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ATMOSPHERIC TURBULENCE SPECTRA FROM B-52 FLIGHT LOADS DATA

RICHARD G. COY

UNIVERSITY OF DAYTON
RESEARCH INSTITUTE

TECHNICAL REPORT AFFDL-TR-67-13

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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FOREWORD

This report was prepared by Richard G. Coy of the University of Dayton Research Institute, Dayton, Ohio, under Air Force Contract AF 33(615)-5033, BPSN 6(611367-6245334). The contract was initiated under Project No. 1367, "Structural Design Criteria", Task No. 136717, "Empirical Loads Interpretation and Analysis". The program was administered by the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Mr. Paul L. Hasty (FDTR), Project Engineer.

The research effort was conducted from 1 May 1966 to 13 January 1967. The manuscript was released by the author in January 1967 for publication as a technical report.

This program was conducted under the general direction of Mr. Dale H. Whitford, Supervisor of Aerospace Mechanics Research, and the author was assigned as Project Engineer.

The author gratefully acknowledges the cooperation and assistance of Mr. William H. Austin, Jr., of the Systems Engineering Group, Research and Technology Division, and of Mr. Ronald L. McAdams and Mr. John E. Kauflin of the University of Dayton Research Institute for the computational and analytical assistance during the program.

This technical report has been reviewed and is approved.

FRANCIS J. JANIK, JR.
Chief, Theoretical Mechanics Branch
Structures Division

ABSTRACT

This report contains the results of a vertical gust load analysis using flight loads data recorded on a large number of B-52 aircraft. The analyzed data will be used in evaluating existing airplane structural design criteria. The first of two analyses utilized power spectral density techniques to convert a 31,114 flight-hour sample of load factor data into true vertical gust velocity distributions which defined the atmospheric turbulence environment encountered by the B-52 in altitude bands from 5,000 to 50,000 feet. A series of equations representing the vertical turbulence environment was developed, one equation for each altitude band. These equations are considered representative of the flight environment over the North American continent. The derived vertical turbulence environment are generally less severe than similar environment presented in MIL-A-8866 and other publications. The second analysis utilized a 20,230 flight-hour sample of unreduced data to obtain the percent of time spent in turbulence for each altitude band. This data sample was also analyzed to obtain frequency distributions of lengths of turbulent encounters for each altitude band.
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A	gust response factor for the center of gravity incremental load factor, ratio of root-mean-square (rms) response to rms gust velocity
L	scale of turbulence
N_o	number of Δn response cycles per second of the aircraft
P	turbulence parameter used in expression representing environment (percent time in turbulence)
U_t	true gust velocity, feet per second or m/sec
V_T	true airspeed, feet per second
$T(\Omega)$	amplitude of aircraft response to unit sinusoidal gust frequency
$\phi_u(\Omega)$	power spectral density function for gust
b	turbulence parameter used in expression representing environment (turbulence intensity)
Δn	incremental normal load factor
$\sigma_{\Delta n}$	rms of Δn response
σ_u	rms gust velocity
Ω	reduced frequency, radians per foot

SECTION I

INTRODUCTION

1. Background

The increased demand for higher aircraft performance, higher structural efficiency, and longer structural life has emphasized the need for better, more complete design criteria. During the last twenty years, the Air Force, Navy, and the National Advisory Committee for Aeronautics have sponsored a number of programs to acquire structural loads data from operational aircraft. These programs resulted in the establishment of the criteria for maneuver and gust loads, presented in USAF specification, MIL-A-8861, and the requirements for repeated loads and fatigue, presented in USAF specification, MIL-A-8866.

Inasmuch as the gust criteria in these specifications were based on data obtained from aircraft flying in different regimes from those of present day and future aircraft, and since modern design techniques are more and more based on a statistical representation of the gust environment, it appears that the gust criteria in both of these specifications should be reevaluated in the light of present aircraft load experiences and newer methods of analysis.

Currently the analysis of aircraft loads and motions in turbulence are being conducted using power spectral density techniques (Reference 1). It is possible, using power spectral density techniques, to convert statistical aircraft acceleration data into a statistical description of the atmospheric turbulence. Recent flight loads programs have yielded large samples of statistically presented gust response load factor data. It appears appropriate, therefore, to convert these data, using power spectral density techniques, into a statistical description of the atmosphere which can be used in the evaluation of current gust criteria.

2. Purposes and Objectives

The purpose of this program was to analyze, interpret, and present available airplane gust load factor data, collected during the B-52 Service Load Recording Program (ECP-1019), using power spectral density techniques. Results of this gust load analysis were to be presented in a form suitable for use in evaluating existing airplane structural design criteria.

The primary objectives of this program were:

1. To define the atmospheric turbulence environment encountered by the B-52 aircraft in altitude bands from 5,000 to 50,000 feet by conversion of measured aircraft normal load factor data into true gust

velocities using power spectral density techniques;

2. To determine the proportion of time flown in turbulence and to develop a frequency distribution of the length of turbulent encounters in each of the altitude bands.

In support of the first objective, a small comparative study was conducted utilizing two techniques for converting the statistical load factor data into true gust velocity distributions. Both methods involved the application of power spectral density techniques but at different phases of the basic data processing associated with the flight loads program. In addition, all available severe load experience data were analyzed and combined with the basic true gust velocity distributions.

In support of the second objective, a study was conducted to verify the criteria to be used in establishing the turbulent areas for the percent time in turbulence study.

3. Description of Data

The data used in this investigation was collected during the B-52 Service Load Recording Program (ECP-1019), which was sponsored and managed by the Oklahoma City Air Material Area, Tinker Air Force Base, Oklahoma. A 40,139 flight-hour sample of data obtained over a two year period from 1962 to 1964 was available for this study. The data were obtained from 114 different B-52 aircraft flying operational Strategic Air Command missions which operated from a total of eleven different Air Force Bases in the continental United States. Time history measurements of airspeed, normal load factor of the aircraft center of gravity, and pressure altitude for each flight were recorded on oscillograph recorders.

Two sets of reduced data were obtained from this program. One set is comprised of a 13,375 flight-hour sample of data which was reduced in detail (Reference 2). This data was presented in the form of frequency distributions of incremental positive and negative primary gust load factor peaks (Δn) for all flight conditions experienced during the 13,375 flight-hour period. A primary peak is defined as the maximum excursion of the load factor trace recording between successive crossings of the mean level. A flight condition is designated by a data block (W-H-V_e) which is a combination of one class interval each of gross weight, altitude, and equivalent airspeed coded in terms of specified ranges for each of the parameters and by the mission segment being flown. The load factor data were further subdivided according to the cause of the load, i.e., peaks were categorized during data reduction as gust peaks or maneuver peaks. Consequently, separate frequency distributions for incremental load factor peaks caused by gusts and by maneuvers were generated and presented for each flight condition including the total time flown in each flight condition. A load factor peak was identified as a gust peak when the duration of the peak either above or below the mean value was less than or equal to two seconds. Separation of gusts and maneuvers was performed only on data reduced in the climb, cruise, and descent mission segments. The class intervals into which the Δn peaks were set for the frequency distributions and a listing of the codes and ranges for the various flight conditions are presented in Table I.

The second set of data (Reference 3) was obtained during the review of all data not selected for detailed reduction. This set of data was in the form of Xerox reproductions of portions of oscillograph records containing severe load experiences. Also included was a table containing estimated values of the gross weight, altitude, airspeed, and incremental load factor for each experience as well as the mission segment being flown and the cause of the load (gust or maneuver).

For this turbulence spectra development, a selected sample of the total available data sample was analyzed. The parameters used in selecting the data are presented in Table II. It should be noted that the lower airspeed limit was established to assure that all data used in the analysis would be for a flaps up airplane configuration.

Table I Incremental Load Factor Class Intervals and Flight Conditions From B-52 Service Load Recording Program

Mission Segments	Hours
Ground Operation	409.86
Take-Off Run and Landing Roll	23.48
Landing Impact	3.16
Climb	1024.41
Cruise	9737.46
Descent	808.65
Low Level	932.68
Refueling	435.46
Total	13,375.16

Δn Intervals

Identification	Range Δn (g)
THR	0 - ±0.04
±05	±0.05 - ±0.09
±10	±0.10 - ±0.14
±15	±0.15 - ±0.19
±20	±0.20 - ±0.24
±25	±0.25 - ±0.34
±35	±0.35 - ±0.44
±45	±0.45 - ±0.54
±55	±0.55 - ±0.64
±65	±0.65 and over

Weight

Interval x 1000 lbs.	Code
0 - 200	1
200 - 240	2
240 - 280	3
280 - 320	4
320 - 360	5
360 - 400	6
400 - 440	7
440 - 450	8
450 - 460	9
460 - 470	10
470 - 480	11
480 - 490	12
over 490	13

Altitude

Interval Feet	Code
0 - 1,000	1
1,000 - 2,500	2
2,500 - 5,000	3
5,000 - 10,000	4
10,000 - 20,000	5
20,000 - 30,000	6
30,000 - 40,000	7
40,000 - 50,000	8
over 50,000	9

Airspeed

Interval Knots	Code
0 - 150	1
150 - 200	2
200 - 250	3
250 - 300	4
300 - 350	5
350 - 400	6
400 - 450	7
450 - 500	8
over 500	9

Table II Parameters for Selecting Data Sample

Mission Segments	Load Factor
Climb Cruise Descent	Peaks attributed to gusts

Altitude Ranges

Interval Feet	Interval Meters	Code
5,000 - 10,000	1,524 - 3,048	4
10,000 - 20,000	3,048 - 6,096	5
20,000 - 30,000	6,096 - 9,144	6
30,000 - 40,000	9,144 - 12,192	7
40,000 - 50,000	12,192 - 15,240	8

Airspeed Ranges

Interval (Knots)	Interval m/sec	Code
200 - 250	102.888 - 128.611	3
250 - 300	128.611 - 154.333	4
300 - 350	154.333 - 180.055	5

SECTION II

DEVELOPMENT OF TRUE GUST VELOCITY SPECTRA

1. Analytical Approach

The power spectral density techniques used in this analysis are presented in Reference 1 and discussed in Reference 4. Only the basic equations applicable to this study are reviewed here for convenience.

The equation relating incremental load factor response peaks, Δn, to the actual turbulence field parameters, P_i and b_i is

$$\frac{M(\Delta n)}{N_o} = \sum_{i=1}^{k} P_i \, e^{-\Delta n / A b_i} \tag{1}$$

where

k	is the number of distributions selected to represent the turbulent environment.
$M(\Delta n)$	is the number of Δn cycles per second of flight equal to or greater than a given value of Δn.
$\frac{M(\Delta n)}{N_o}$	is the probability of reaching or exceeding a given value of true gust velocity U_t
$\Delta n/A$	is the true gust velocity, U_t

The aircraft response factors A and N_o for every combination of W-H-Ve, considered in this study, were obtained from Reference 2. These values were computed using the power spectrum of gust velocity, $\phi_u(\Omega)$, expressed by

$$\phi_u(\Omega) = \sigma_u^2 \frac{L}{\pi} \frac{1 + 3\Omega^2 L^2}{(1+\Omega^2 L^2)^2} \tag{2}$$

as an input to a 16-degree-of-freedom dynamic loads model of the B-52 aircraft. The scale of Turbulence L was taken to be 1000 feet for all W-H-V_e conditions. The response factors, A and N_o are related to the power spectrum by

$$A = \frac{\sigma(\Delta n)}{\sigma_u} = \left[\int_0^\infty \phi_u(\Omega)\, T^2(\Omega)\, d\Omega \right]^{1/2} \tag{3}$$

$$N_o = \frac{V_T}{2\pi} \left[\frac{\int_0^\infty \Omega^2 \phi_u(\Omega)\, T^2(\Omega)\, d\Omega}{\int_0^\infty \phi_u(\Omega)\, T^2(\Omega)\, d\Omega} \right]^{1/2} \tag{4}$$

Using the above information, the basic frequency distributions of acceleration peaks were converted into the form of $M(\Delta n)/N_0$ versus $\Delta n/A$ for specified altitude bands and airspeed bands within each altitude band. In addition a curve of the form of Equation (1) was fitted to the data defining the overall environment of each altitude band. The two methods studied for accomplishing this conversion are described below.

2. Comparison of Two Conversion Techniques

The conversion of statistical load factor data into true gust velocity distributions, using power spectral density techniques, can be accomplished at different phases of the required data processing associated with current flight loads programs. Technique I uses flight loads data that has been processed and presented in tabular distributions of the number of peak counts of Δn for specified class intervals of Δn. These distributions are usually combined and presented for given flight conditions encountered. With this information and the vehicle response factors A and N_0, the conversion of the peak count load factor data into true gust velocity distributions can be accomplished. However, since the data at this phase of processing is presented by data block (W-H-V_e), it is necessary to use A and N_0 values corresponding to the mid-range values of the W-H-V_e parameters.

Technique II would be applied in the early phase of the data processing. During this phase the actual value of each load factor peak and the instantaneous values of weight, altitude, and airspeed are computed. Later, these actual values are tallied as occurrences in a frequency distribution, and the actual identity of each parameter value is lost. Therefore if conversion of the data is accomplished during this early phase of processing the actual, instead of the mid-point values, of W-H-V_e are used to obtain A and N_0, and the actual load factor peak values can be used in the conversion.

Both of the above techniques were considered for possible application in converting the B-52 data into true gust velocity distributions. Technique II is, of course, the most correct technique since the actual W-H-V_e and Δn values would be used in developing the true gust velocity distributions. In the application of this technique it would be necessary to modify the basic B-52 flight loads computer program in order to generate the required distributions from the original raw input data in digitized form. A detailed study indicated that the calendar time and computer time required to handle the estimated 2.5 million data cards, modify the computer program, and generate the required distributions would represent a rather extensive and costly effort. Technique I would utilize B-52 data which has already been computed and presented as incremental load factor tabular distributions. Application of this technique would require the conversion of the tabular distributions in digital form and modification of part of the basic B-52 computer program. Evaluation of this technique indicates that a substantial cost savings would result if this technique were used to generate the true gust velocity distributions. The disadvantage of this technique is that mid-range values of W-H-V_e and Δn peaks for specific Δn class intervals would be used instead of actual W-H-V_e and Δn values.

Therefore, this comparative study was conducted, using both techniques, to determine the relative accuracy prior to selecting the technique to be used in generating the true gust velocity distributions from the 13,375 hour sample of B-52 data.

For this study it was necessary to review and use the computer output tab for the representative B-52 flight obtained during the original data processing which was conducted by the University of Dayton Research Institute. A computer output tab for each flight (which is unpublished) indicates the total time and air miles traveled as well as the loads distribution data for each flight condition in its chronological order as experienced during the entire flight. The time and miles information was tabbed whenever there was a change in the mission segment, weight block, altitude block, or airspeed block. The information presented for each flight condition included the following in addition to the gust and maneuver incremental load factor data:

1. Mission segment code.
2. Weight block code.
3. Altitude block code.
4. Airspeed block code.
5. Record time, i.e., the time after take-off when these conditions existed.
6. Airspeed in knots.
7. Pressure altitude in feet.
8. Gross weight in pounds.
9. Time increment for this condition in minutes.

In addition to the computer output tab, the corresponding original raw input data tab for each flight was required. This tab, also unpublished, contains the actual digital readings of the load factor peaks coded for gust or maneuver and identified by flight times corresponding to those included on the computer output tab. Therefore actual peak load factor values could be computed from the digital readings for each flight condition.

The manual reduction procedure for each technique and the comparative results are presented in the following paragraphs.

a. Technique I

For this technique the distributions of peak incremental load factor counts were converted into true gust velocity distributions using A and N_0 values corresponding to the mid-range values of the W-H-V_e parameters. The detailed steps involved are listed below.

1. A peak count distribution of Δn due to gust was obtained for each W-H-V_e combination experienced during this study from the computer output tab of B-52 reduced data.

2. These distributions were then converted into distributions of cumulative cycles of Δn due to gust at various class intervals of Δn. The number of cumulative cycles for a given Δn class interval is equal to one-half the sum of the Δn peaks for all positive and negative Δn class intervals having magnitudes greater than or equal to the given Δn class interval magnitude.

3. The Δn class interval boundaries for each W-H-V_e were then converted into true gust velocity class interval boundaries by dividing the Δn boundaries by the appropriate gust Response Factor A. The A factor was obtained from Reference 2 for the mid-range values of the W-H-V_e being considered.

4. For each W-H-V_e, a semi-log plot of cumulative cycles versus $\Delta n/A$ was constructed.

5. Assuming an exponential distribution between $\Delta n/A$ values determined in Step 3, interpolations were made to obtain new frequency distributions in terms of $\Delta n/A$ for each W-H-V_e at assigned $\Delta n/A$ class intervals.

6. The new $\Delta n/A$ distributions for each W-H-V_e were then converted into distributions of cumulative cycles of $\Delta n/A$ per second greater than or equal to a given value of $\Delta n/A$ (assigned class intervals).

7. The resulting distributions were then converted into normalized cumulative distributions by dividing the cumulative cycles per second in each $\Delta n/A$ interval by the appropriate Response Factor N_0. The N_0 factors were obtained from Reference 2 for the mid-range values of the W-H-V_e being considered.

8. The normalized distributions were then combined for each altitude band.

9. Because of the small amount of data used, a time-weighted average from all altitude bands was computed for use in this comparative study.

b. Technique II

In this technique the true gust velocity distributions were obtained using the actual values of each load factor peak and A and N_o values corresponding to the instantaneous values of the W-H-V_e parameters. The detailed steps involved are listed below.

1. From the computer output tab the instantaneous values of W-H-V_e were obtained for a given time interval. These values were then applied to all data recorded during that time interval.

2. The A and N_o factors for the mid-range values of W-H-V_e were obtained from Reference 2. By interpolating, the A and N_o factors for the instantaneous values of W-H-V_e were obtained.

3. From the original raw input tab, the actual digital readings for each gust peak were obtained for each applicable W-H-V_e condition. With these readings and the appropriate calibration data, the actual value of each load factor peak was computed. Over 2,000 gust peaks were manually computed using this process.

4. Each Δn magnitude was then divided by the appropriate A factor to obtain the corresponding true gust velocity value, $\Delta n/A$.

5. Each Δn magnitude was represented as a load factor frequency of 1 peak. Each load factor frequency peak was divided by the appropriate N_o factor to obtain the corresponding gust frequency value, $1/N_o$.

6. The gust frequency values of $1/N_o$ were summed under the assigned $\Delta n/A$ class intervals. The $\Delta n/A$ class intervals into which the $1/N_o$ values would fall were determined in Step 4.

7. The total time flown was summed for each established W-H-V_e condition.

8. The resulting distributions of $1/N_o$ values versus positive and negative $\Delta n/A$ intervals by W-H-V_e were converted into cumulative distributions of $1/N_o$ versus $\Delta n/A$. The number of cumulative cycles of gust frequency values, $1/N_o$, for a given $\Delta n/A$ class interval, is equal to one-half the sum of the $1/N_o$ values for all positive and negative $\Delta n/A$ class intervals having magnitudes greater than or equal to the given $\Delta n/A$ class interval magnitude.

9. For each altitude band the values of the cumulative distributions of $1/N_o$ were summed for each $\Delta n/A$ interval and the resulting values divided by the total time in seconds in the altitude band. The

results of these computations yielded the normalized cumulative distributions $M(\Delta n)/N_0$ for each altitude band.

10. Because of the small amount of data used, a time-weighted average from all altitude bands was computed for use in this comparative study.

c. Comparative Results

The derived cumulative probability distribution data from Table III were plotted in the form of $M(\Delta n)/N_0$ for both techniques and are presented in Figure 1. Since the results from this study were relatively close for the limited data sample used, it was decided that Technique I would be adequate for converting the 13,375 flight-hour sample of processed B-52 data into true gust velocity distributions.

Table III Comparison of $M(\Delta n)/N_0$ Data Determined From Two Techniques

		Cumulative Gust Occurrences $(10^{-6}$ $(M(\Delta n)/N_0) \geq$ True Gust Velocity $(\Delta n/A = U_t)$						
Technique	Time Seconds	2.5	5.0	7.5	10.0	12.5	17.5	20.0
I	24,912	33,220	5,860	1,104	251.7	36.13	25.69	25.69
II	24,912	35,210	5,822	1,352	347.5	86.95	24.50	24.50

3. Conversion of B-52 Load Factor Data

This phase of the study involved the conversion of the 13,375 hour sample of data into true gust velocity distributions using the technique described in Section II.2.a. The data sample obtained from Reference 2 was presented in the form of cumulative distributions of load factor cycles per second versus incremental load factor, Δn, for every W-H-V_e combination by mission segment. The load factor class intervals and flight conditions used are presented in Table I. A computer program was written to accept the data in digital form and to generate the required true gust velocity distributions. The general procedure and results are discussed below.

The cumulative frequency distributions for the parameters listed in Table II, and the corresponding time, A, and N_0 values for the mid-range values of W-H-V_e were extracted from Reference 2. A deck of punched cards containing this information was then generated and used as the

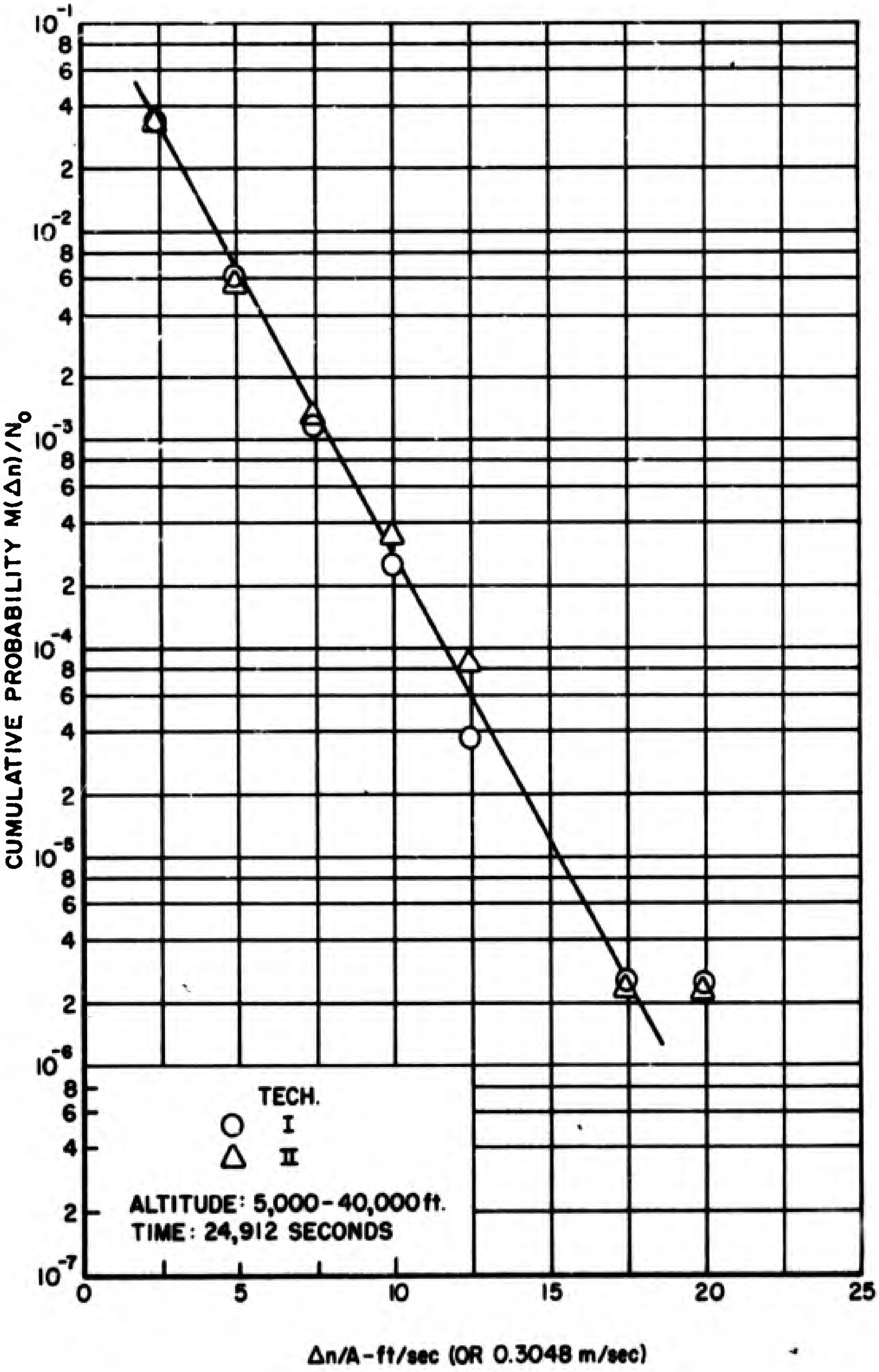

Figure 1 Comparison of $M(\Delta n)/N_0$ Versus $\Delta n/A$ Data Determined From Two Techniques

input to the computer. A noncoded flow chart presented in Figure 2 indicates the general steps involved in generating the required distributions.

The true gust velocity distributions derived from this phase of the effort are presented in Table IV. Included are distributions for each altitude-airspeed band combination and a time-weighted average for each altitude band considered for this study.

The data were plotted in the form of $M(\Delta n)/N_0$ versus $\Delta n/A$ to represent the vertical turbulence environment. The vertical turbulence environments for each altitude band indicating the variation with airspeed are presented in Figures 3 through 7. A composite of the time-weighted average from each altitude band is presented in Figure 8.

It should be noted that the application of power spectral density techniques in converting statistical load factor data should yield true gust velocity distributions which are independent of vehicle characteristics and W-H-V_e parameters. However, the data sample used in this study yielded true gust velocity distributions which varied with airspeed, as indicated in Figures 3 through 6. This variation could be attributed to several factors, such as (1) the use of mid-range values of the W-H-V_e parameters; (2) the assumed power spectrum and scale of turbulence; (3) the determination of the vehicle response factors; and (4) the operational procedures employed during turbulence encounters.

4. Analysis of Severe Loads Data

During the second year of the B-52 Service Loads Recording Program, documentation of all of the extreme or severe load factor data points from all recorded flights was maintained. The general criteria used was that the incremental load factor peak should equal or exceed 0.8. A tabulation of the severe loads data points obtained from the B-52 program is presented in Table V. Also included in Table V are the interpolated values of A and N_0 obtained from basic data presented in Reference 2.

The severe load data points used in this evaluation were obtained from the 17,739 flight-hour B-52 data sample which was not selected for detailed reduction. However, in order to incorporate these severe load points in the $M(\Delta n)/N_0$ versus $\Delta n/A$ distributions, it was necessary to know the flight condition (W-H-V_e) at the time of each severe load encounter and the total amount of time flown during the 17,739-hour period in each altitude-airspeed combination. The W-H-V_e data had been computed and tabulated at the time each severe load encounter was analyzed. However, the total time spent in each H-V_e combination was

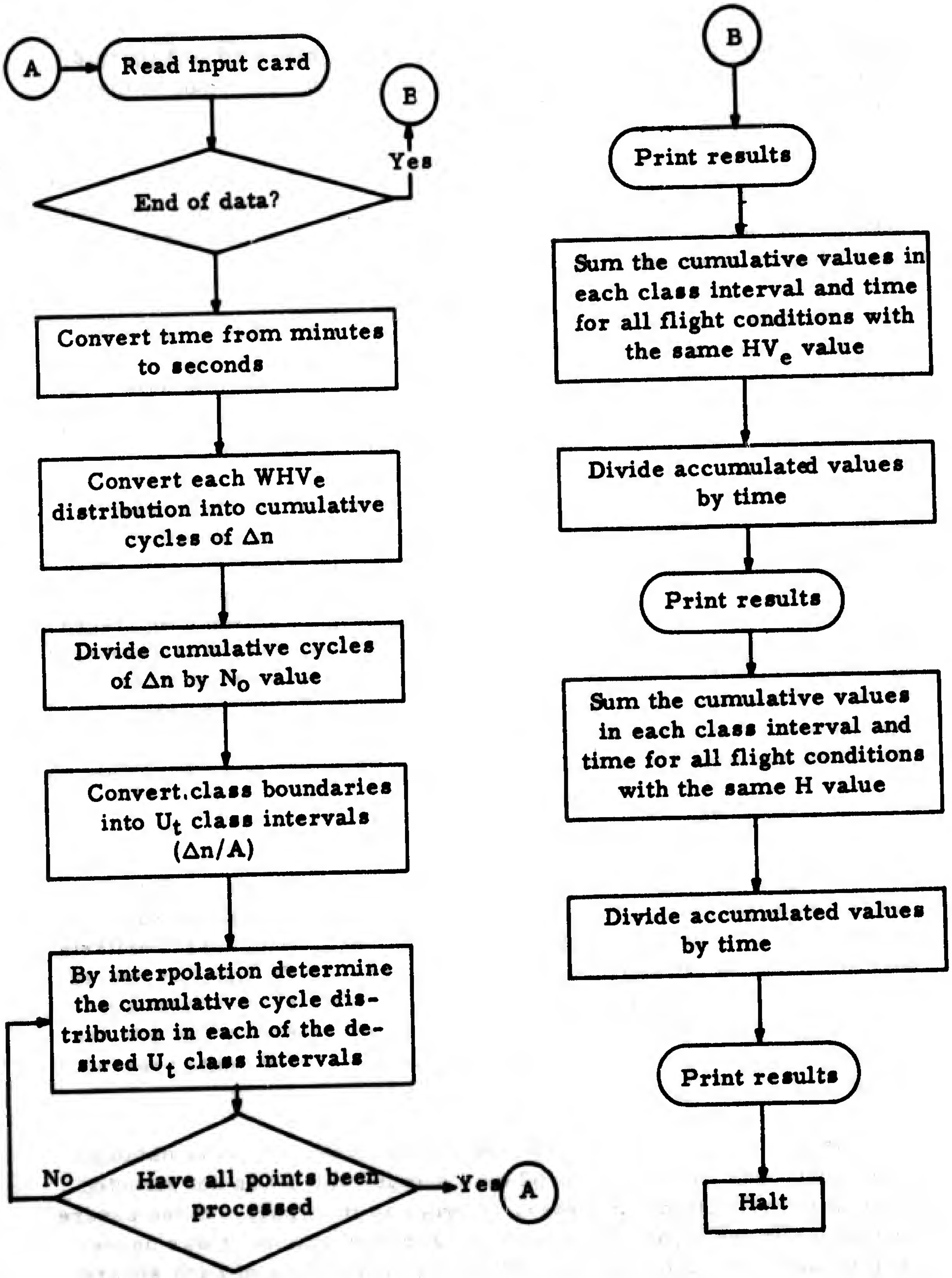

Figure 2 Noncoded Flow Chart, True Gust Velocity Distributions

Table IV Vertical Turbulence Environment by Airspeed

Flight Cond. Code H-V_e	Time (Seconds)	Cumulative Gust Occurrences (10^{-6} $M\Delta n/N_0$) ≥ True Gust Velocity ($\Delta n/A$ - U_t)											
		2.5 0.762	5.0 1.524	7.5 2.286	10.0 3.048	12.5 3.810	17.5 5.334	20.0 6.096	25.0 7.620	30.0 9.144	35.0 10.668	40.0 12.192	*U_t -ft/sec U_t -m/sec
		Altitude 5,000 - 10,000 feet (1,524 - 3,048 meters)											
4-3	203,184	94,535	25,366	7,813.00	2,796.01	1,090.84	198.67	64.65	7.74	2.85			
4-4	1,516,548	71,100	20,927	7,023.70	2,512.44	934.64	137.21	50.65	7.42				
4-5	40,854	45,194	9,675	2,761.95	754.14	268.91	28.83	20.78					
4-**	1,760,586	73,204	21,178	7,015.90	2,504.37	937.22	141.78	51.57	7.29	0.329			
		Altitude 10,000 - 20,000 feet (3,048 - 6,096 meters)											
5-3	580,236	49,512	11,939	3,387.77	1,131.45	420.61	77.78	40.99	13.78	1.76	1.21		
5-4	1,894,488	35,640	8,309	2,560.39	927.72	368.31	70.84	32.11	7.52	0.695			
5-5	27,282	29,540	6,964	2,038.27	732.92	259.89	43.71	28.75					
5-**	2,502,006	38,791	9,136	2,746.57	972.84	379.26	72.16	34.14	8.89	0.936	0.282		
		Altitude 20,000 - 30,000 feet (6,096 - 9,144 meters)											
6-3	1,902,882	29,412	8,543	2,287.07	690.17	229.94	33.03	14.84	3.74	1.45	0.364		
6-4	4,638,558	21,206	3,588	797.48	233.46	82.49	14.85	5.85	1.46	0.405			
6-5	47,574	21,431	3,663	778.86	89.23	39.90	12.06						
6-**	6,589,014	23,578	5,020	1,227.54	364.31	124.76	20.08	8.40	2.11	0.705	0.105		
		Altitude 30,000 - 40,000 feet (9,144 - 12,192 meters)											
7-3	15,685,932	16,076	4,753	1,281.19	407.03	145.79	24.62	11.01	2.90	1.01	0.382	0.219	
7-4	9,765,300	12,752	2,140	477.62	131.18	43.07	6.87	3.33	0.800	0.163			
7-5	95,184	602	78	21.54									
7-**	25,546,416	14,748	3,737	969.32	300.07	105.98	17.74	8.04	2.09	0.682	0.234	0.134	
		Altitude 40,000 - 50,000 feet (12,192 - 15,240 meters)											
8-3	1,074,528	19,127	4,786	1,355.59	463.53	182.15	24.75	10.35	1.64	0.561			
8-4	414	5,896											
8-**	1,074,942	19,122	4,785	1,355.07	463.35	182.08	24.74	10.35	1.64	0.561			

Airspeed Code V_e: 3 -- 200 to 250 Knots (102.888 to 128.611 meters/second)
4 -- 250 to 300 Knots (128.611 to 154.333 meters/second)
5 -- 300 to 350 Knots (154.333 to 180.055 meters/second)

* U_t values listed are lower boundary of class interval
** Weighted average

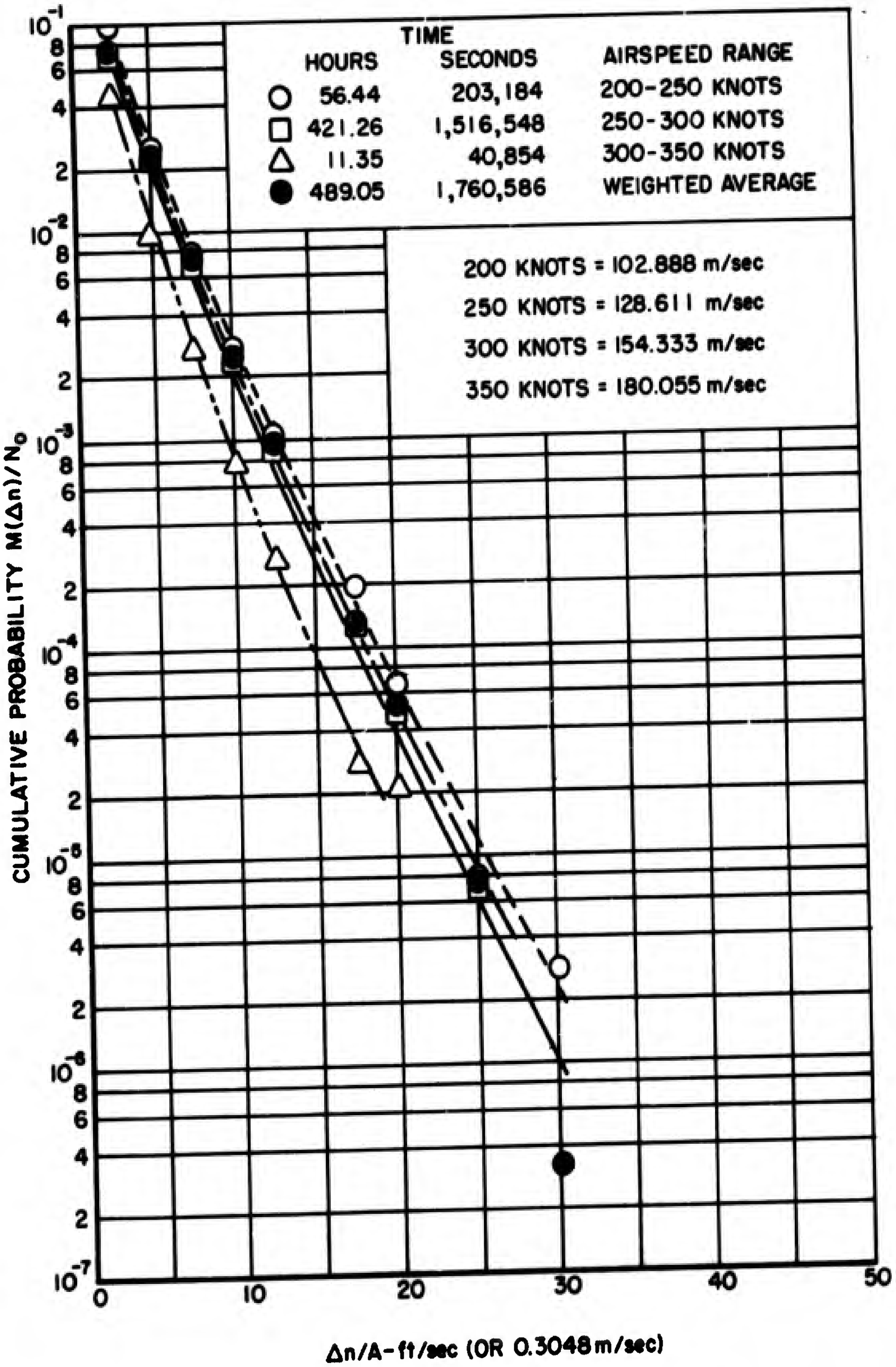

Figure 3 Vertical Turbulence Environment by Airspeed Altitude 5,000 - 10,000 feet (1,524 - 3,048 meters)

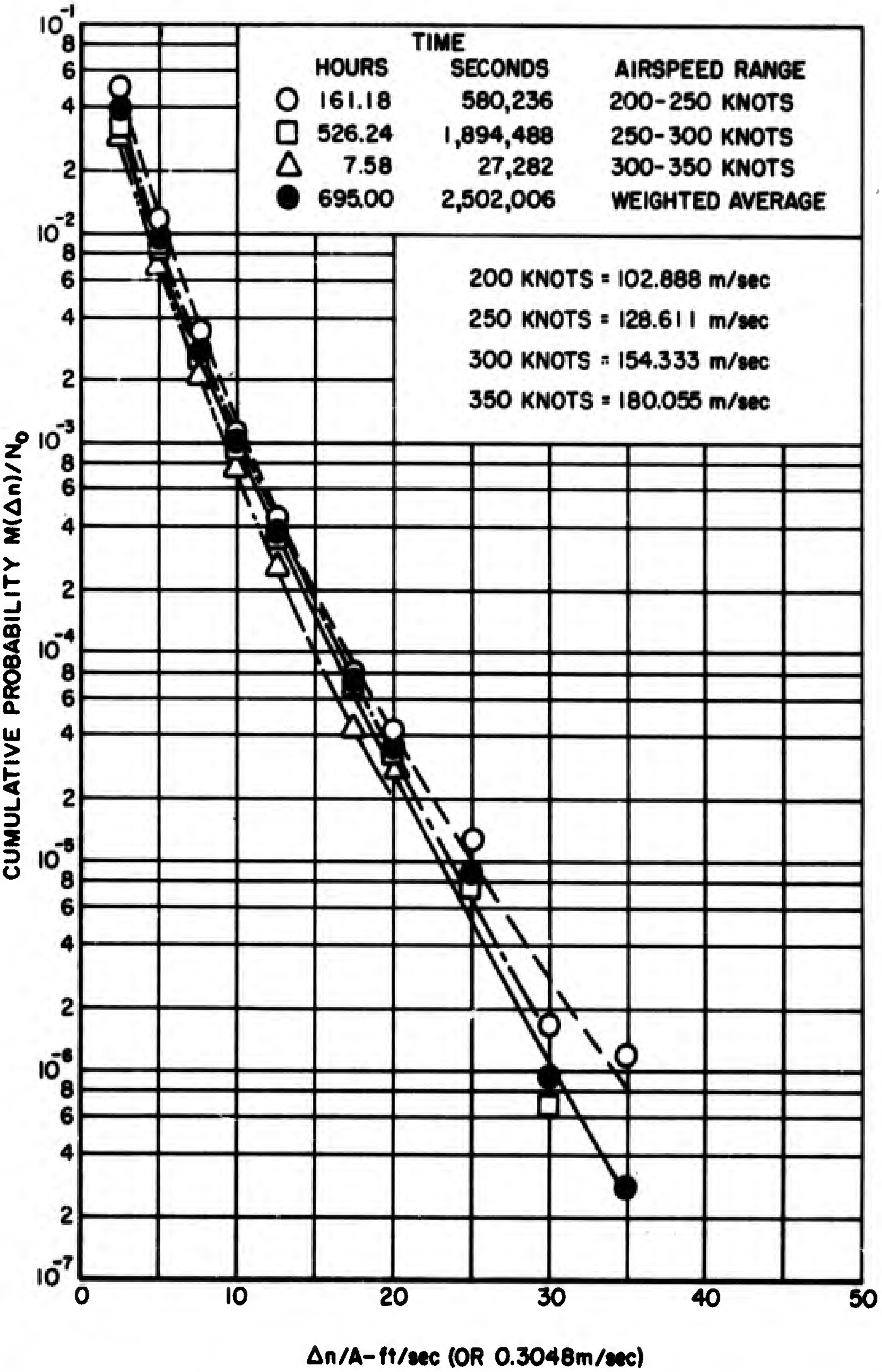

Figure 4 Vertical Turbulence Environment by Airspeed Altitude 10,000 - 20,000 feet (3,048 - 6,096 meters)

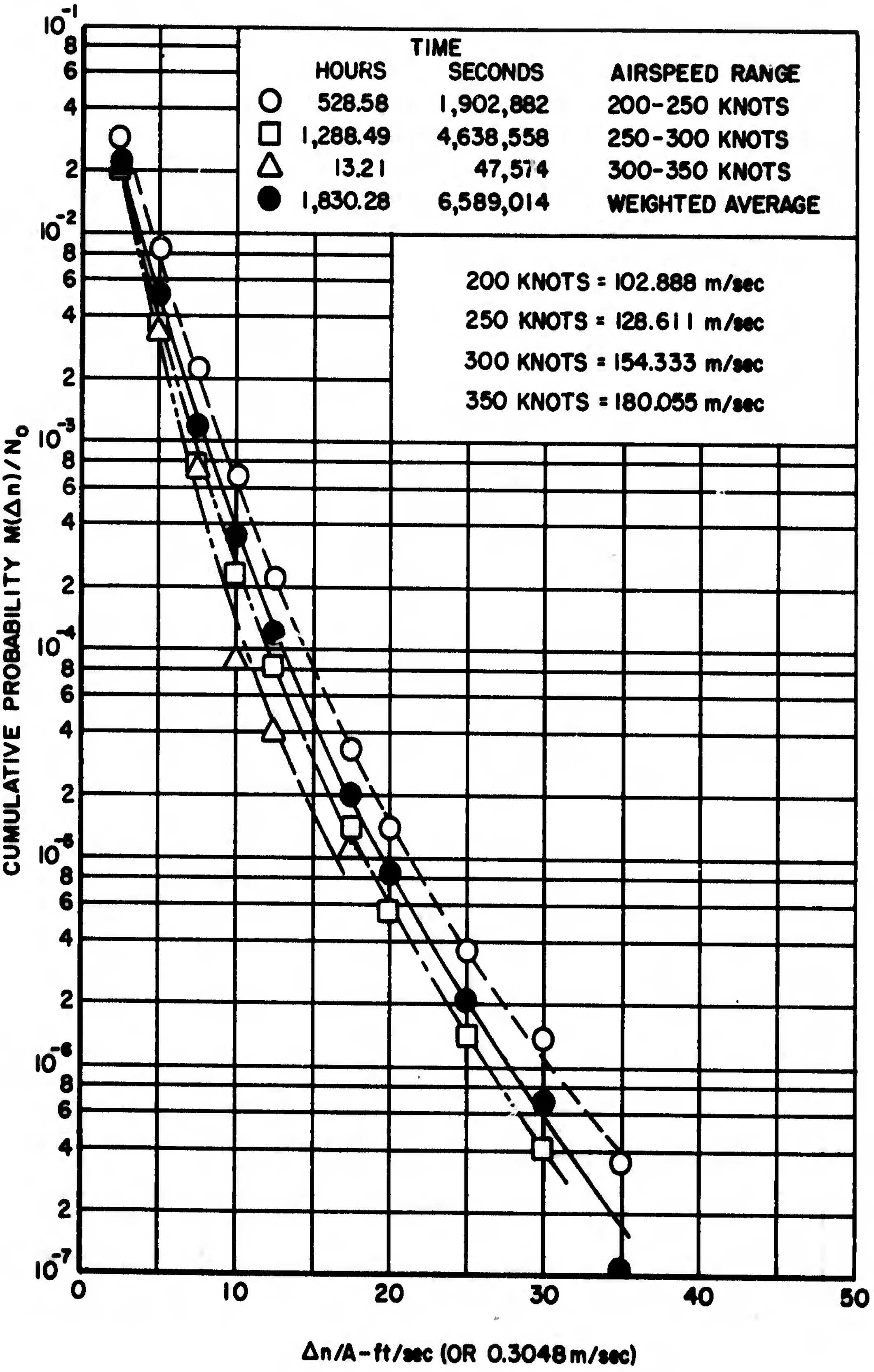

Figure 5 Vertical Turbulence Environment by Airspeed
Altitude 20,000 - 30,000 feet (6,096 - 9,144 meters)

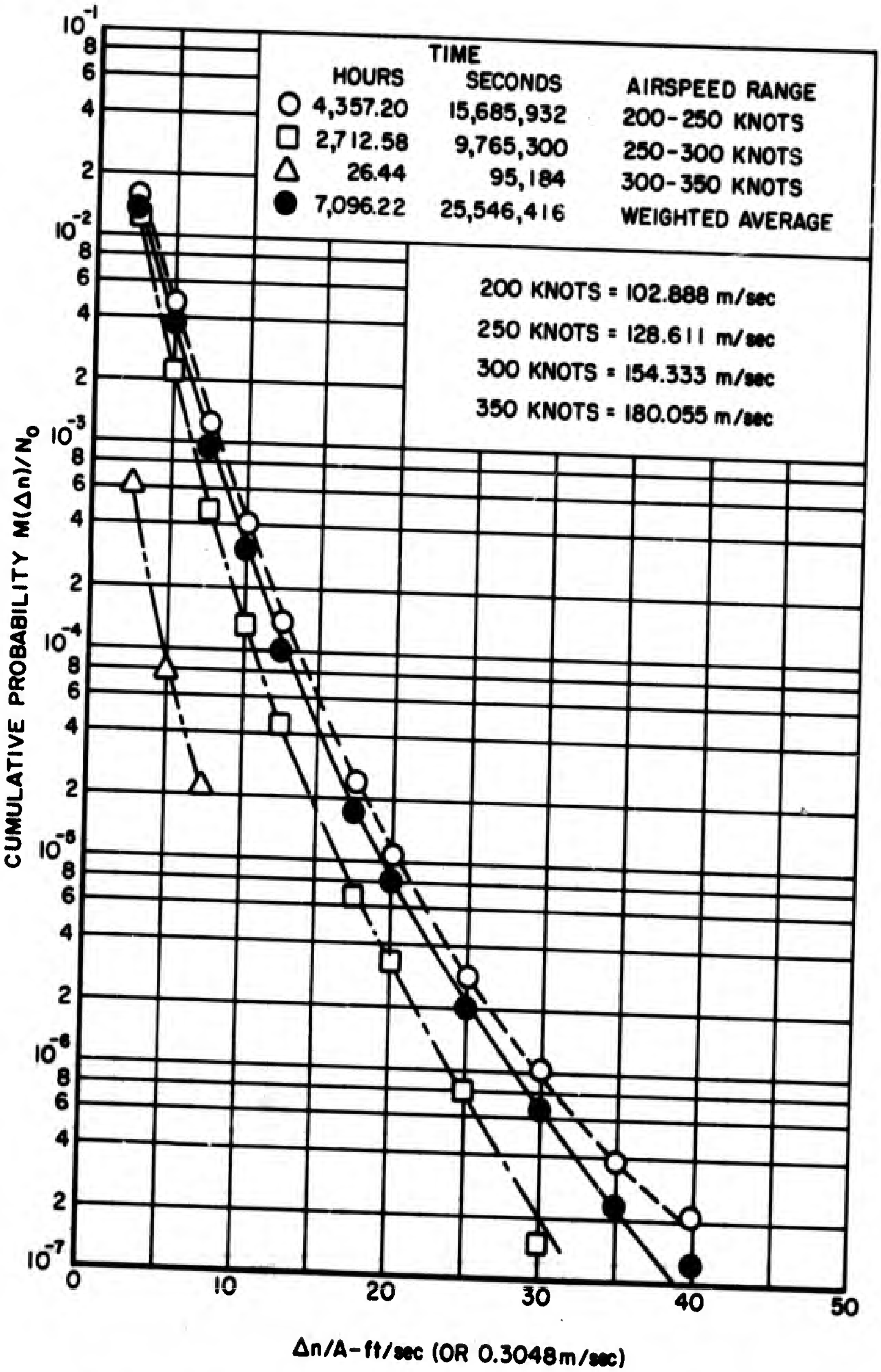

Figure 6 Vertical Turbulence Environment by Airspeed
Altitude 30,000 - 40,000 feet (9,144 - 12,192 meters)

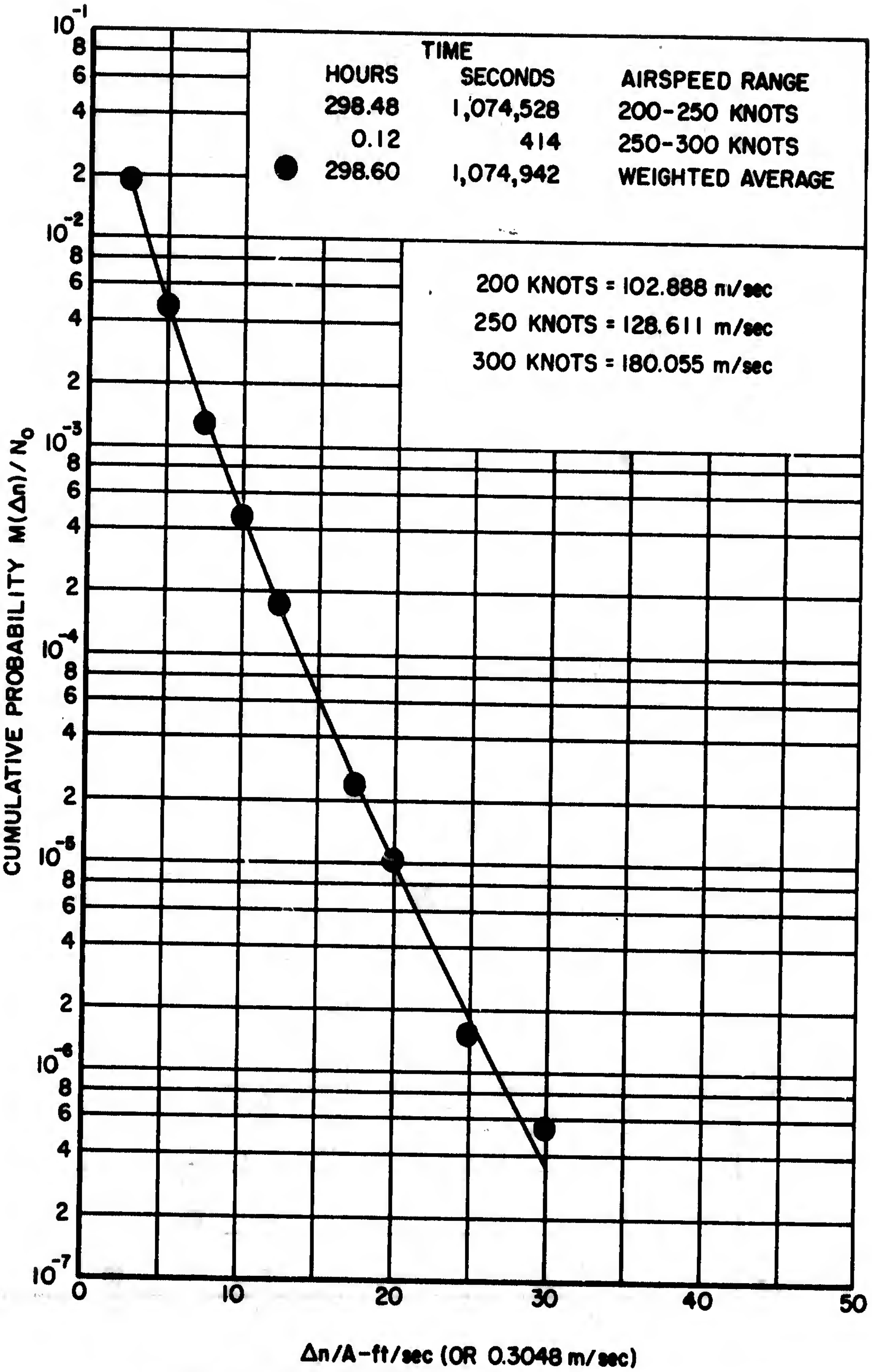

Figure 7 Vertical Turbulence Environment by Airspeed
Altitude 40,000 - 50,000 feet (12,192 - 15,240 meters)

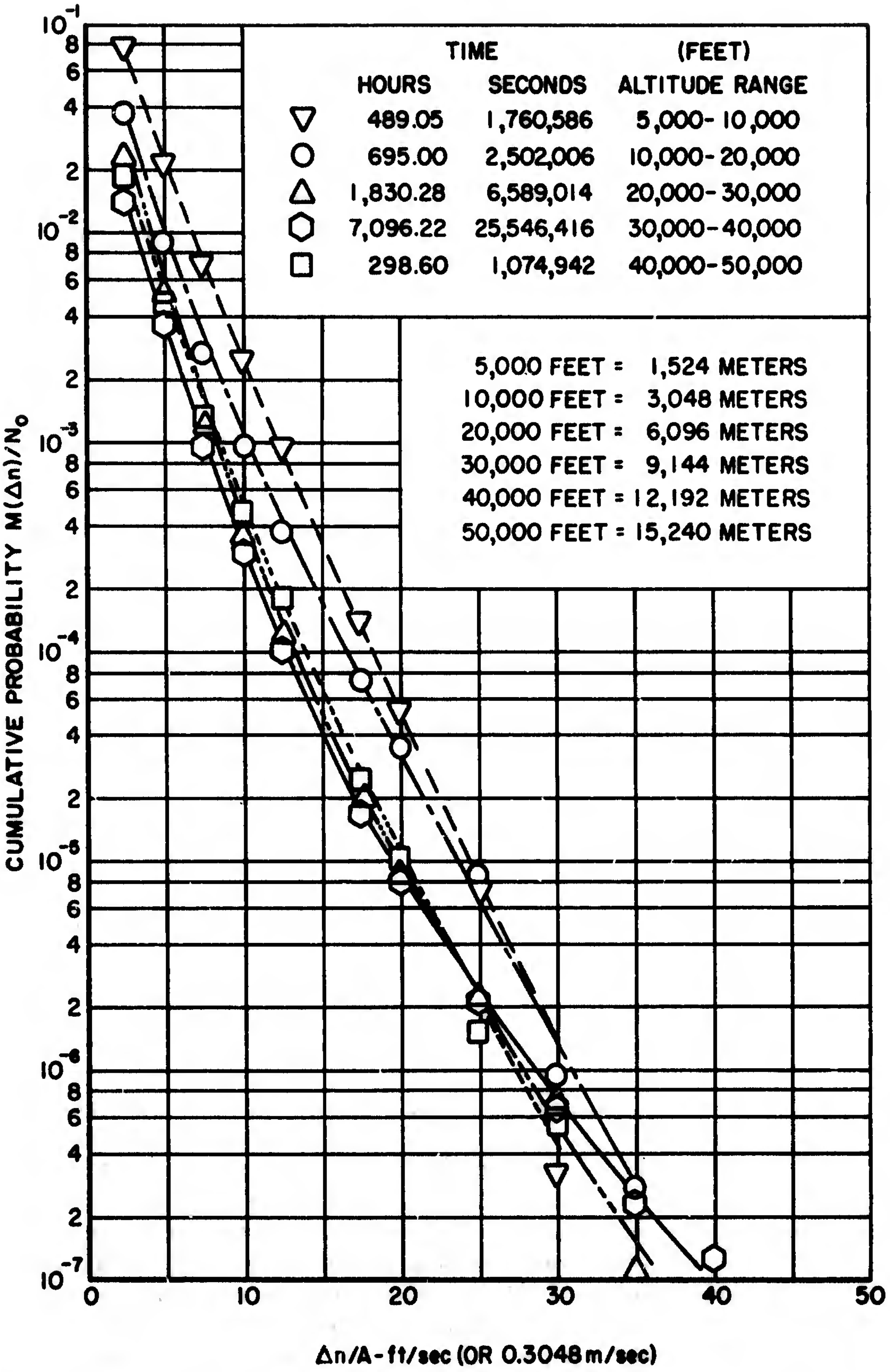

Figure 8 Vertical Turbulence Environment by Altitude Airspeed Range 200 - 350 Knots (102.888 - 180.055 ms^{-1})

Table V Summary of Severe Load Experience Data From B-52 Service Load Recording Program

Flight Condition Code			Gust	Airplane Response Factors	
W (Lbs.)	H (Feet)	V_e KEAS	Δn "g"	A	N_o
270,000	38,600	225	0.83	.0185882	.886091
259,900	8,900	285	-0.84	.0257566	.925739
301,700	16,000	270	-1.00	.0229502	1.047312
313,400	10,050	270	-0.75	.0234035	.934496
313,400	10,050	270	0.82	.0234035	.934496
313,400	10,050	270	-0.77	.0234035	.934496
363,000	35,700	245	-0.87	.0180511	.820097
368,500	32,300	310	1.14	.0242047	.969344
283,400	26,320	295	-0.86	.0261089	1.139426
280,600	26,320	265	-0.90	.0230364	1.043192
280,600	26,150	270	0.92	.0235724	1.056854
280,600	26,150	275	1.12	.0241060	1.071237
280,600	25,330	290	0.85	.0257028	1.108280
280,200	25,330	285	-0.81	.0251891	1.092950
318,300	27,700	295	0.85	.0243449	1.062024

not available because detailed data reduction would have been required to obtain this information. Therefore, estimates of the time spent in each H-V_e combination were made based on the assumption that the percentage of time spent in each H-V_e combination was the same for both a 5,229-hour reduced data sample and the 17,739-hour unreduced data sample. The 5,229-hour reduced data sample upon which this estimate was based represented B-52 flights over the same calendar period represented in the 17,739-hour sample. In view of the nature of B-52 operations, the method used to select data for detailed reduction, and the large size of the data sample, it is believed that this method of estimating time spent in each H-V_e block is sufficiently reliable for this analysis.

Each severe load data point was converted to the form of $\Delta n/A$ using the actual Δn peak value and the frequency peaks were converted to gust frequency values ($1/N_0$) using the data in Table V. These $\Delta n/A$ versus $1/N_0$ values were then tallied in a frequency distribution of $\Delta n/A$ ordered from the largest negative $\Delta n/A$ value to the largest positive $\Delta n/A$ value for each H-V_e combination. The resulting frequency distributions were then converted into cumulative cycle gust frequency distributions of $1/N_0$ values equal to or greater than a given $\Delta n/A$ value. The number of cumulative cycles of gust frequency values, $1/N_0$, for a given magnitude of $\Delta n/A$, is equal to one-half the sum of the $1/N_0$ values for all positive and negative $\Delta n/A$ magnitudes greater than or equal to the given $\Delta n/A$ magnitude. The cumulative values of $1/N_0$ were then divided by the estimated H-V_e time in seconds to obtain the normalized cumulative distributions of $M(\Delta n)/N_0$ versus $\Delta n/A$ for each H-V_e combination. The resulting vertical turbulence environments for each altitude-airspeed band combination and a time-weighted average for each altitude band are presented in Table VI.

5. Combined Results

The vertical turbulence environments obtained from the conversion of the basic data sample, Section II. 3, and from the severe loads data, Section II. 4, were combined to obtain the composited environment for each altitude band as shown in Figures 9 to 13. The final equations, selected to fit the experimental data, are of the general form of Equation (1) and are also presented in Figures 9 to 13.

The turbulence parameters, P, represent the proportion of time or distance spent in a turbulent environment. The b values are scale parameters (or a measure of the intensity) of the turbulence experienced. The general method used to derive these values, presented in Reference 1, assumes that the actual $\Delta n/A$ distribution describing the turbulence environment can be represented by exponential distributions where the log of $M(\Delta n)/N_0$ is plotted as a function of $\Delta n/A$. Therefore, P and b values are determined for each component best describing the turbulent environment for each altitude band. The P value is the intercept of the straight line on the $M(\Delta n)/N_0$ axis and the b value is the inverse slope of the line.

The graphical method, described in Reference 1, was used to establish the initial straight-line components for each altitude band. The large amplitude $\Delta n/A$ values, obtained ~~from the~~ basic data sample, were considered along with the severe loads data points in establishing the straight-line component which is tangent to the tail of the combined $\Delta n/A$ distribution. In this approach less emphasis is given to the

Table VI Vertical Turbulence from Severe Load Experience Data

Flight Condition H-V_e	Time Seconds	Units of U_t Values	Cumulative Gust Occurrences (10^{-6} $M\Delta n/N_o$) ≥ True Gust Velocity ($\Delta n/A = U_t$)						
		ft/sec	32.61						
		m/sec	9.940						
4-4	1,953,100		0.276						
4-*	2,271,303		0.237						
		ft/sec	32.04	32.90	35.03	43.57			
		m/sec	9.765	10.027	10.677	13.280			
5 4	2,925,030		0.705	0.529	0.346	0.163			
5-*	3,751,891		0.555	0.412	0.269	0.127			
		ft/sec	32.15	32.93	33.07	34.91	39.02	39.06	46.46
		m/sec	9.799	10.037	10.079	10.640	11.893	11.905	14.161
6-4	6,663,977		0.485	0.417	0.351	0.283	0.212	0.141	0.0700
6-*	9,730,759		0.332	0.285	0.240	0.194	0.145	0.0972	0.0479
		ft/sec	44.65	47.09	48.19				
		m/sec	13.609	14.353	14.688				
7-3	18,978,362		0.0618						
7-5	8,914			57.86					
7-*	33,126,950		0.0510	0.0339	0.0184				

Altitude Code H:
4 5,000 to 10,000 feet (1,524 to 3,048 meters)
5 10,000 to 20,000 feet (3,048 to 6,096 meters)
6 20,000 to 30,000 feet (6,096 to 9,144 meters)
7 30,000 to 40,000 feet (9,144 to 12,192 meters)

Airspeed Code V_e:
3 200 to 250 knots (102.888 to 128.611 m/sec)
4 250 to 300 knots (128.611 to 154.333 m/sec)
5 300 to 350 knots (154.333 to 180.005 m/sec)

* Weighted average

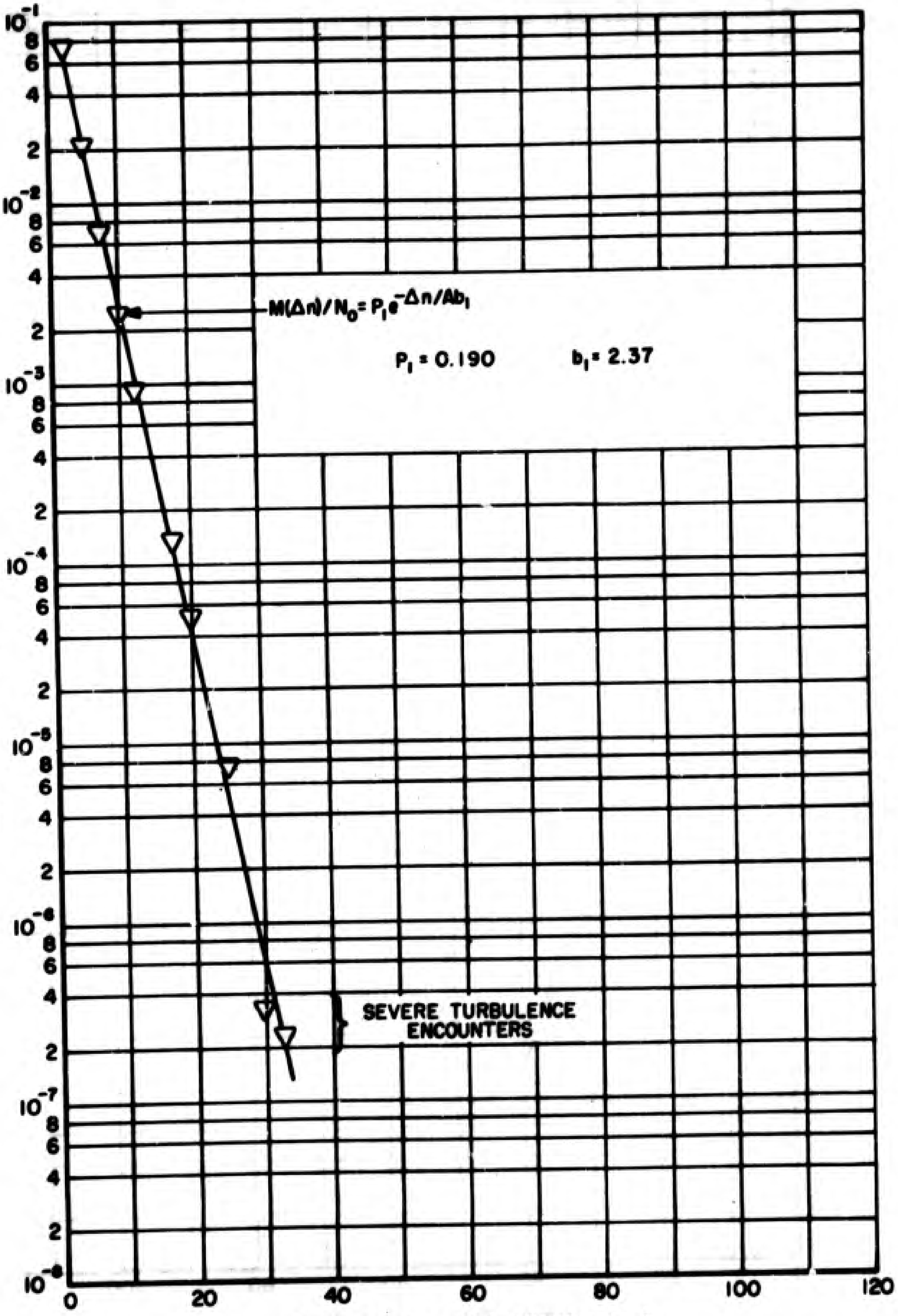

Figure 9 Combined Vertical Turbulence Environment and Severe Turbulence Encounter
Altitude Range 5,000 - 10,000 feet (1,524 - 3,048 meters)

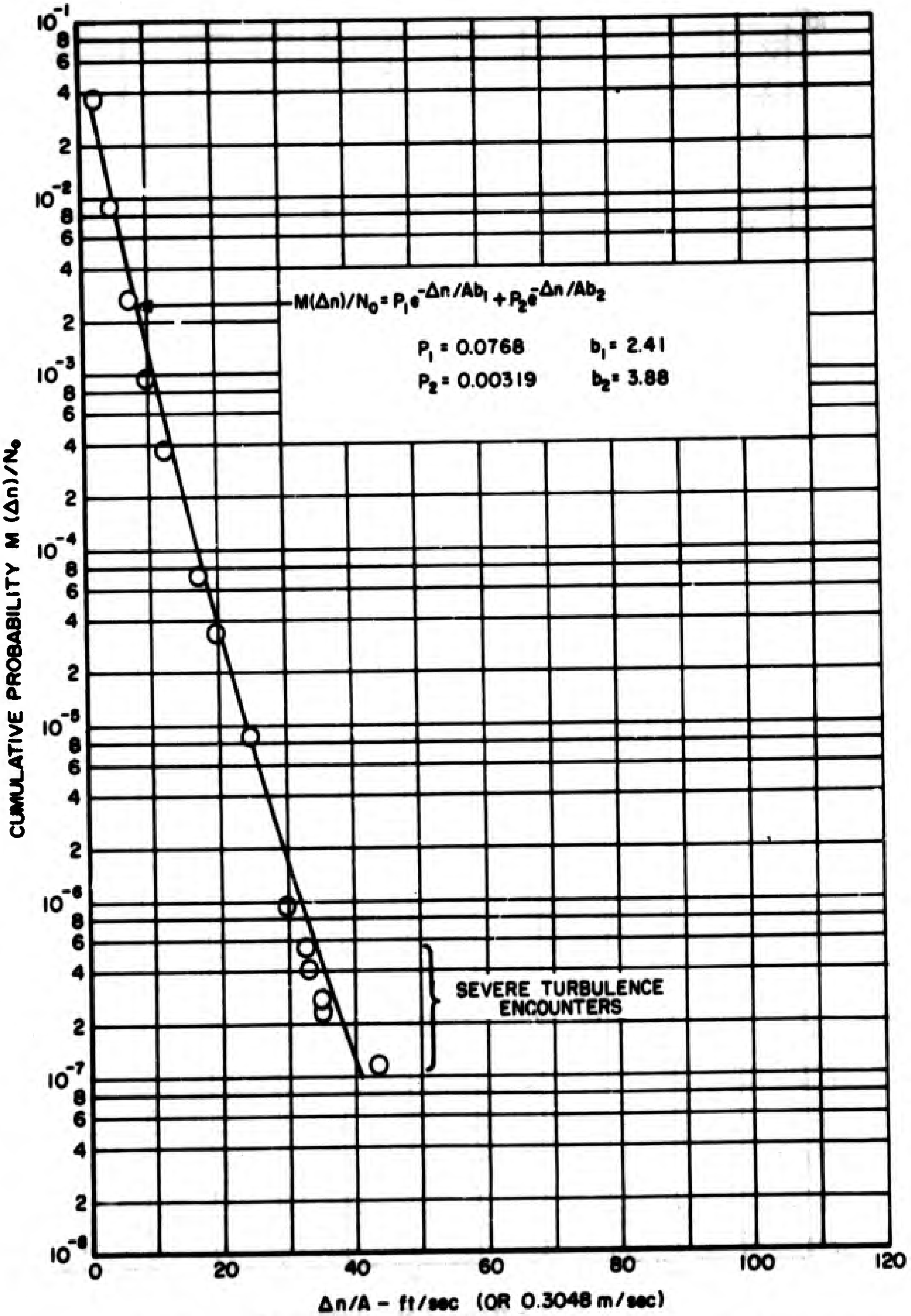

Figure 10 Combined Vertical Turbulence Environment and Severe Turbulence Encounter
Altitude Range 10,000 - 20,000 feet (3,048 - 6,096 meters)

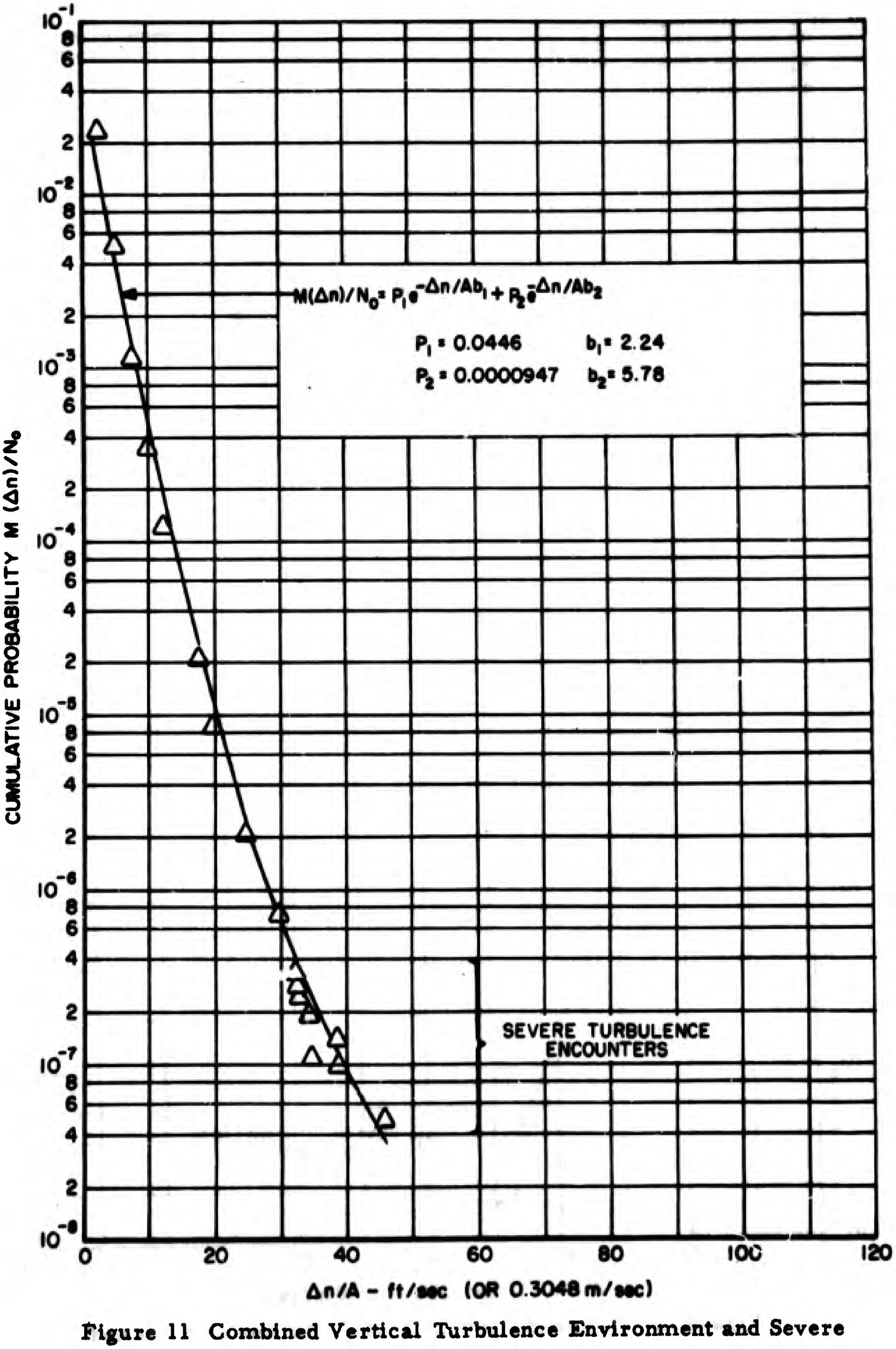

Figure 11 Combined Vertical Turbulence Environment and Severe Turbulence Encounters
Altitude Range 20, 000 - 30, 000 feet (6, 096 - 9, 144 meters)

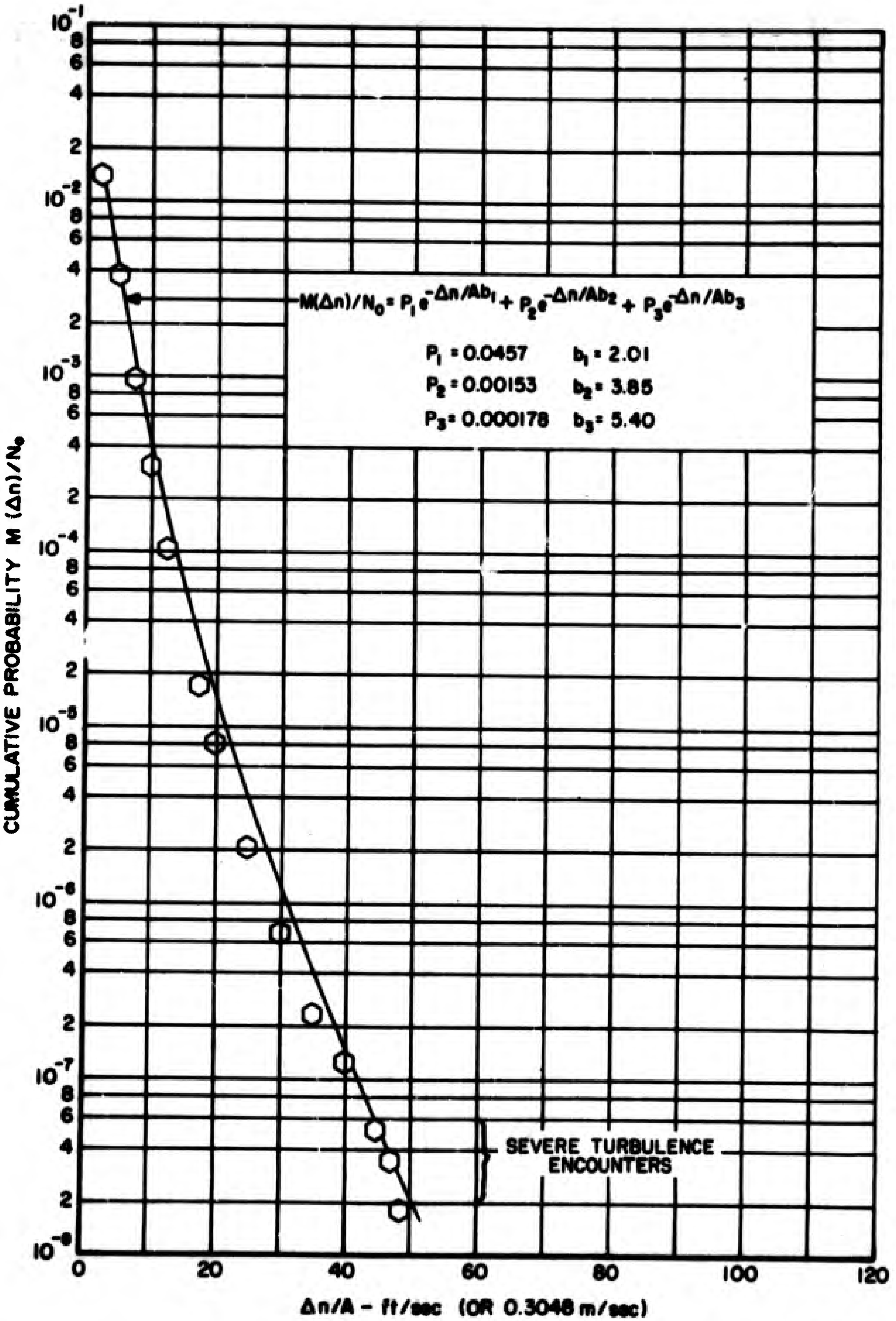

Figure 12 Combined Vertical Turbulence Environment and Severe Turbulence Encounters
Altitude Range 30,000 - 40,000 feet (9,144 - 12,192 meters)

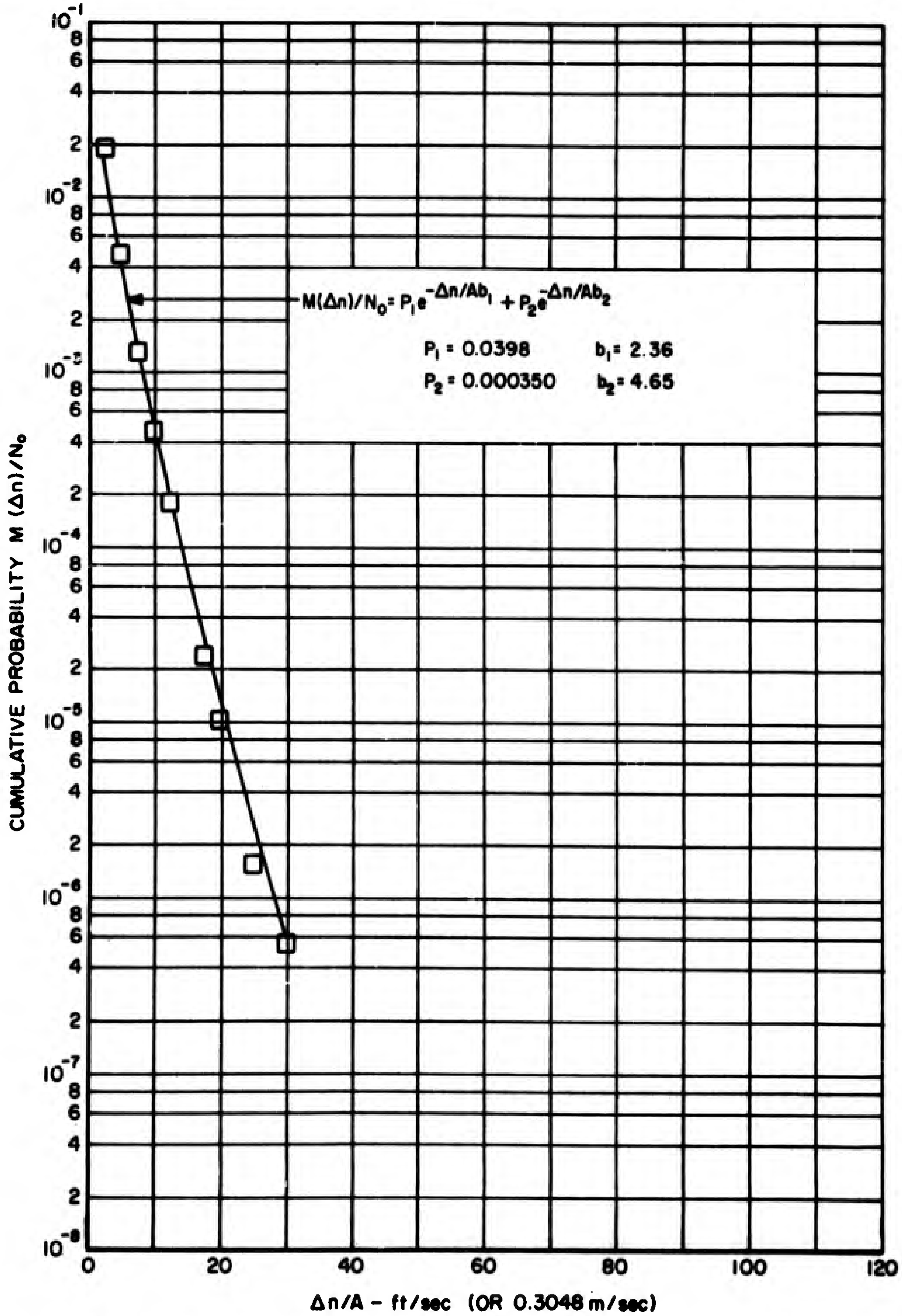

Figure 13 Combined Vertical Turbulence Environment and Severe Turbulence Encounters
Altitude Range 40,000 - 50,000 feet (12,192 - 15,240 meters)

severe loads $\Delta n/A$ distributions which may be less accurate than the reduced data because only estimated $H\text{-}V_e$ flight times were used in converting the peak severe loads data to the form of $M(\Delta n)/N_0$ versus $\Delta n/A$. The actual data points, establishing the initial straight-line components, were then used to determine the least square lines which represented the final straight-line components. The number of components selected for each curve was that which provided the best curve fit. From one to three components were used as indicated by the derived turbulence parameters presented in Table VII.

Similar presentations of the vertical turbulence parameters from Reference 7 and the USAF specification MIL-A-8866 are included in Table VII. The resulting environments are compared with those derived during this program in Figures 14 to 18 for each applicable altitude band.

The comparison of the vertical turbulence environments presented in Figures 14 to 18 show that the derived environments for all altitudes are generally less severe than those obtained from Reference 7 by Boeing. The environments from Reference 7 were derived using the same B-52 data sample considered in this program plus an additional data sample collected during an extension of the B-52 program. The same values of A and N_0 were used in generating both environments. The difference in the two environments was caused primarily by the criteria used in selecting the data sample. For this investigation, only the load factor distributions caused by gust were used, whereas the load factors caused by both gust and maneuver inputs were combined and used to derive the environments presented in Reference 7. Had the gust and maneuver inputs been combined for this program, the total number of load factor peaks evaluated would have been increased by approximately 50 percent, as estimated from the gust and maneuver distributions presented in Reference 5. Since the same time base would have been used in evaluating $M(\Delta n)/N_0$, a substantial increase in the severity of the derived environment would be expected. Therefore, the difference between the turbulence environments derived in this investigation and those in Reference 7 would be expected. However, because maneuver content was included in the Reference 7 environment, it is believed that the environment generated herein is a better representation of the atmospheric environment.

Table VII Turbulence Parameters

Altitude							
Feet	Meters	P_1	b_1	P_2	b_2	P_3	b_3
		Derived Environment					
5,000 - 10,000	1,524 - 3,048	0.190	2.37	---	---	---	---
10,000 - 20,000	3,048 - 6,096	0.0768	2.41	0.00319	3.88	---	---
20,000 - 30,000	6,096 - 9,144	0.0446	2.24	0.0000947	5.78	---	---
30,000 - 40,000	9,144 - 12,192	0.0457	2.01	0.00153	3.85	0.000178	5.40
40,000 - 50,000	12,192 - 15,240	0.0398	2.36	0.000350	4.65	---	---
		Reference 7					
0 - 10,000	0 - 3,048	0.30	2.6	0.01	4.8	---	---
10,000 - 20,000	3,048 - 6,096	0.20	2.6	0.01	4.8	---	---
20,000 - 30,000	6,096 - 9,144	0.15	2.4	0.01	4.8	---	---
30,000 - 40,000	9,144 - 12,192	0.13	1.8	0.01	4.8	---	---
40,000 - 50,000	12,192 - 15,240	0.13	1.8	0.01	4.8	---	---
		MIL-A-8866					
2,000 - 10,000	609.6 - 3,048	0.08	3.8	0.00125	4.8	---	---
10,000 - 20,000	3,048 - 6,096	0.045	3.7	0.0015	10.4	---	---
20,000 - 30,000	6,096 - 9,144	0.06	3.5	0.0012	11.2	---	---
30,000 - 40,000	9,144 - 12,192	0.065	3.4	0.0006	11.1	---	---
40,000 - 50,000	12,192 - 15,240	0.023	3.1	0.0002	11.7	---	---

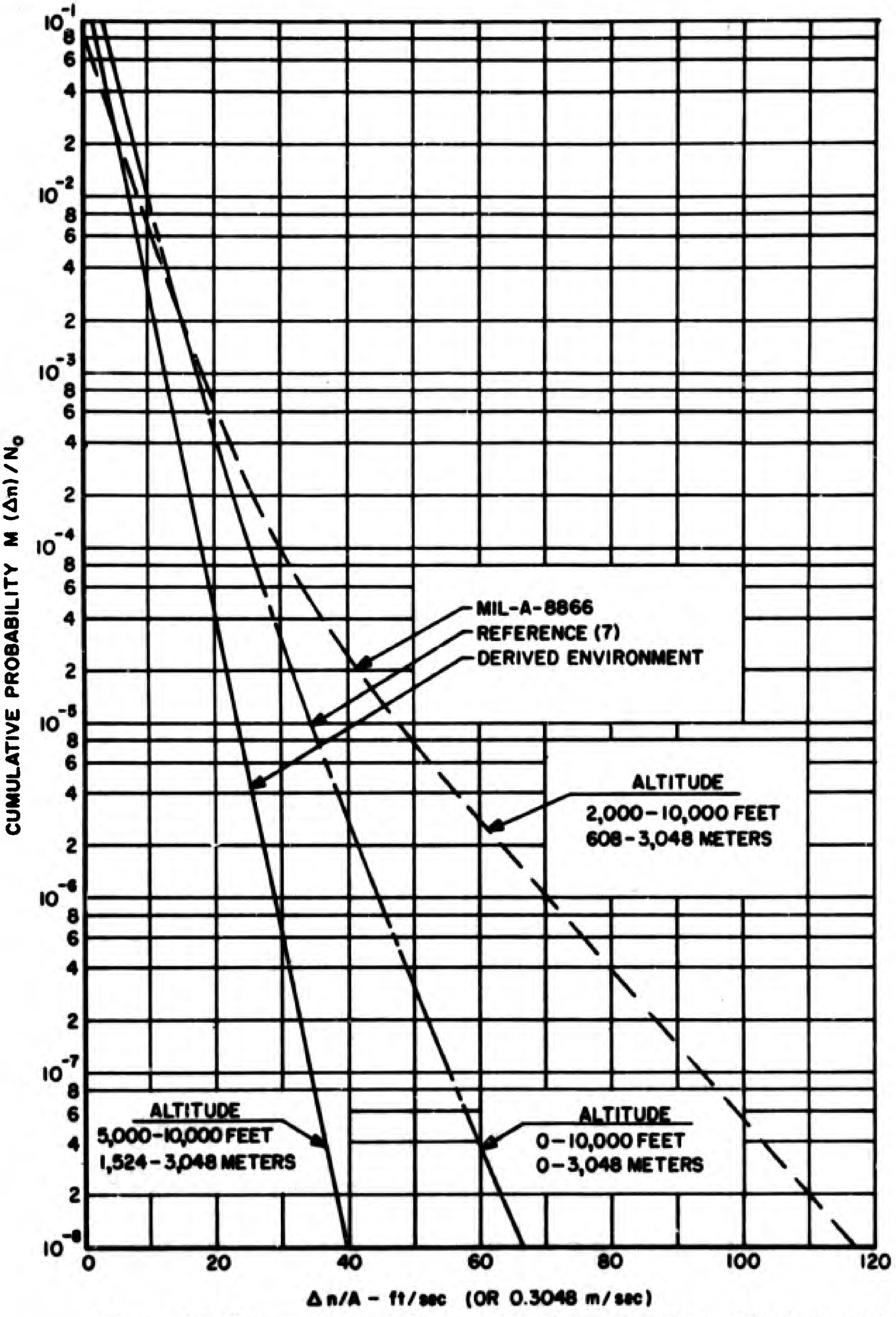

Figure 14 Comparison of Derived Vertical Turbulence Environments For Altitude Ranges Indicated

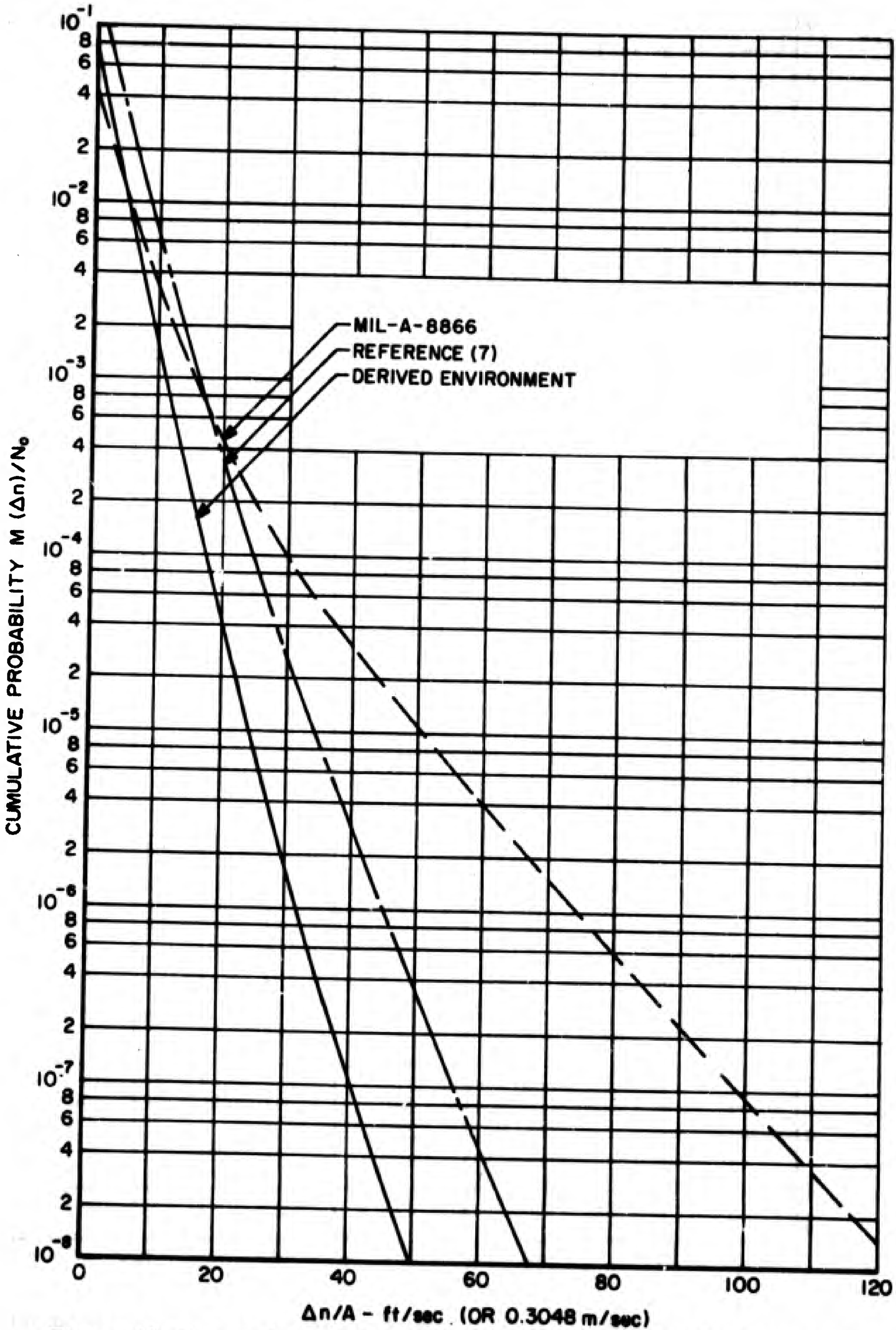

Figure 15 Comparison of Derived Vertical Turbulence Environments Altitude Range 10,000 - 20,000 feet (3,048 - 6,096 meters)

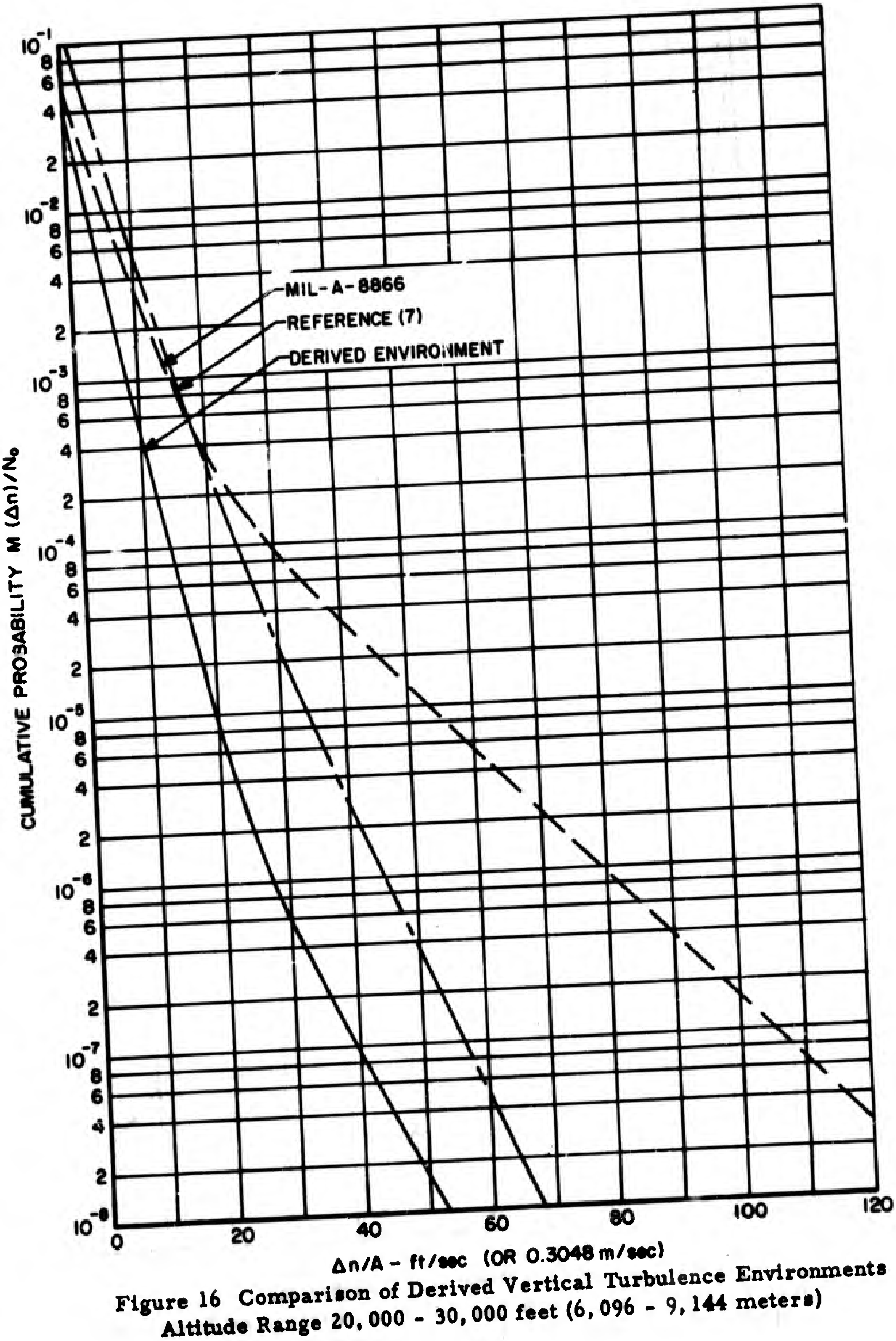

Figure 16 Comparison of Derived Vertical Turbulence Environments Altitude Range 20,000 - 30,000 feet (6,096 - 9,144 meters)

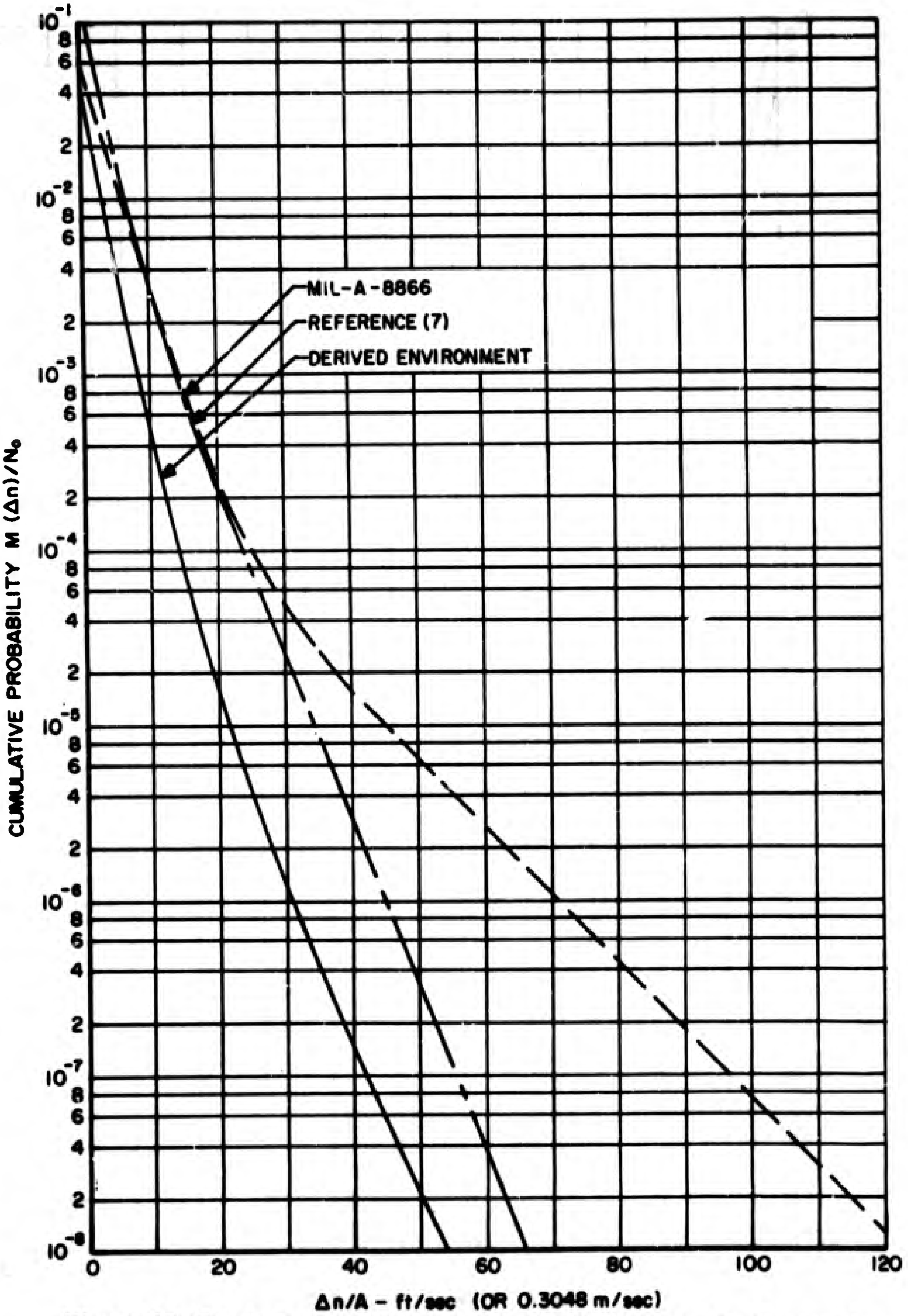

Figure 17 Comparison of Derived Vertical Turbulence Environments Altitude Range 30,000 - 40,000 feet (9,144 - 12,192 meters)

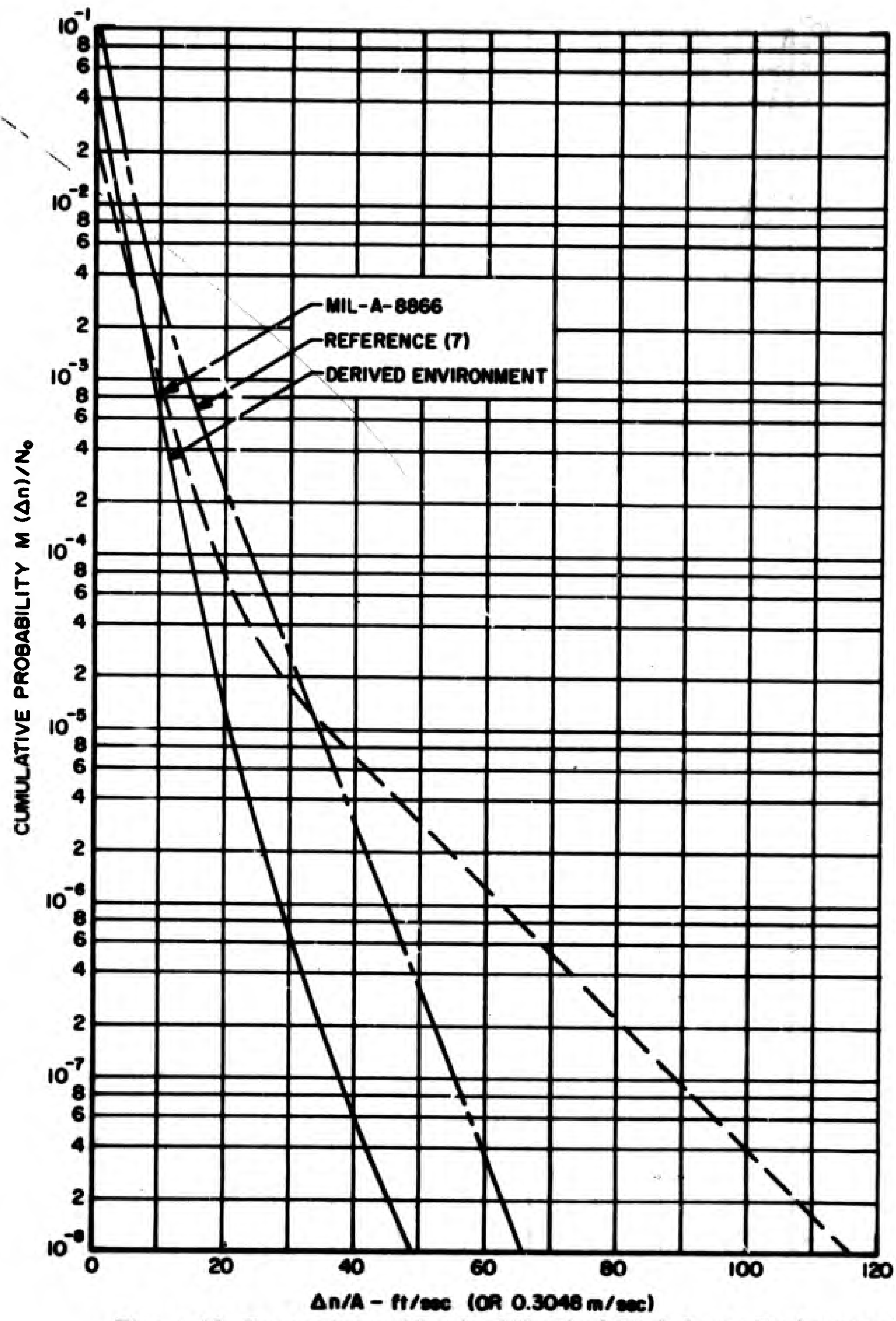

Figure 18 Comparison of Derived Vertical Turbulence Environments Altitude Range 40,000 - 50,000 feet (12,192 - 15,240 meters)

SECTION III

PERCENT TIME IN TURBULENCE

1. Turbulent Area Criteria Study

The determination of the percent time in turbulent areas from flight loads data can be obtained from an expression similar to the one presented and discussed in Section II. 5. This, of course, assumes that the data sample has been reduced in detail and analyzed using the technique and procedure discussed in Section II. 3. However, one of the objectives of this program was to determine the percent time in turbulence from time history recordings of flight loads data that had not been reduced in detail. Therefore, the analysis of these types of data could not be accomplished using the techniques described in Section II. In order to compute the percent time in turbulence it was necessary first to establish the criteria to be used to identify the turbulent areas on the time history recordings. Therefore, this phase of the effort was conducted to determine the criteria to be used in establishing the turbulent areas from an approximately 20,000 flight-hour sample of data recorded on oscillograph recorders but not reduced in detail.

One criteria that has been used on a recent C-135 flight loads program provides for an area to be considered turbulent when the recorded measurement of the load factor, (Δn trace) is continuously disturbed and when the Δn trace contains at least two peaks at the 0.05 "g" and one peak at the 0.10 "g" incremental load factor level. It was decided, therefore, to test the applicability of this C-135 criteria in determining the percent time in turbulence from a representative recorded flight of B-52 data. The general procedure and results are discussed below.

The B-52 flight chosen for the test was one in which the data had been reduced in detail. This permitted a comparable evaluation to be conducted using the power spectral density techniques discussed in Section II. 3. In applying the C-135 criteria, the computer output tab was used to determine the total time in each altitude band for the parameters listed in Table II. The flight record was then viewed to determine the turbulent areas and resulting time in turbulence using the C-135 criteria. Because of the limited data sample the total time from all altitude bands and resulting total time in turbulence were used to compute the percent time in turbulence. For comparison, the peak count load factor data for this flight were then evaluated using the power spectral density technique presented in Section II. 3 to obtain the $M(\Delta n)/N_0$ versus $\Delta n/A$ curve. The zero intercept of this curve on the $M(\Delta n)/N_0$ axis, which is a measure of the proportion of time spent in nonstorm turbulence, was established from the curve of the time-weighted average from all altitude bands. The resulting percent time in turbulence established using the C-135 criteria was 11.2 percent compared to 12.7 percent obtained from the zero intercept of the $M(\Delta n)/N_0$ versus $\Delta n/A$ curve on the $M(\Delta n)/N_0$ axis. Considering the close agreement from the limited data sample used, it was considered that the C-135 criteria was adequate and would therefore be used as the basis for establishing turbulent areas in determining the percent time in turbulence from the 20,000 flight-hours of unreduced B-52 data.

2. Analysis of Unreduced B-52 Data

This phase of the effort involved the analysis of 2,267 original B-52 flight records, totalling 20,230 flight-hours (that had not been selected for detailed reduction during the B-52 program) to determine the percent time in turbulence. The records were visually inspected using the C-135 criteria in the areas described by the parameters listed in Table II to identify information required to compute percent time in turbulence and the length of the turbulent encounter. A computer program was written to accept the required information in digital form and generate the percent of flight time flown in turbulence and the frequency distribution in terms of the length of each turbulent encounter for each altitude band. The general procedure and results are discussed below.

a. Procedure

The data was recorded in time-history form on oscillograph recorders. The analog representation of the various altitude, airspeed, and load factor measurements were recorded as individual traces on the oscillograph recording paper. Each set of altitude, airspeed, and accelerometer transducers and associated recording instrumentation were reviewed to obtain the conversion factors required to establish the actual recorded measurements of each parameter. This information was then used to develop an overlay similar to the one shown in Figure 19 for each set of transducers used in recording the flight records being analyzed.

Each flight record was reviewed to identify and mark the climb, cruise, and descent mission segments and the flight time from take-off to landing. Within each mission segment area the beginning and end of each applicable altitude band was identified when the airspeed was within 200-350 knots. The use of the appropriate overlay was required for this and subsequent operations. The turbulent areas were then identified within the altitude bands using the C-135 criteria. In order to compute the length of turbulent areas, each turbulent area was marked into smaller intervals for each ten knot change in the airspeed. A deck of punched cards containing the above information was then generated and used as input to the computer. The noncoded flow chart, indicating the general steps involved in generating the required distributions, is presented in Figure 20.

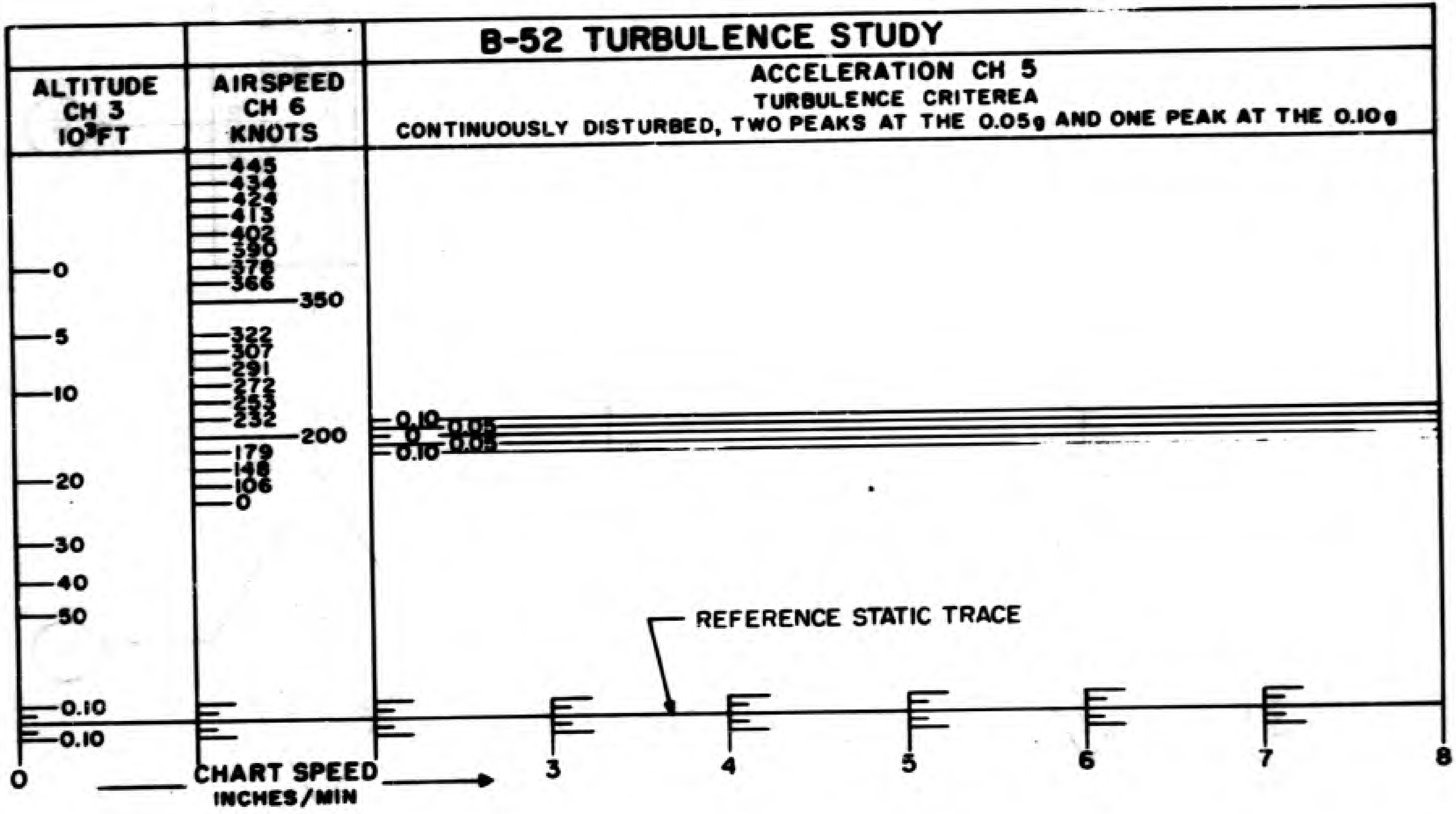

Figure 19 Turbulence Criteria Overlay

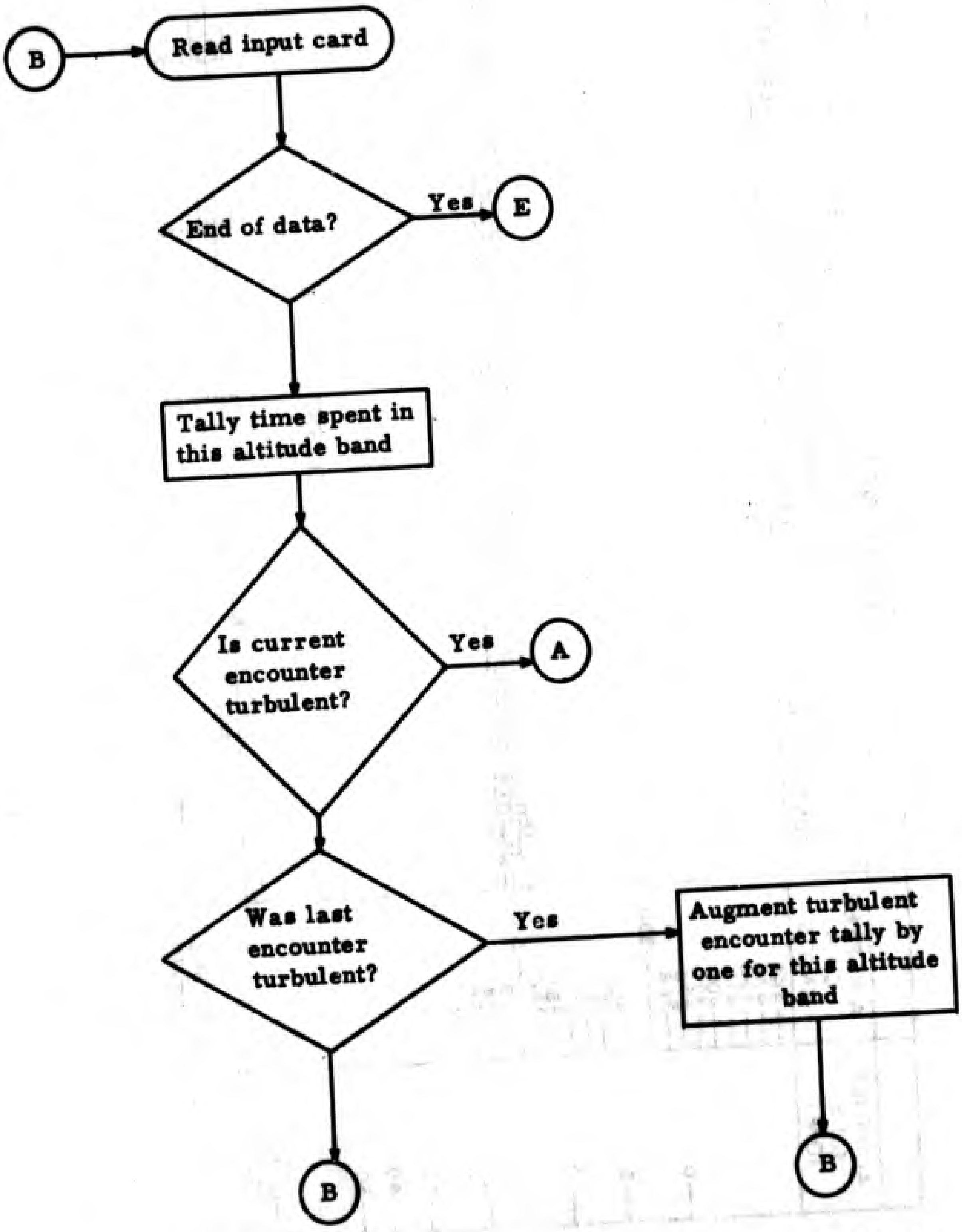

Figure 20 (a) Noncoded Flow Chart, Percent Time in Turbulence

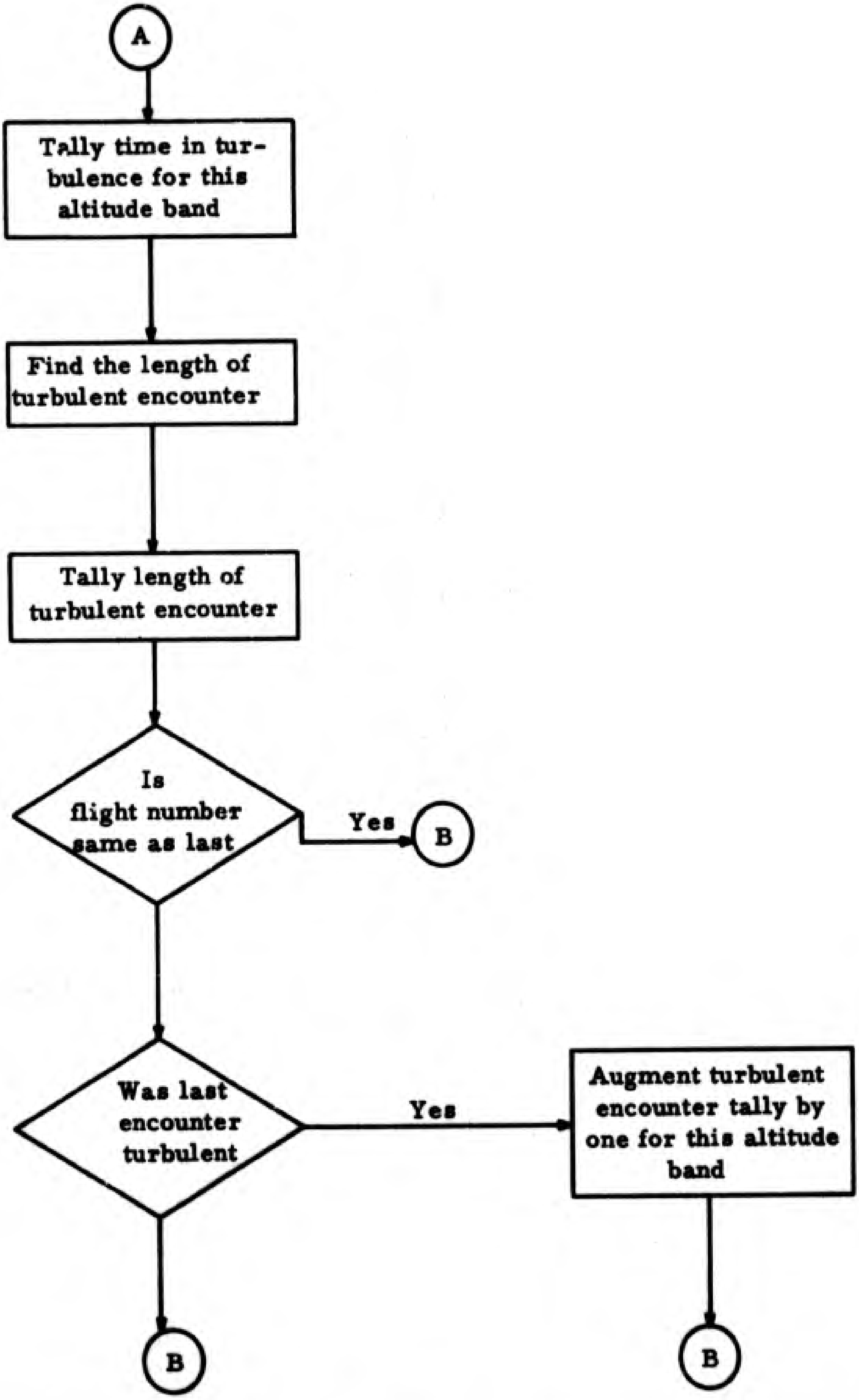

Figure 20 (b) Noncoded Flow Chart, Percent Time in Turbulence, (Continued)

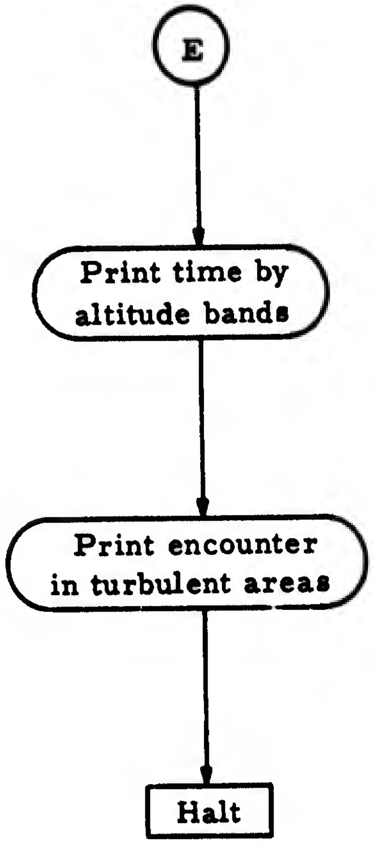

Figure 20(c) Noncoded Flow Chart, Percent Time in Turbulence, (Concluded)

b. Results

The distribution of the percent time in turbulence by altitude derived from this phase of the effort is presented in Table VIII, including the time in turbulence and time reduced. A plot of the proportion of time in turbulence by altitude is presented in Figure 21 and compared with similar data derived from the basic reduced sample using power spectral density techniques and with data obtained from References 8, 9, and 10.

The derived frequency distributions of the number of turbulent encounters versus the length of encounter for each altitude band are presented in Table IX. The frequency distributions as presented in Table IX are indications of the air distance traveled while in a turbulent condition and are not necessarily a measure of the lengths of turbulent areas or patches. This is the result of the method used in computing and tabulating the encounters and the fact that data from the climb, cruise, and descent mission segments were combined for this study. For example, if the vehicle encountered a turbulent area in the 5,000-10,000 feet altitude range and did not leave the turbulent area until reaching an altitude of 40,000 - 50,000 feet, one turbulent encounter was tallied for each altitude band in the appropriate length of encounter interval instead of one long encounter between altitudes of 5,000 feet and 50,000 feet.

It should be noted that the technique used to derive the percent time in turbulence data from the 20,230 flight-hour sample of unreduced data yielded lower values compared to similar data derived from the basic reduced data sample of 13,375 flight-hours using power spectral density techniques. See Tables VII and VIII. It is reasonable to assume that both data samples were obtained in comparable environments; therefore, the percent time in turbulence derived from both data samples should also be comparable. It is believed that the differences in the derived percent time in turbulence values can be attributed to the differences in the analysis techniques.

In the analysis of the reduced data sample, all of the incremental load factor peaks caused by gust, having absolute values greater than 0.05 "g" were used in deriving the vertical turbulence environment and hence the percent time in turbulence. In determining the percent time in turbulence from the unreduced data sample, an area was considered turbulent only when the Δn trace was continuously disturbed and contained at least two peaks at the 0.05 "g" and one peak at the 0.10 "g" incremental load factor level. This criteria was established in order to make the analysis economically feasible. It is believed, therefore, that the turbulent criteria used in evaluating the unreduced data sample does limit the ability to identify areas of light turbulence and in particular those turbulent areas of lengths less than six statute miles. This is further evident from cumulative

Table VIII Percent Time in Turbulence by Altitude

* Altitude Bands		4	5	6	7	8	Total
Time in Turbulence	(Sec)	157,386	216,024	399,306	1,295,814	160,560	2,229,090
	(Hrs)	43.72	60.01	110.92	359.95	44.60	619.19
Time Reduced	(Sec)	1,655,838	3,486,606	11,578,986	35,793,882	4,811,784	57,327,096
	(Hrs)	459.96	968.50	3,216.38	9,942.74	1,336.61	15,924.19
Percent Time In Turbulence		9.5	6.2	3.4	3.6	3.3	3.9

* Altitude Bands	Feet	Meters
4	5,000 - 10,000	1,524 - 3,048
5	10,000 - 20,000	3,048 - 6,096
6	20,000 - 30,000	6,096 - 9,144
7	30,000 - 40,000	9,144 - 12,192
8	40,000 - 50,000	12,192 - 15,240

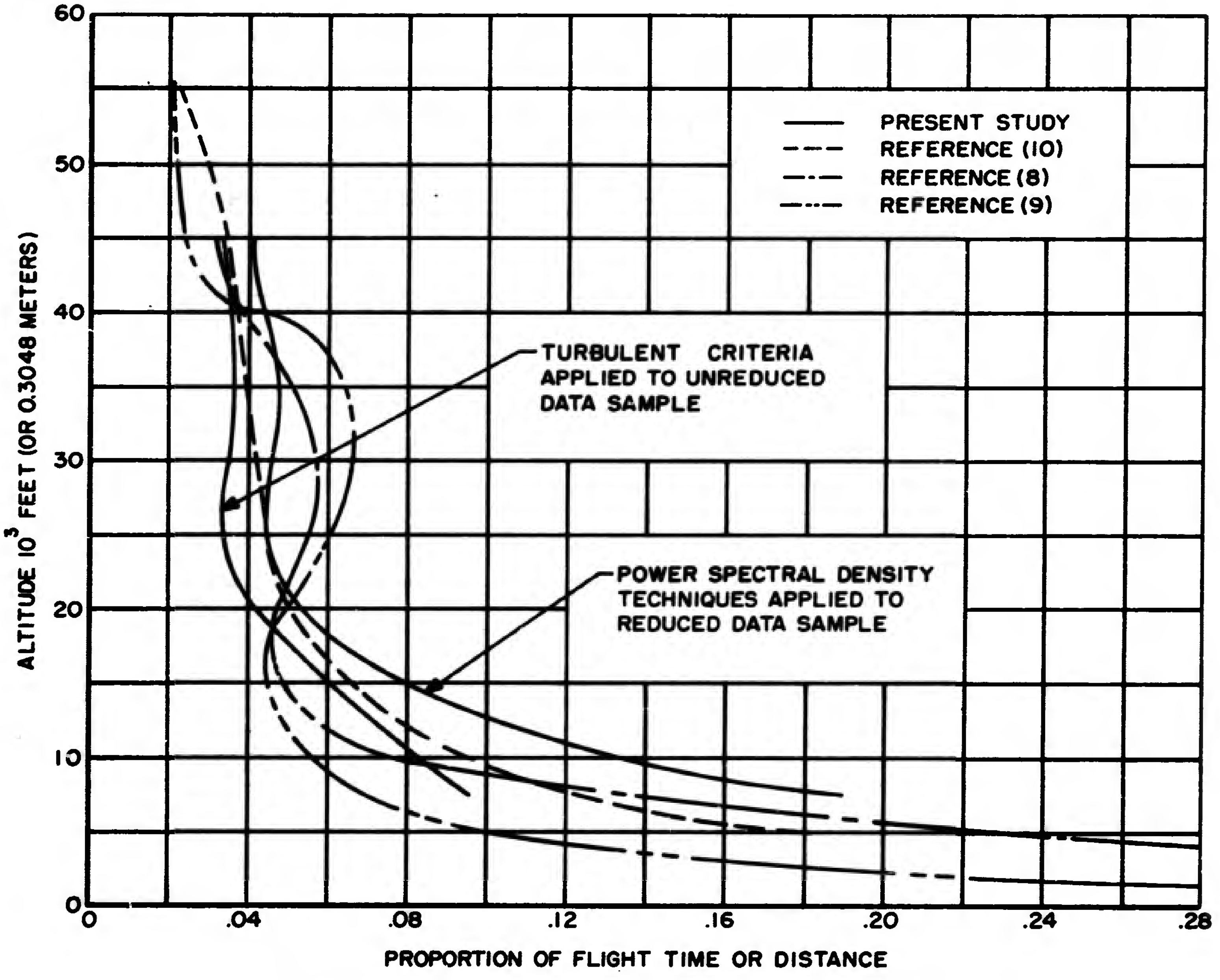

Figure 21 Proportion of Time in Turbulence With Altitude

Table IX(a) Frequency Distributions of Length of Turbulent Encounters by Altitude Bands

Length of Encounters by Class Intervals Lower Boundaries Listed		Altitude Bands*				
		4	5	6	7	8
Statute Miles	**Meters**	**Number of Encounters**				
0	0	15	34	22	50	14
2	3,219	80	110	167	382	64
4	6,437	88	147	239	463	74
6	9,656	73	116	165	425	79
8	12,875	95	81	146	322	52
10	16,093	114	149	263	658	81
15	24,140	75	97	203	425	67
20	32,187	42	70	131	300	44
25	40,234	30	45	75	220	42
30	48,280	18	29	58	166	14
35	56,327	18	28	43	114	17
40	64,374	7	19	35	115	16
45	72,420	10	11	28	87	10
50	80,467	7	8	19	72	10
55	88,514	4	11	24	56	8
60	96,561	8	5	15	50	3
65	104,607	5	5	16	33	4
70	112,654	3	2	11	39	7
75	120,701	0	11	12	28	3
80	128,748	1	2	9	26	6
85	136,794	2	1	7	32	3
90	144,841	3	2	3	25	1
95	152,888	1	7	2	12	3
100	160,934	1	3	4	9	2
105	168,981	1	4	4	11	1
110	177,028	3	3	3	14	1
115	185,074	0	1	3	9	1
120	193,121	1	1	0	16	1
125	201,168	0	0	3	12	1
130	209,215	3	1	3	7	0
135	217,261	0	1	1	9	1
140	225,308	1	0	2	6	1
145	233,355	1	1	2	2	0
150	241,402	1	1	0	10	1

Table IX(b) Frequency Distributions of Length of Turbulent Encounters by Altitude Bands (concluded)

Length of Encounters by Class Intervals Lower Boundaries Listed		Altitude Bands*				
		4	5	6	7	8
Statute Miles	Meters	Number of Encounters				
160	257,495	2	1	0	9	0
170	273,588	0	0	1	5	1
180	289,682	0	0	1	5	1
190	305,775	0	1	5	1	0
200	321,869	0	0	0	5	0
210	337,962	0	1	0	5	1
220	354,056	0	0	1	3	0
230	370,149	0	0	0	1	1
240	386,242	0	0	0	2	0
250	402,336	0	0	0	5	1
260	418,429	0	0	0	2	0
270	434,523	1	0	0	1	1
280	450,616	0	0	0	2	0
290	466,710	1	1	0	1	0
300	482,803	0	0	1	1	0
310	498,897	0	0	0	0	0
320	514,990	1	0	0	0	2
330	531,084	0	0	0	2	0
340	547,177	0	0	0	0	0
350	563,270	1	0	0	0	0
360	579,364	0	0	0	0	0
370	595,457	1	0	0	0	0
380	611,551	0	0	0	0	0
440	708,111	0	0	0	1	0
450	724,205	0	0	0	0	0
470	756,392	0	0	0	1	0
480	772,485	0	1	0	0	0
490	788,578	0	1	0	1	0
500	804,672	0	0	1	7	3

* Altitude Bands	Feet	Meters
4	5,000 - 10,000	1,524 - 3,048
5	10,000 - 20,000	3,048 - 6,096
6	20,000 - 30,000	6,096 - 9,144
7	30,000 - 40,000	9,144 - 12,192
8	40,000 - 50,000	12,192 - 15,240

frequency curves of the number of turbulent encounters equal to or greater than a given length of encounter developed from data presented in Table IX. Therefore, it is believed that the percent time in turbulence values derived by power spectral techniques are more accurate than those derived from the 20,230-hour unreduced data sample. The differences between the two methods are explainable, and the data from the unreduced data sample should provide a lower-bound estimate of the percent time in turbulence.

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IV. CONCLUDING REMARKS

True gust velocity distributions defining the atmospheric vertical turbulence environment in altitude bands from 5,000 to 50,000 feet have been developed from a 31,114 flight-hour sample of B-52 flight loads data. The flight loads data used in this investigation were obtained from 114 B-52 aircraft operating from eleven Air Force bases in the continental United States and flying operational Strategic Air Command missions. These flight loads data and hence the derived vertical turbulence environment are considered to be representative of flight over the North American continent.

The vertical turbulence environment developed herein is considerably lower than the MIL-A-8866 environment for all altitude bands from true gust velocity values of 10 feet per second and greater.

The derived vertical turbulence environment for all altitude bands are less severe than the environment obtained from Reference 7 by Boeing, using the same B-52 data sample considered in this program. The difference in the two environments was caused by the criteria used in selecting the data sample. In this investigation, only load factor distributions caused by gust were used, whereas the load factors caused by both gust and maneuver inputs were combined and used to derive the environment presented in Reference 7.

The results derived from the application of the turbulent criteria in the analysis of the 20,230 flight-hour sample of unreduced B-52 data are considered to be the lower limit of the experienced percent time in turbulence. The percent time in turbulence for each altitude band obtained from the power spectral analysis of the 13,375-hour sample of B-52 data is considered to be more representative of the actual turbulent environment.

The frequency distributions of the number of turbulent encounters versus the length of encounter are considered reliable for encounter lengths greater than six statute miles and provide additional information for mission analysis.

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13. ABSTRACT
This report contains the results of a vertical gust load analysis using flight loads data recorded on a large number of B-52 aircraft. The analyzed data will be used in evaluating existing airplane structural design criteria. The first of two analyses utilized power spectral density techniques to convert a 31,114 flight-hour sample of load factor data into true vertical gust velocity distributions which defined the atmospheric turbulence environment encountered by the B-52 in altitude bands from 5,000 to 50,000 feet. A series of equations representing the vertical turbulence environment was developed, one equation for each altitude band. These equations are considered representative of the flight environment over the North American continent. The derived vertical turbulence environment are generally less severe than similar environment presented in MIL-A-8866 and other publications. The second analysis utilized a 20,230 flight-hour sample of unreduced data to obtain the percent of time spent in turbulence for each altitude band. This data sample was also analyzed to obtain frequency distributions of lengths of turbulent encounters for each altitude band. (This abstract is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Flight Dynamics Laboratory (FDTR), Wright-Patterson Air Force Base, Ohio 45433.)

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