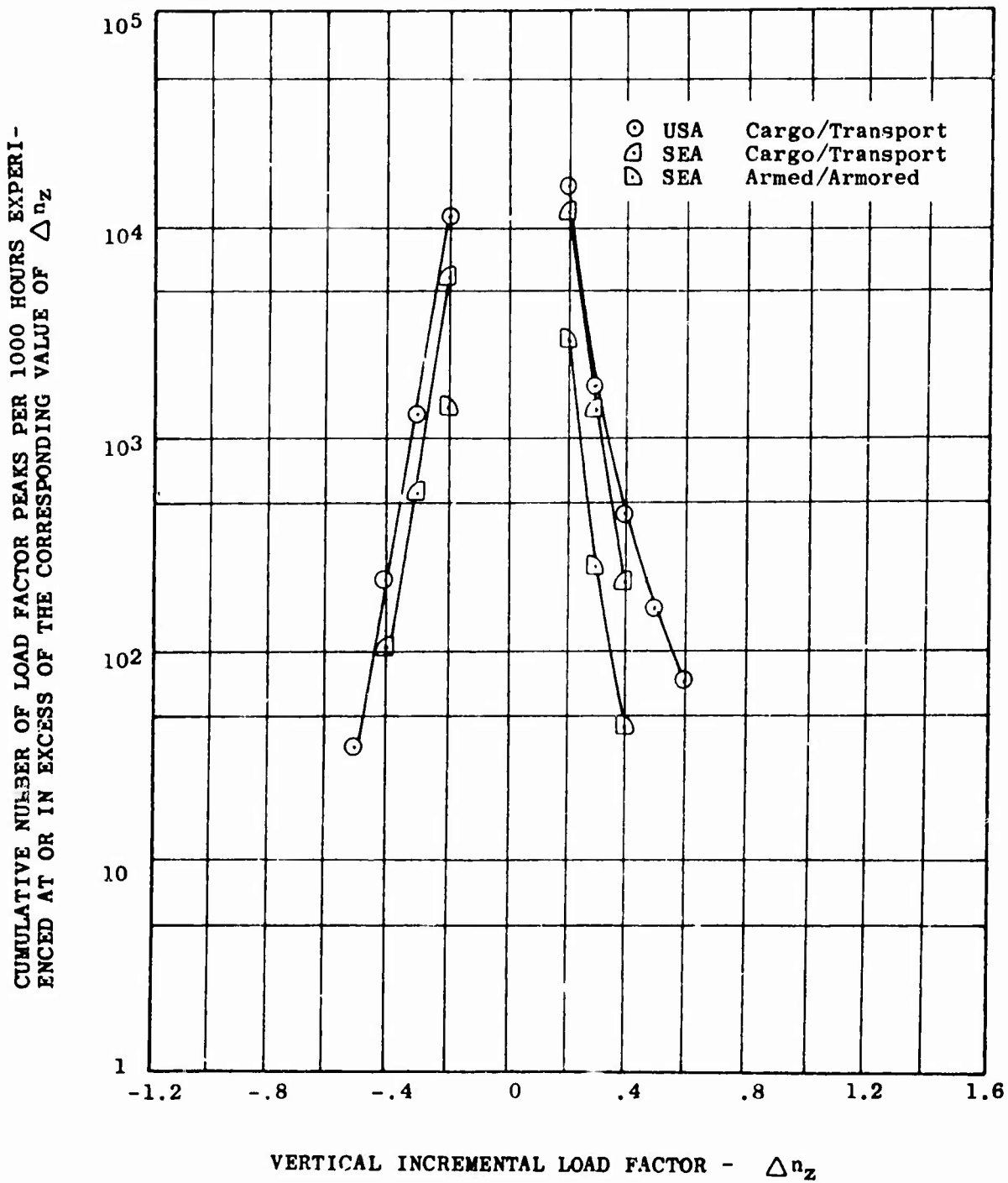
(a) Ascent.

Figure 13. Cumulative Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Mission Segment.



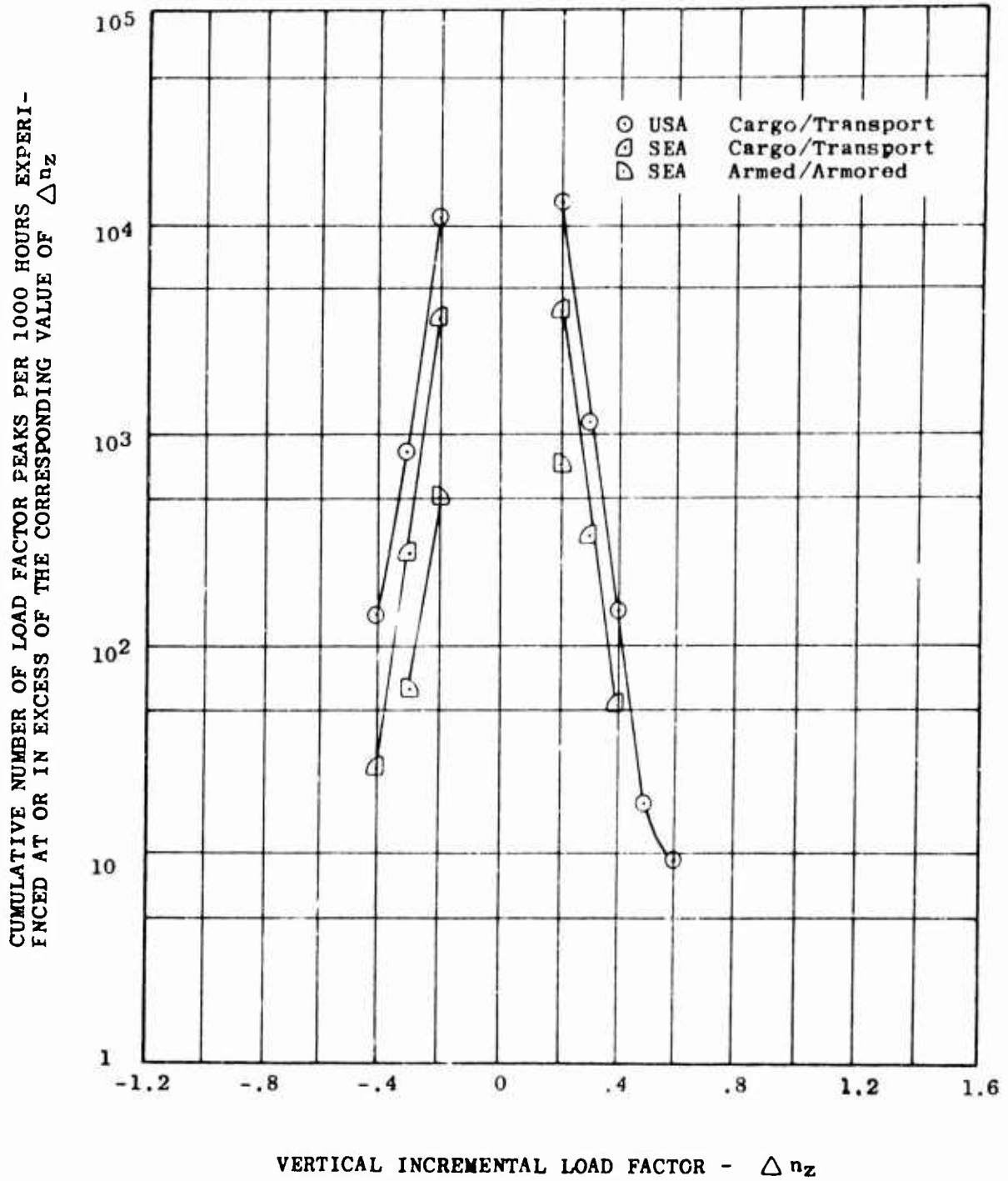
(b) Maneuver.

Figure 13. Continued.



(c) Descent.

Figure 13. Continued.



(d) Steady State.

Figure 13. Continued.

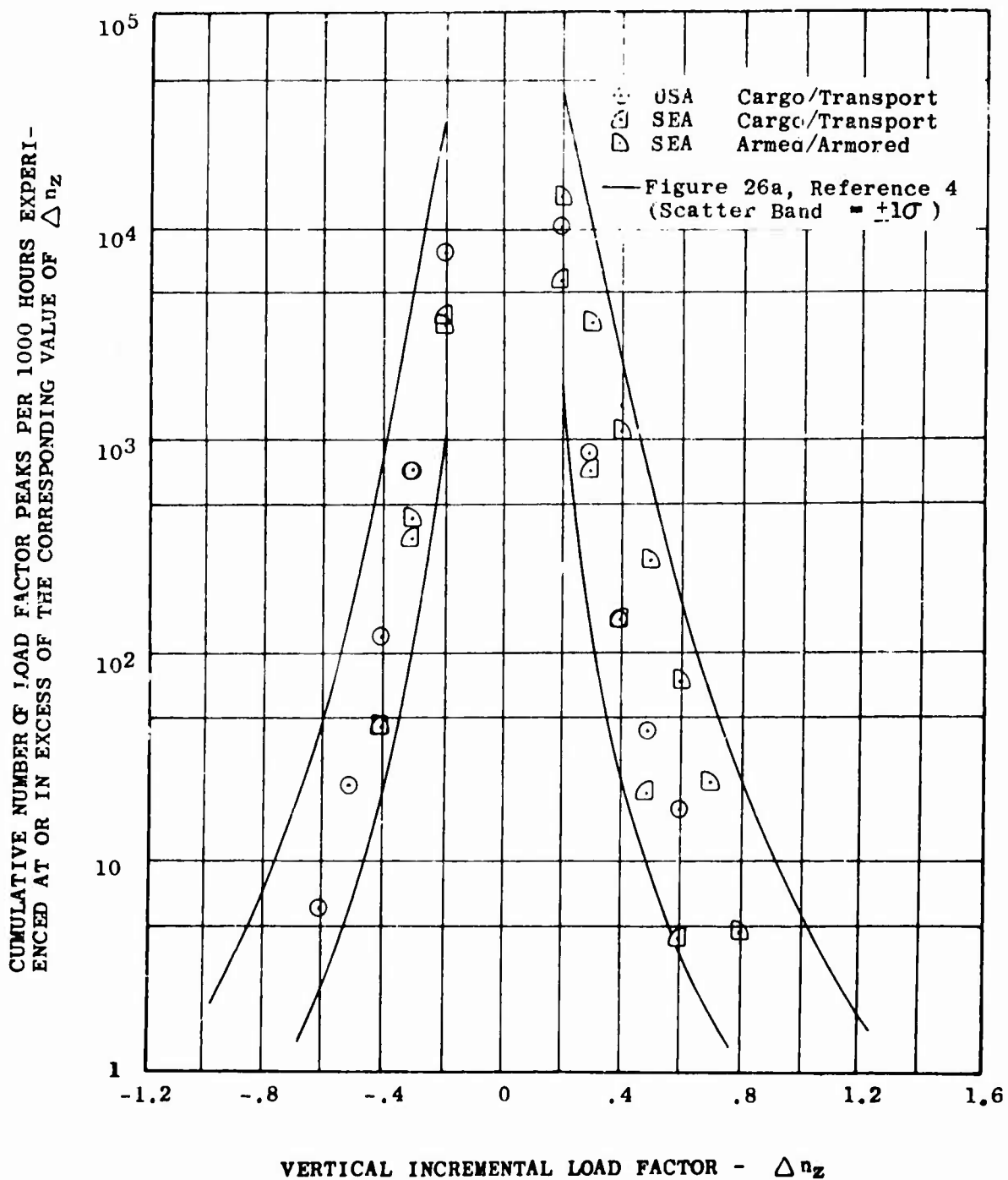
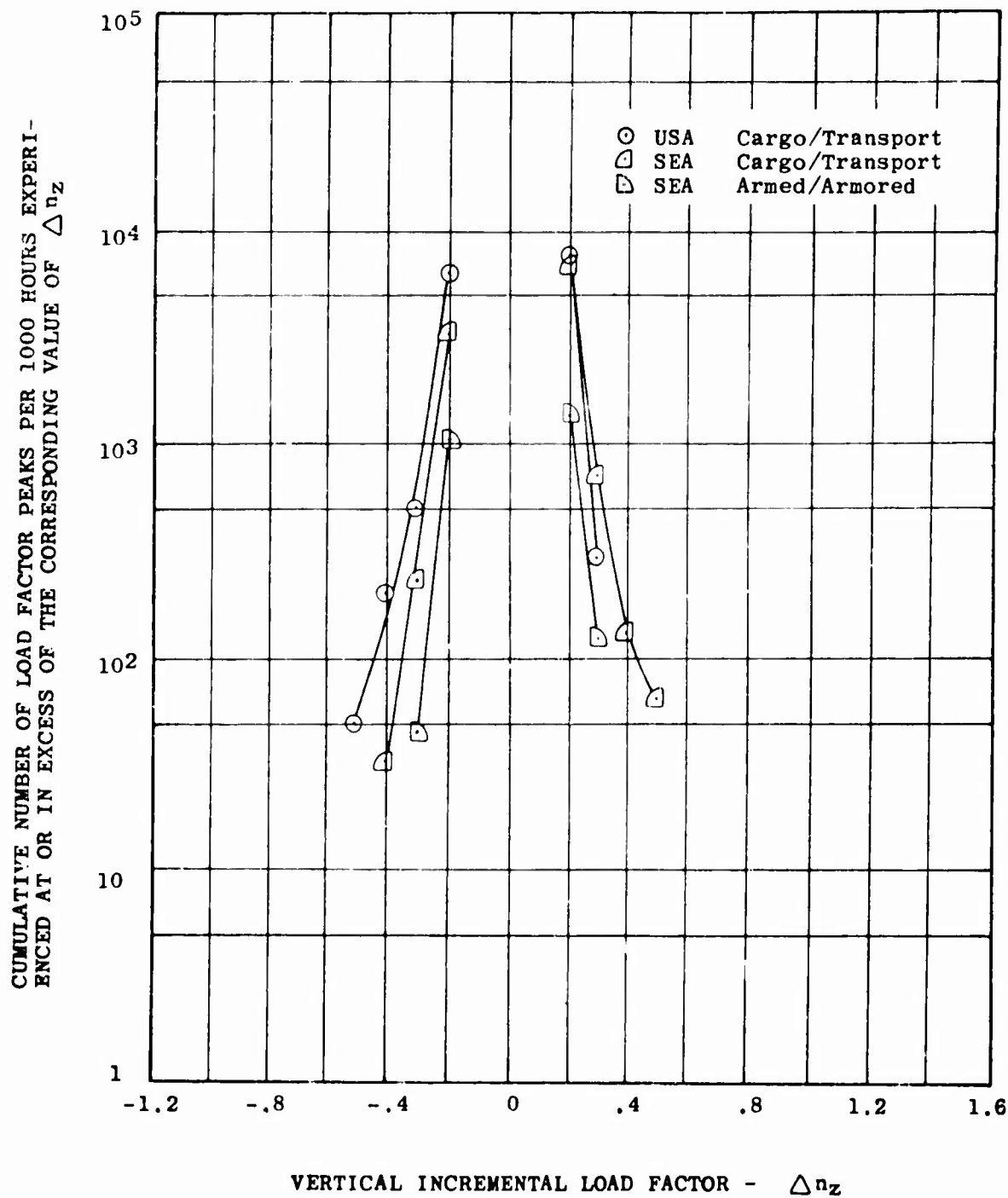
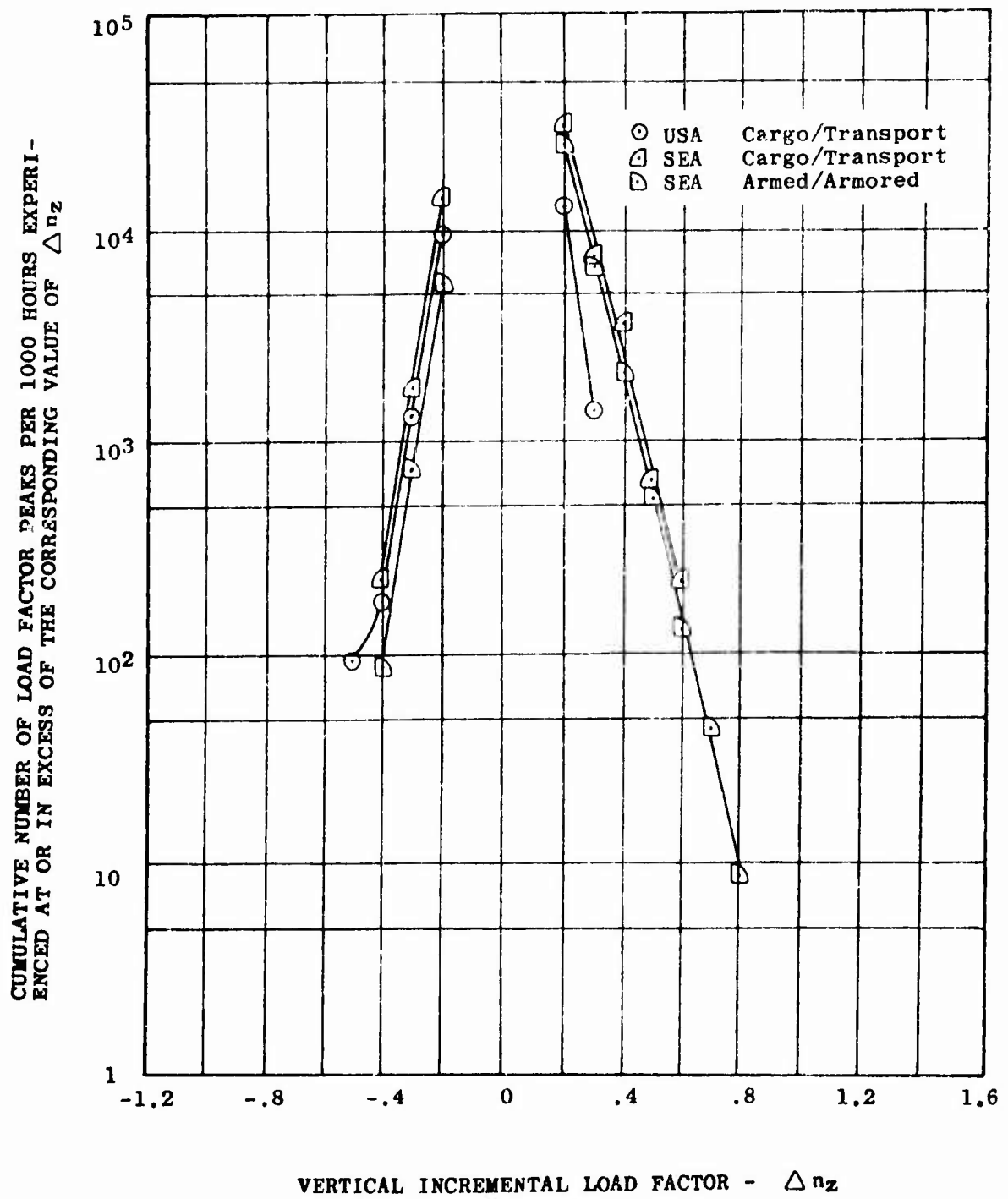


Figure 14. Cumulative Maneuver-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments Compared to Those Obtained From Other Helicopters.



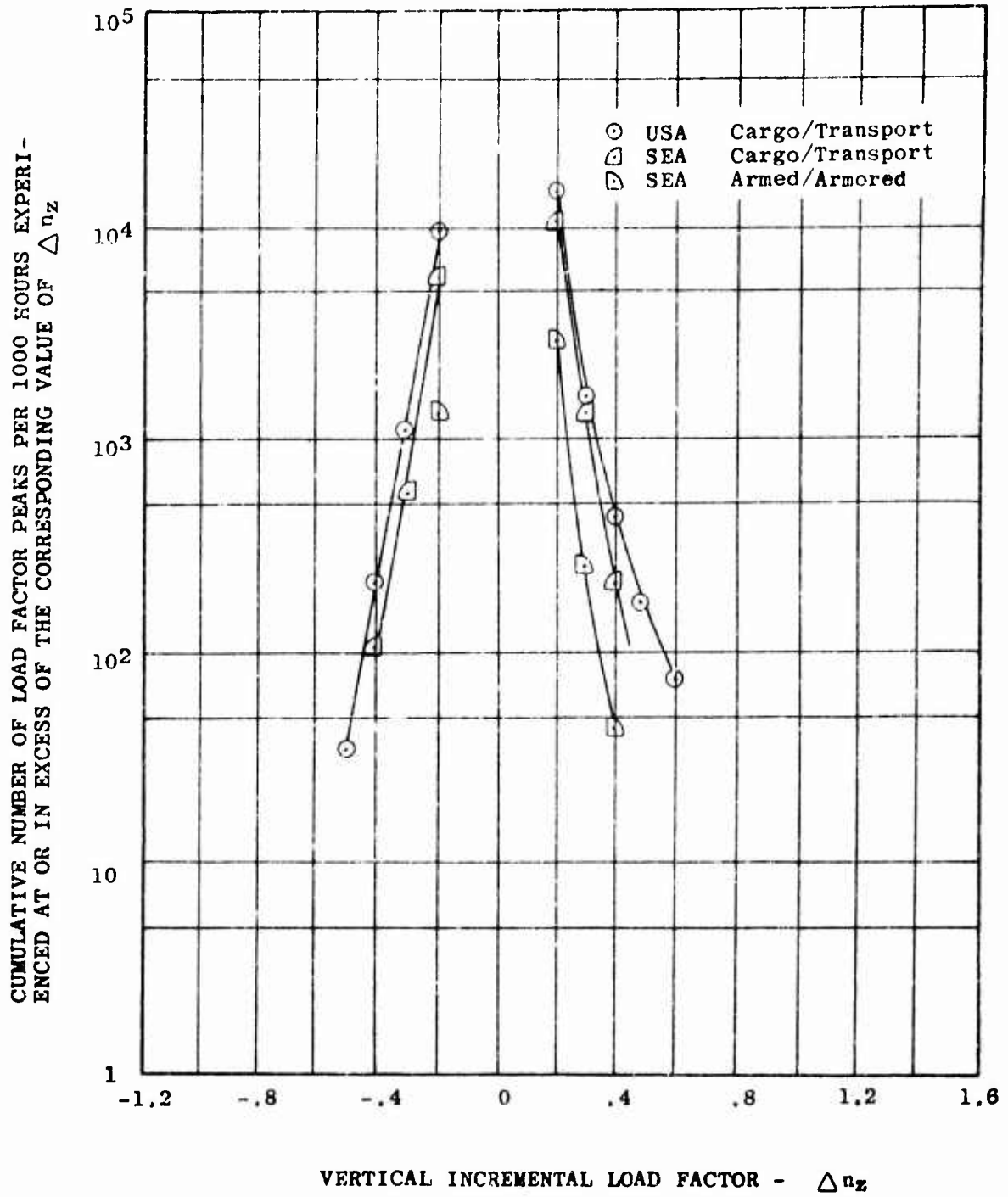
(a) Ascent.

Figure 15. Cumulative Maneuver-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Mission Segment.



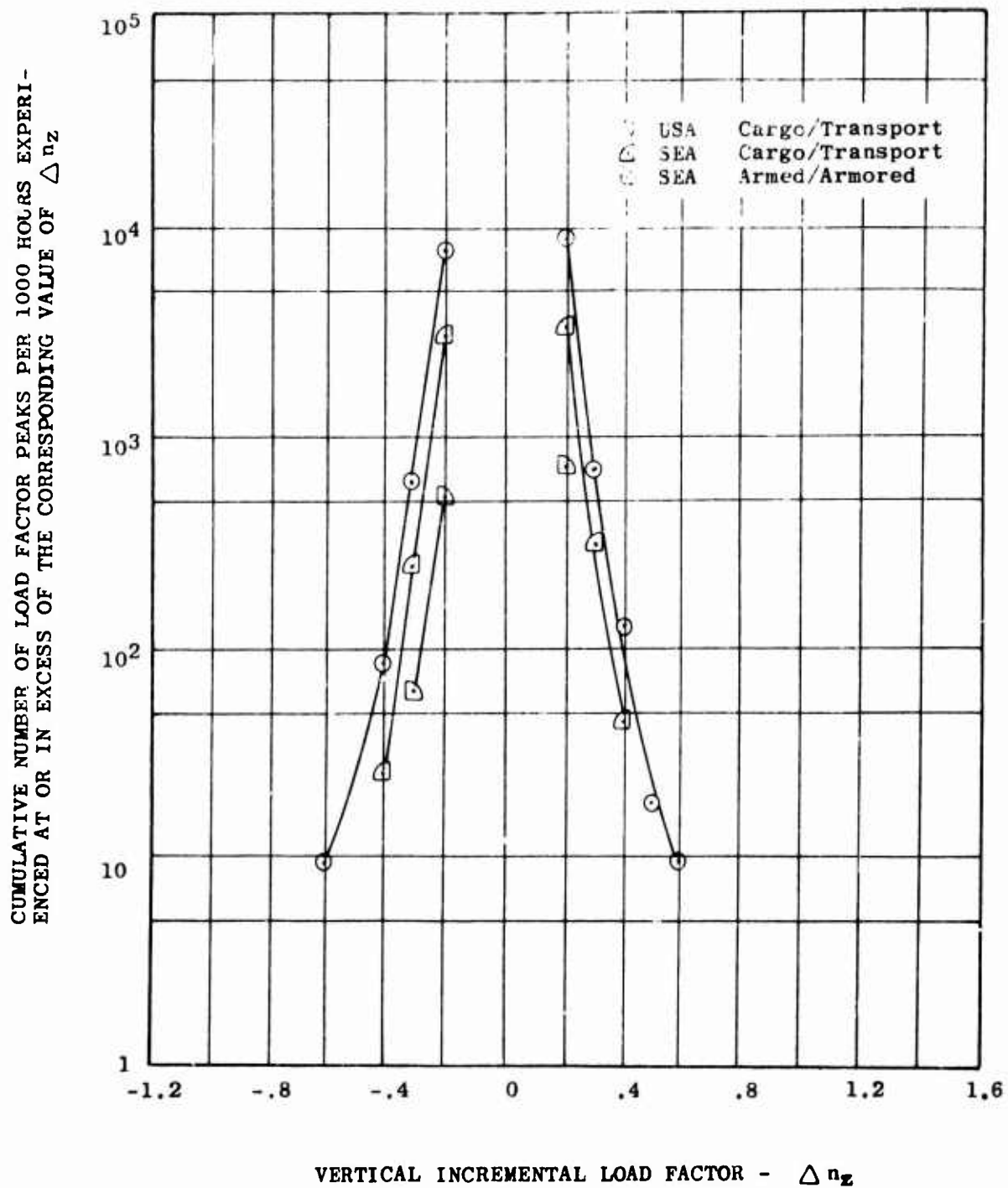
(b) Manuever.

Figure 15. Continued.



(c) Descent.

Figure 15. Continued.



(d) Steady State.

Figure 15. Continued.

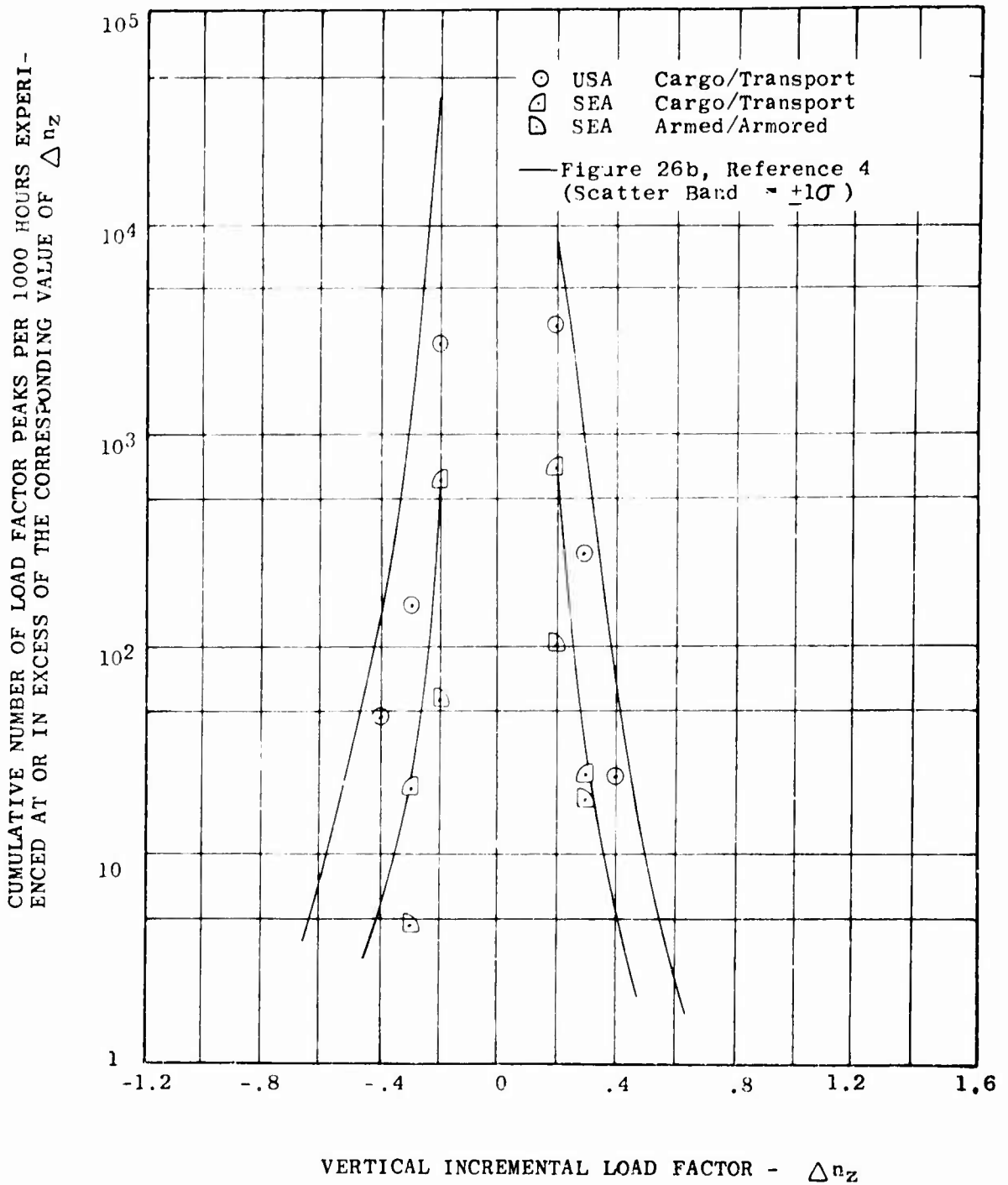
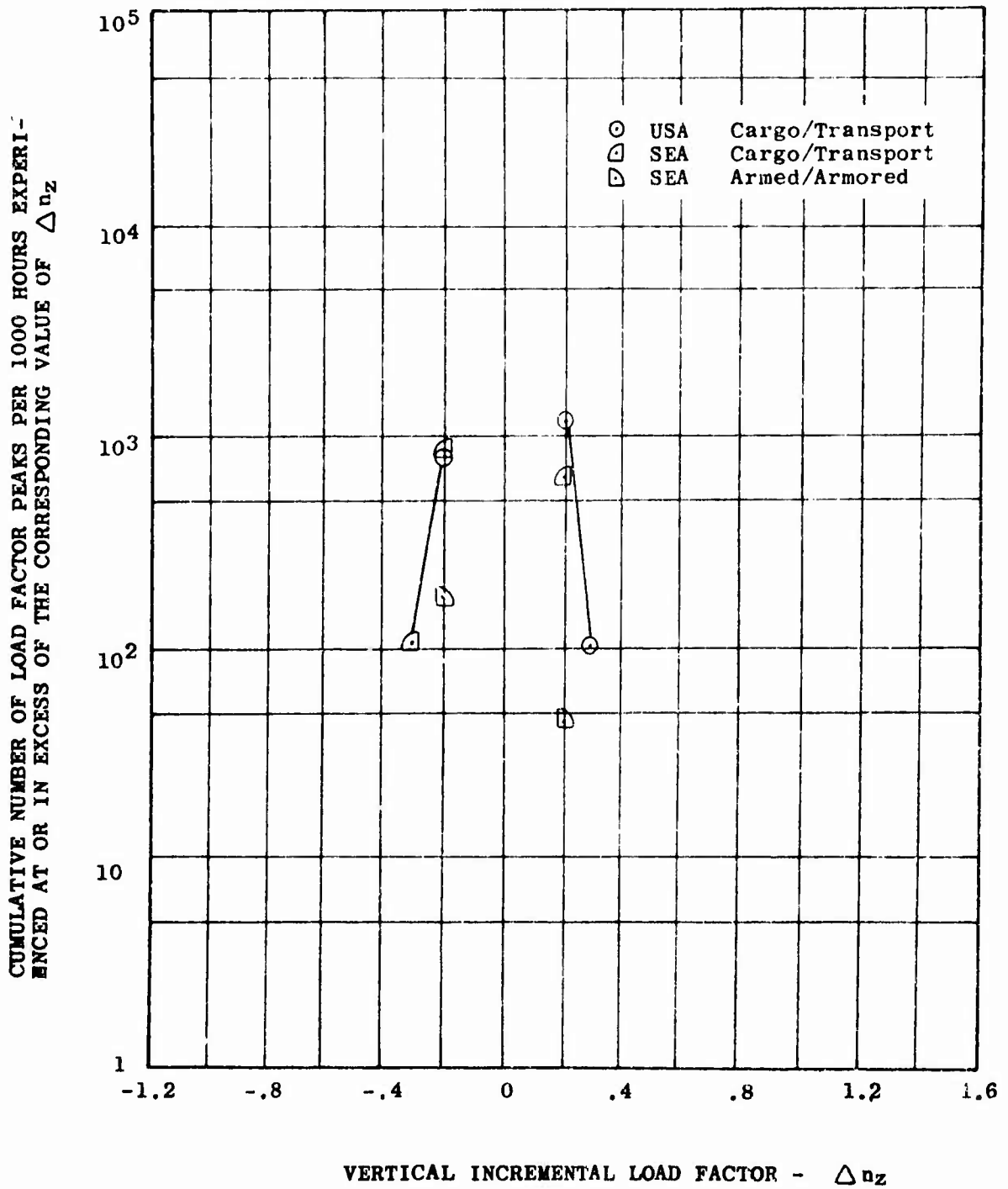
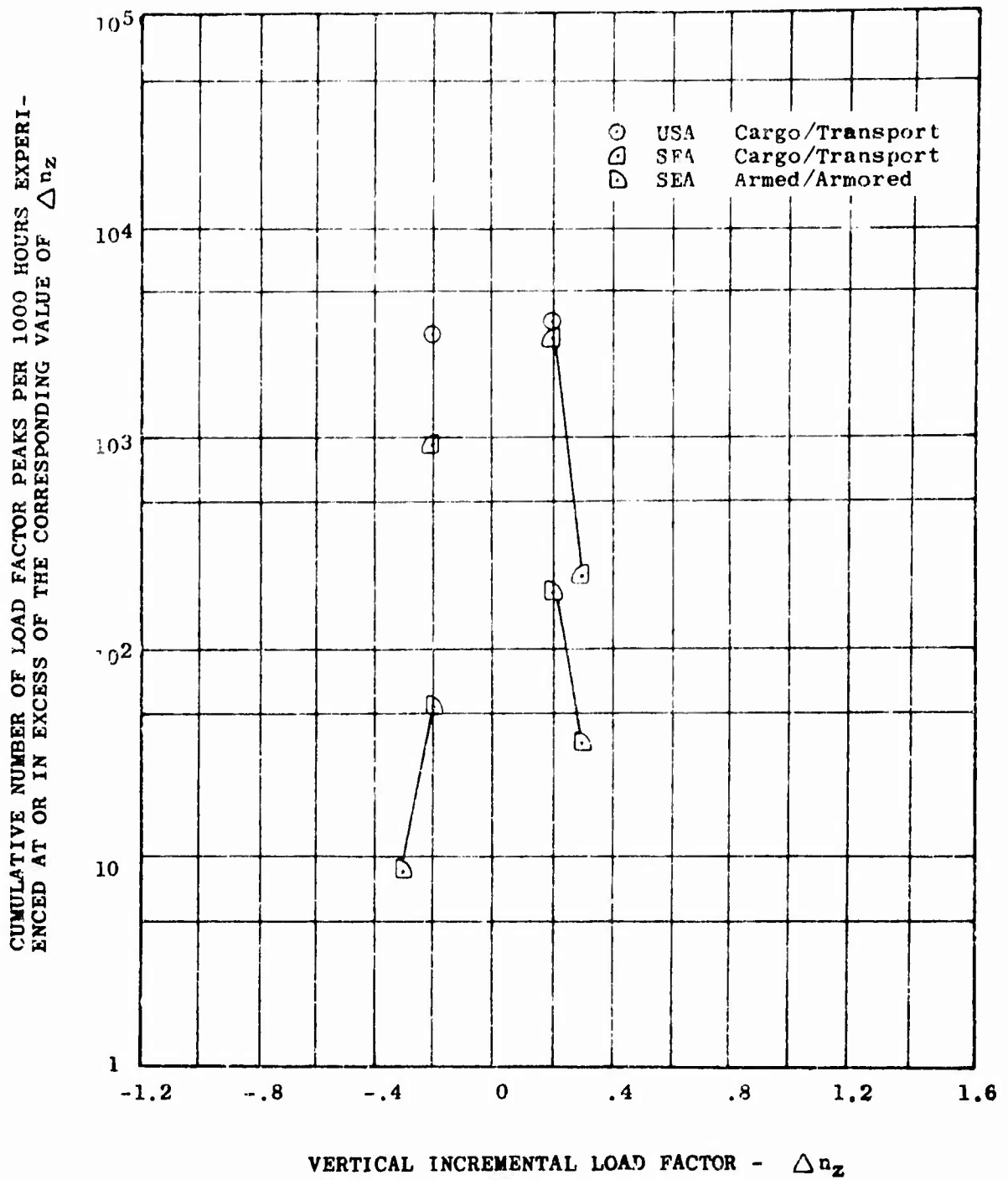


Figure 16. Cumulative Gust-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments Compared to Those Obtained From Other Helicopters.



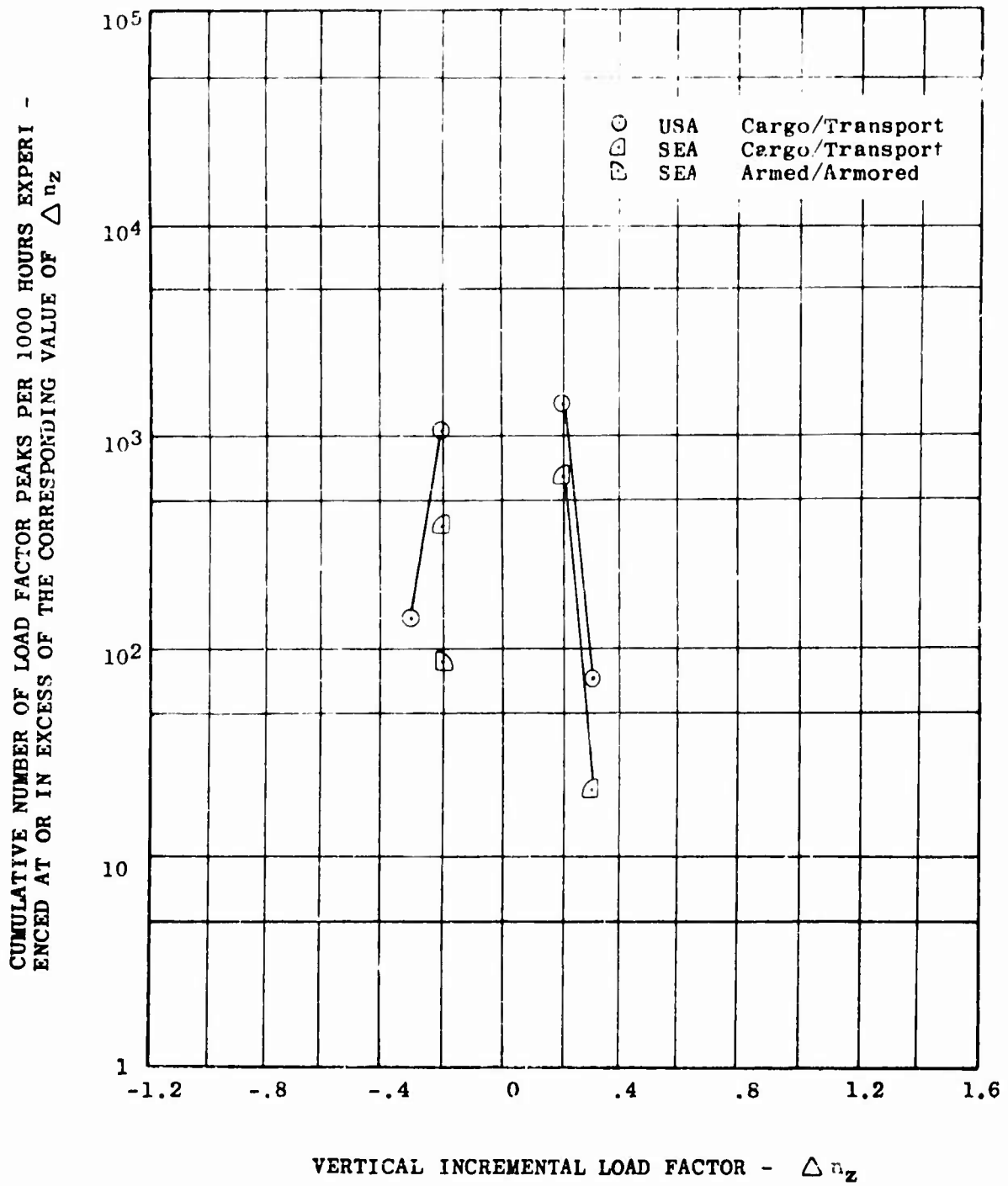
(a) Ascent.

Figure 17. Cumulative Gust-Induced Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Mission Segment.



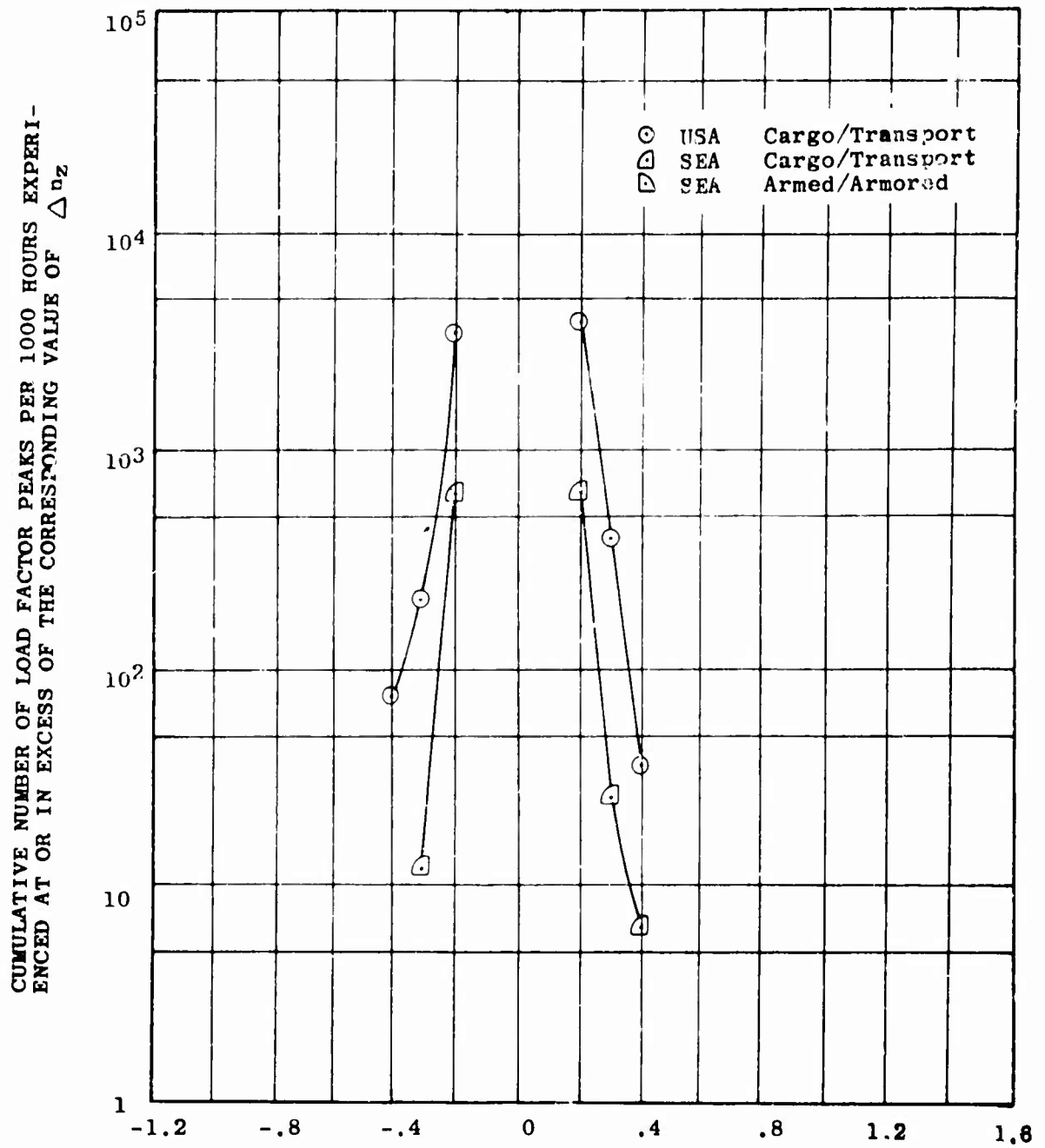
(b) Maneuver.

Figure 17. Continued.



(c) Descent.

Figure 17. Continued.

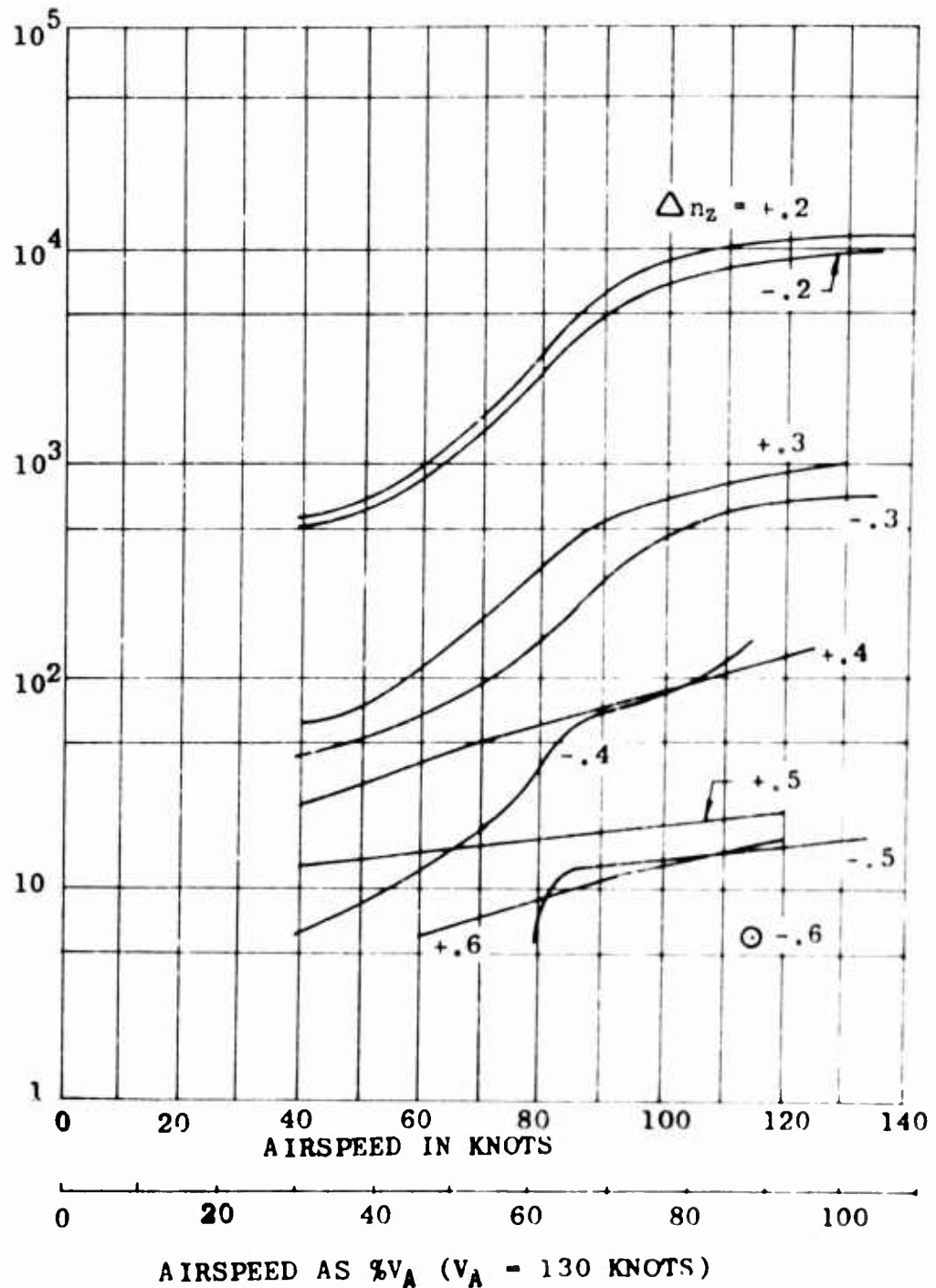


VERTICAL INCREMENTAL LOAD FACTOR -  $\Delta n_z$

(d) Steady State.

Figure 17. Continued.

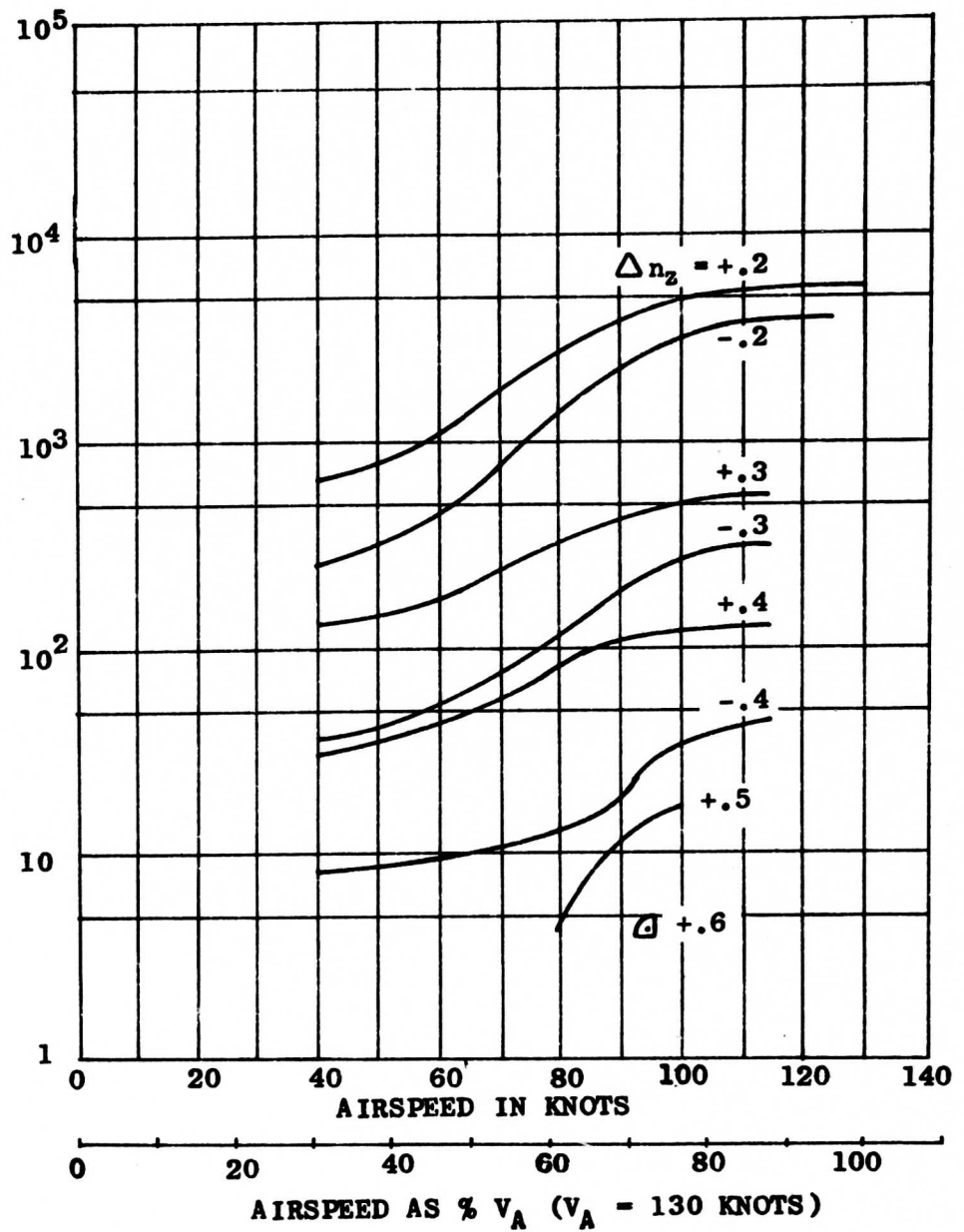
CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(a) USA Cargo/Transport.

Figure 18. Cumulative Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Airspeed.

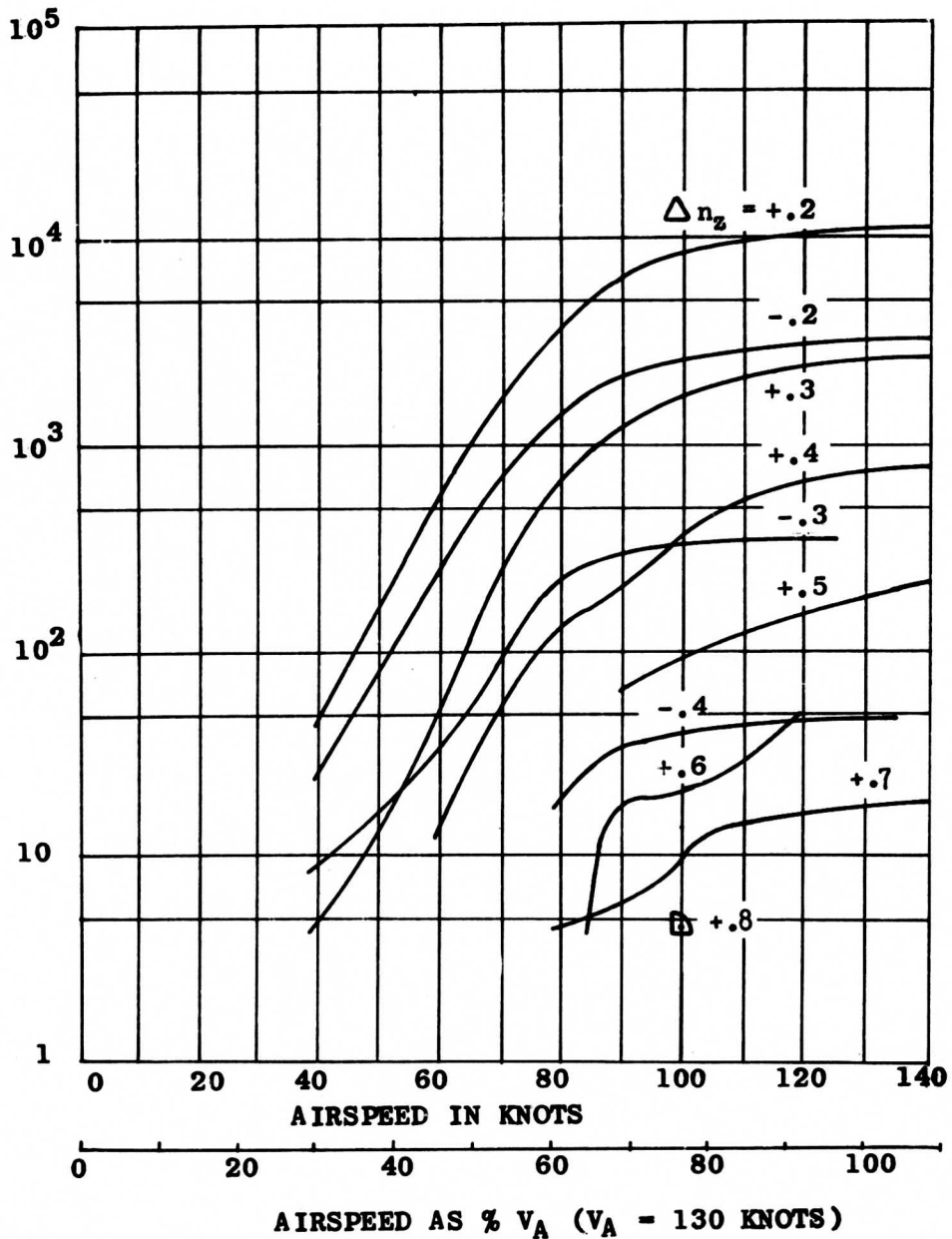
CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(b) SEA Cargo/Transport

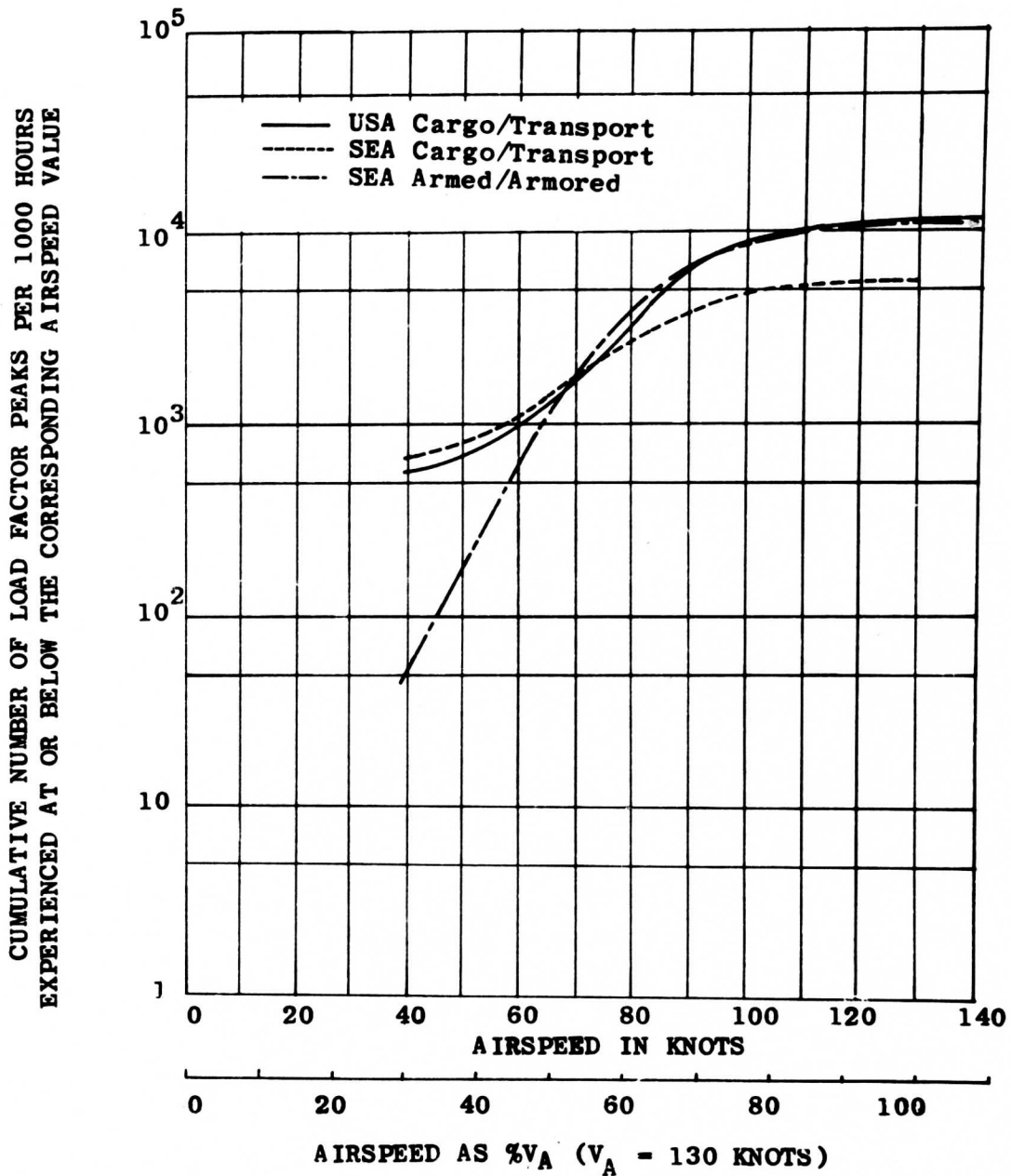
Figure 18. Continued.

CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(c) SEA Armed/Armored.

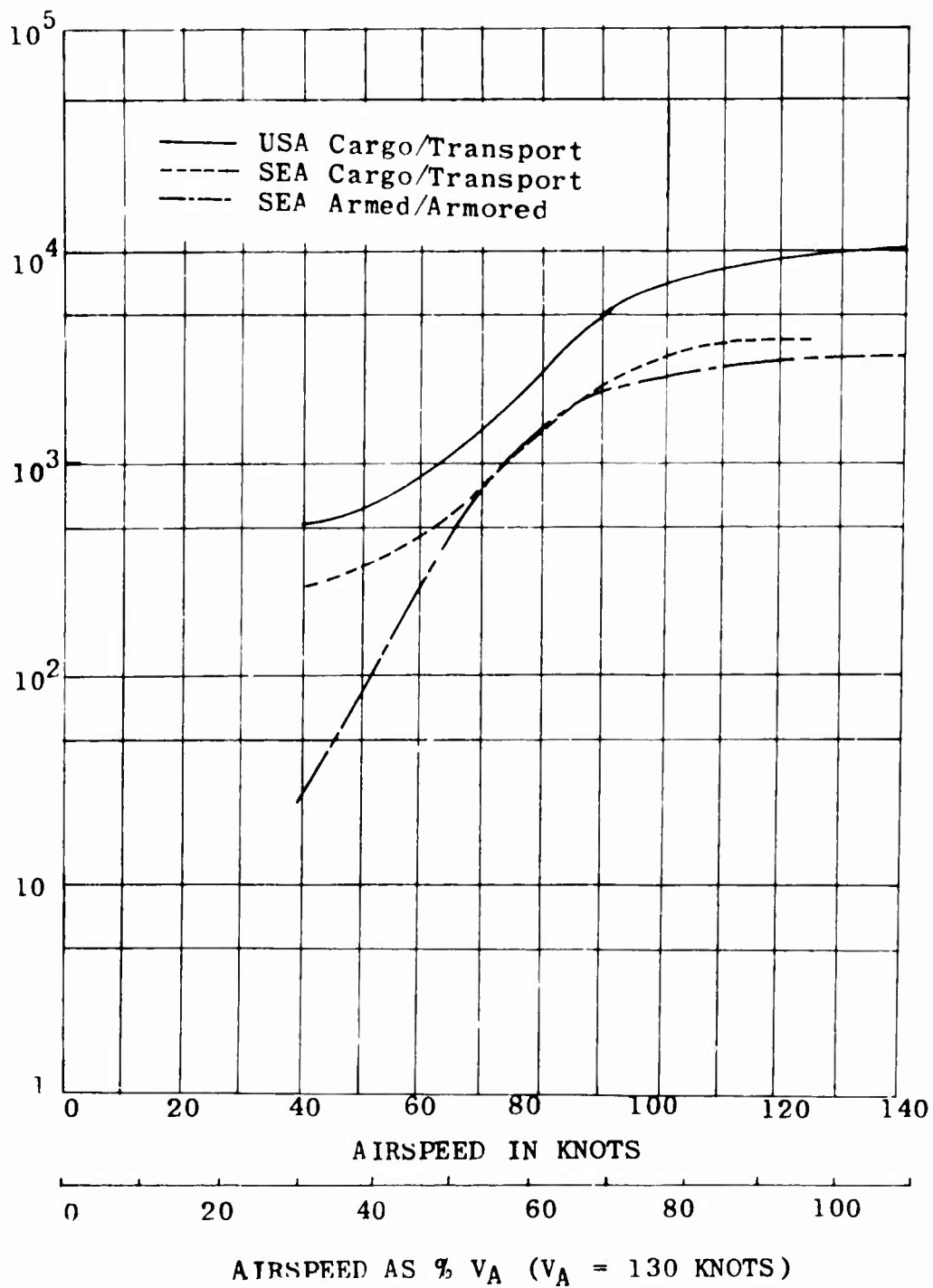
Figure 18. Continued.



(a)  $\Delta n_z = .2 g.$

Figure 19. Composite of Cumulative Vertical Load Factor Frequency Distributions for Three CH-47A Mission Assignments by Airspeed.

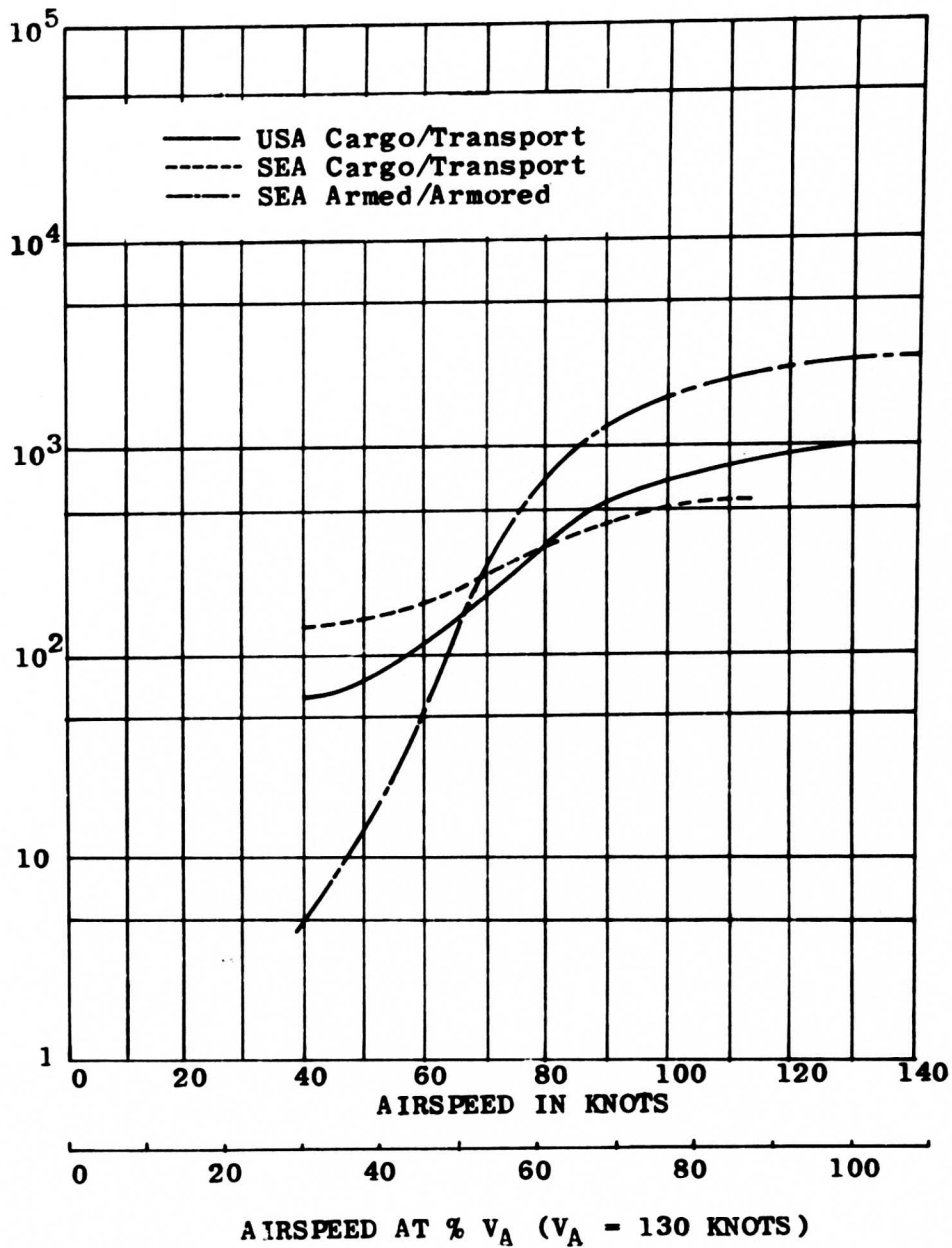
CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



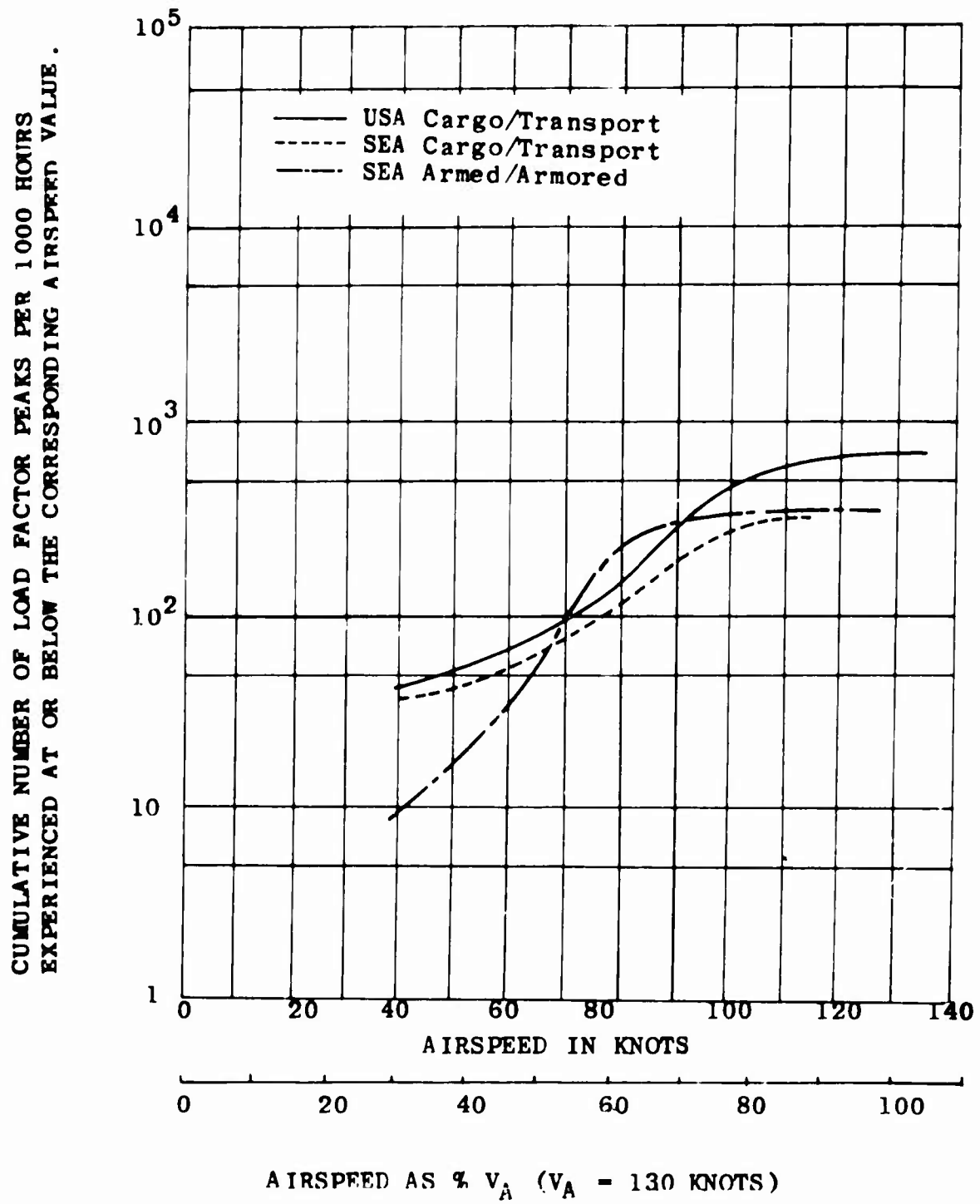
(b)  $\Delta n_z = -.2$  g.

Figure 19. Continued.

CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS  
EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



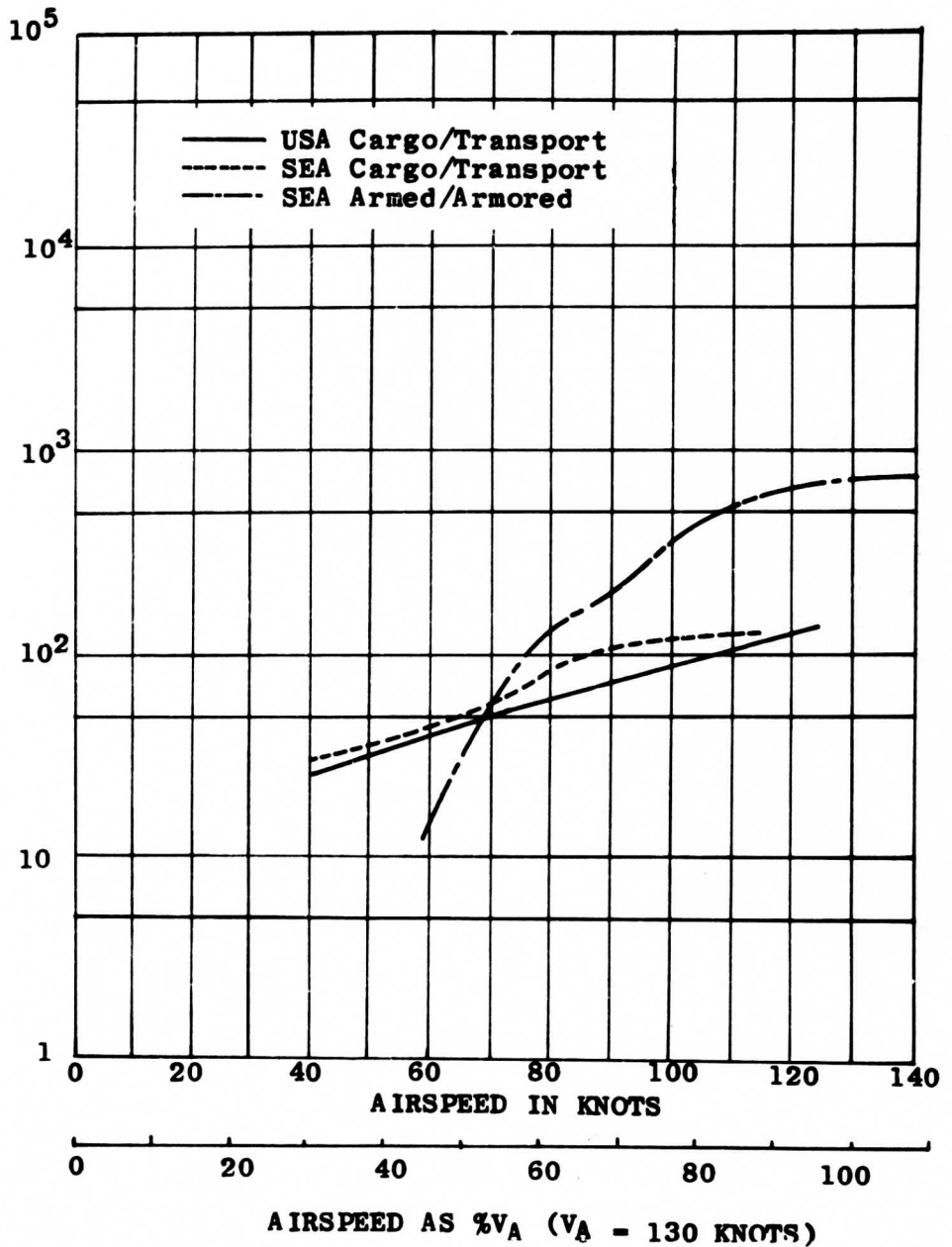
(c)  $\Delta n_z = .3$  g.  
Figure 19. Continued.



(d)  $\Delta n_z = -.3$  g.

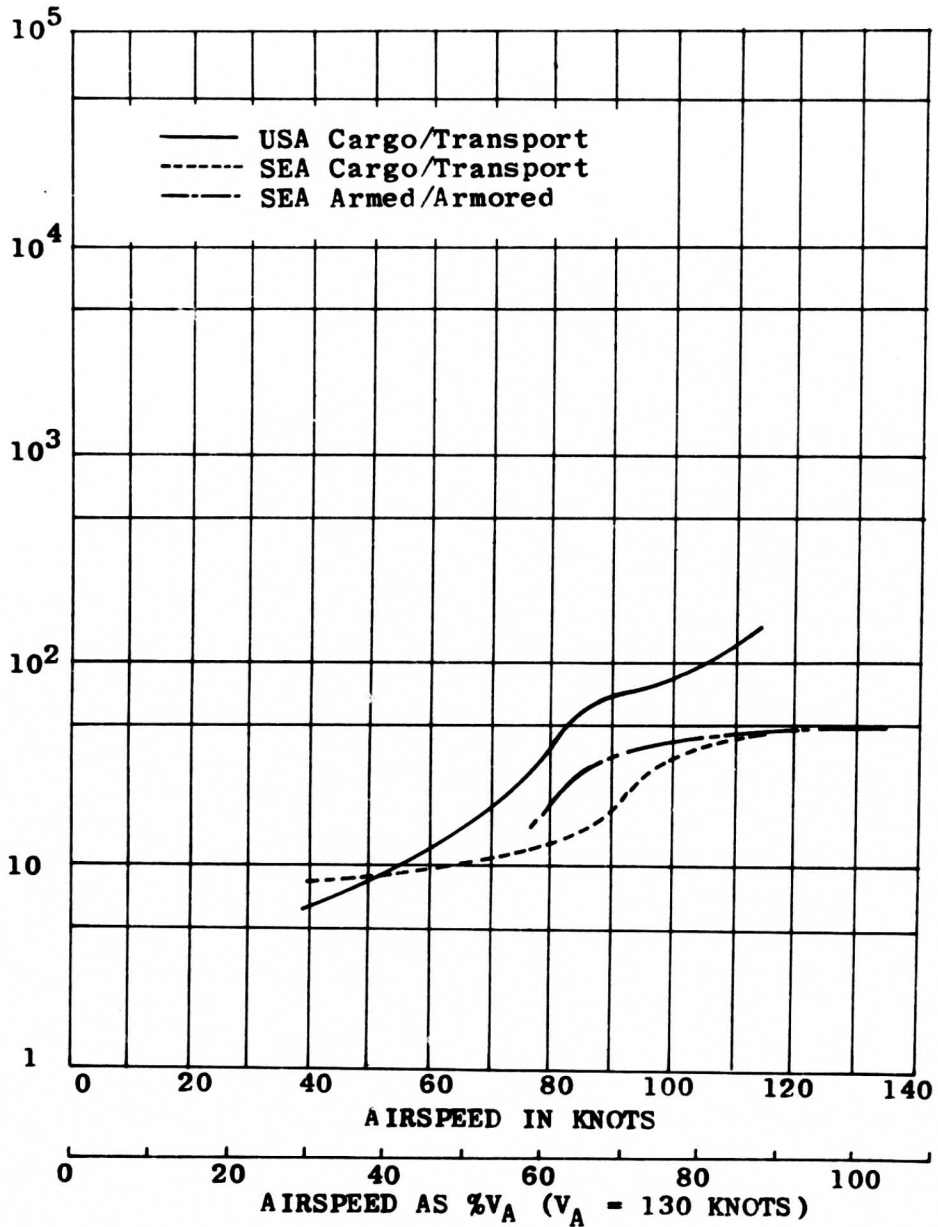
Figure 19. Continued.

CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS  
EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(e)  $\Delta n_z = .4 g.$   
Figure 19. Continued.

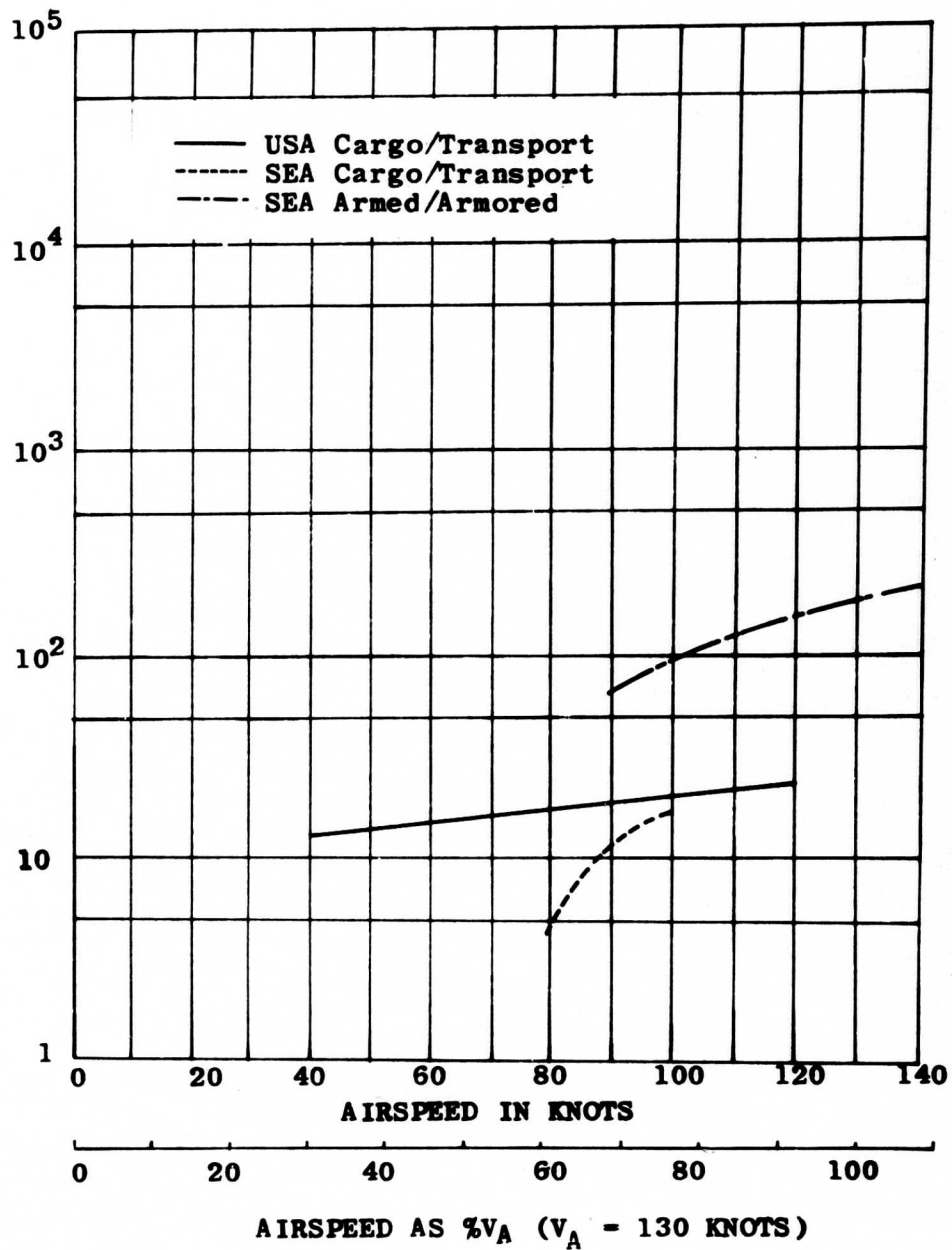
CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(f)  $\Delta n_z = -.4 g.$

Figure 19. Continued.

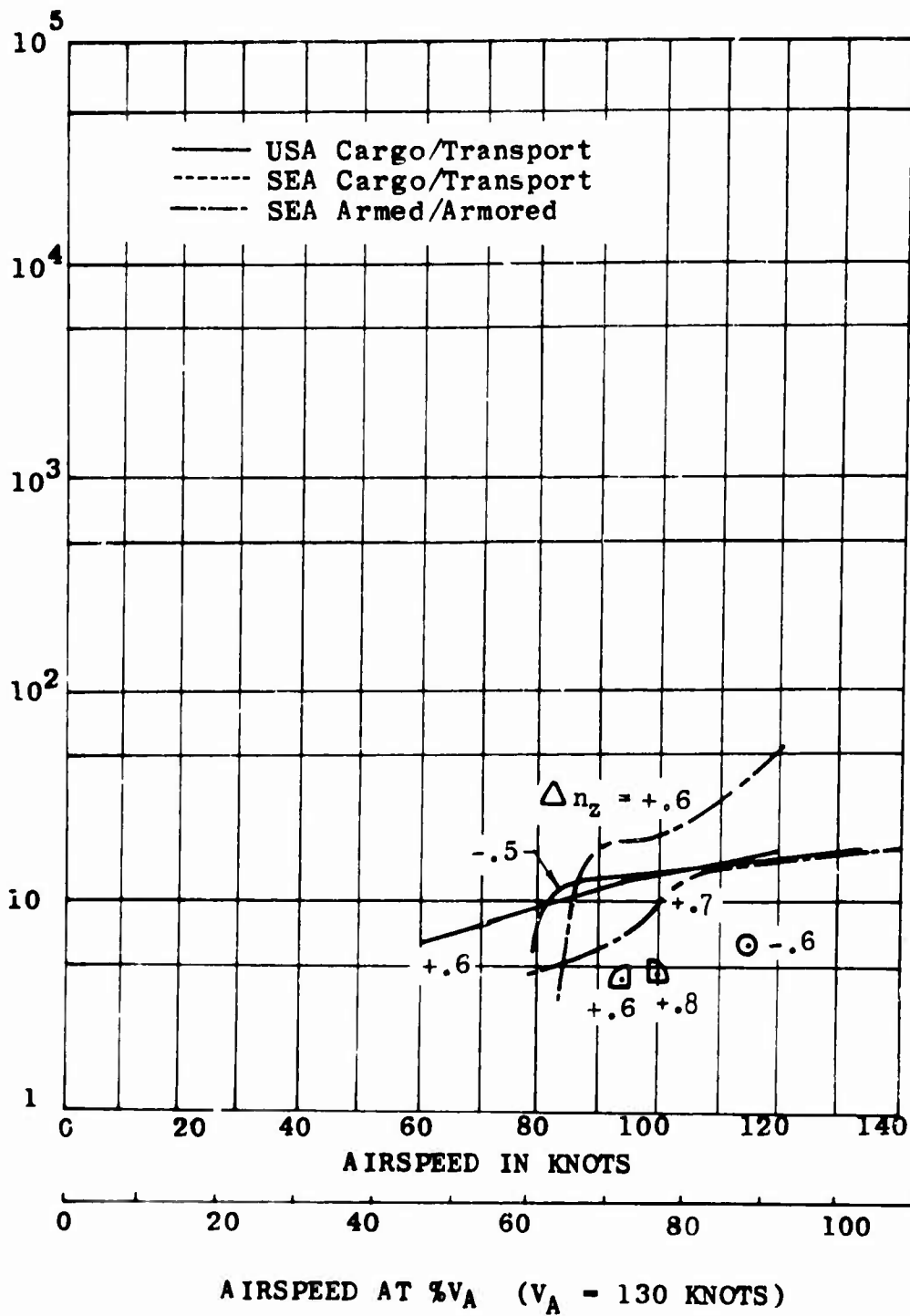
CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS  
EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(g)  $\Delta n_z = .5 g.$

Figure 19. Continued.

CUMULATIVE NUMBER OF LOAD FACTOR PEAKS PER 1000 HOURS  
EXPERIENCED AT OR BELOW THE CORRESPONDING AIRSPEED VALUE



(h)  $\Delta n_z = -.5, .6, .7, \text{ and } .8 \text{ g.}$

Figure 19. Continued.

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13. ABSTRACT This report evaluates flight spectra data for three different mission assignments flown by CH-47A helicopters. Two of these missions were flown in Southeast Asia under actual combat conditions: one as an armed/armored helicopter and one as a cargo/transport helicopter. The third mission was flown as a cargo/transport helicopter during simulated maneuvers in the United States. The CH-47A flight spectra data for these missions were compared to each other; to flight spectra data obtained from other helicopters; to the CAM-6 spectrum; and to a fatigue substantiation spectrum used initially to establish component fatigue lives for the CH-47A. Evaluations and correlations of these spectra are presented; and where variations occur, their probable cause and possible effects on fatigue life are discussed.		

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