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on

A Summary of Atmospheric Turbulence recorded by NATO Aircraft

by

Cyril G. Peckham

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NORTH ATLANTIC TREATY ORGANIZATION
ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

A SUMMARY OF ATMOSPHERIC TURBULENCE
RECORDED BY NATO AIRCRAFT

by

Cyril G. Peckham
Technology Incorporated
Dayton, Ohio, USA

This report has been sponsored by the Working Group on Environmental
Statistical Data of the AGARD Structures and Materials Panel.

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Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

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SUMMARY

This document describes 150,000 hours of turbulence data collected from seven participating NATO countries, the instruments used to measure the data, and the methods of processing the data and of separating the turbulence data from the maneuver data. In addition, it details the power spectral density methods used to derive gust velocities which are presented by altitude, in Section 3. The original data as well as these gust velocities are presented in more detail in both magnetic tape files and in a voluminous summary report, copies of which have been sent to a representative in each of the participating countries. All work covered in this document was performed under Contract AGARD-OTAN SMP 67-68.

Ce document présente les données relatives à la turbulence atmosphérique recueillies par 7 nations participantes dans le cadre de l'OTAN, ainsi que l'instrumentation utilisée pour effectuer les mesures requises, les méthodes de traitement des dites données et les critères de séparation entre les données relatives aux manoeuvres de l'avion et celles relatives à la turbulence.

De plus, les techniques de densité spectrale de puissance utilisées pour calculer les vitesses de rafale sont décrites en détail. La Section 3 présente les résultats de ce calcul sous forme de tables en fonction de l'altitude.

L'information originale ainsi que les vitesses de rafale sont présentées de façon plus détaillée sur bandes magnétiques et dans un rapport sommaire dont les copies ont été envoyées aux représentants de chaque nation participante. Le travail couvert par ce document a été effectué sous contrat AGARD-OTAN SMP 67-68.

FOREWORD

This report is the culmination of the first cooperative effort of the NATO nations, who both funded and otherwise supported the effort to collect the turbulence data described in AGARD Report 555. This data has now been preserved in a data base which has been distributed to the participating NATO nations.

Technology Incorporated is for the most part responsible for the success of this action.

G. COUPRY
Chairman,
AGARD Structures and Materials Panel
Working Group on Environmental
Statistical Data

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A SUMMARY OF ATMOSPHERIC TURBULENCE
RECORDED BY NATO AIRCRAFT

Cyril G. Peckham

INTRODUCTION

Until recently, for the design of an aircraft structure, the loads due to turbulence have been derived by assuming that gusts can be described as a sequence of discrete events. Amongst the deficiencies of this discrete gust approach are:

- Gusts in fact occur continuously when the aircraft is flying in turbulent air.
- Only a one-degree-of-freedom of movement (plunging) of the aircraft is considered.
- Gusts were assumed to have only one wave length; i.e., loads resulting from an excitation - due to gusts of the natural modes (dynamic response) of the structure - cannot be described adequately.

In order to overcome these deficiencies, the Structures and Materials Panel of AGARD (Advisory Group for Aerospace Research and Development) agreed with the suggestions of various experts from different NATO countries that both power spectral and extreme value methods should be applied to the measured response of operational aircraft to turbulent air.

A previous study (Reference 1) had shown that there were sufficient data distributed in the NATO countries that could be made available for this purpose. Accordingly, a committee was set up to work with a coordinator to both gather and reprocess these data. The committee consisted of Harry Hall and later Richard Sewell of Canada, Gabriel Coupry of France, Otto Buxbaum of Germany, Jack Burnham, A. J. Atkinson and later Norman Bullen of the U.K., William Austin and later Clem Schmid of the U.S. The countries who made their data available and provided funds to underwrite the project were Canada, France, Germany, Italy, the Netherlands, the United Kingdom, and the United States.

The funds were released through a contract between AGARD and Technology Incorporated of Dayton, Ohio, USA, which supplied the coordinator. The contract was initially monitored by William B. Miller and later by Col. Charles K. Grimes, both of Wright-Patterson AFB of the United States.

Initially, three types of data were sought. These were VGH data, extreme values occurring once per flight or flight segment, and true gust velocity data. The VGH data measured all vertical accelerations at the center of gravity along with the coincident values of airspeed and altitude. Either the extreme values were extracted from the VGH data or only the maximum and minimum gust accelerations in each flight or flight segments were read during the initial processing. The true gust velocity data were obtained from aircraft equipped with vanes or gust booms, and these aircraft were flown through patches of turbulence to obtain continuous gust data.

To meet the objectives of the AGARD work, the three coincident values of acceleration, airspeed, and altitude plus the coincident weight were required for the first two types of data. The data are not reported in this form; if this coincidence is preserved at all, it is preserved only at the site where the data were first processed. Here it exists in the form of computer listings, IBM cards, or reels of magnetic tapes. Thus, all data delivered under this project required additional effort on the part of persons at the source to make the data available. This additional effort was made willingly by the different participating countries.

Approximately 150,000 hours of VGH data were culled from the data made available. Of these hours, 76,000 could be used to generate the maximum and minimum gust accelerations for each flight.

The true gust velocity data were obtained from short-time measurements in continuous turbulence. The programs under which they were collected, as well as the information available, are described.

All of these data have been reported in three ways: this document designed for general distribution, two sets of magnetic tapes of five reels each which contain all of the original data as well as the calculated gust velocities and their modified frequency distributions, and a detailed summary data report. The last two forms of the data have a limited distribution but are available through selected representatives in each of the participating countries, each of whom has a complete set of data.

The last two forms of the data as well as the processing are discussed in the following sections, and the reasons for the limited distribution will become apparent when the sheer bulk of data and the number of persons who could use the data in these forms are considered.

SECTION 1

DATA AVAILABLE

The bulk of the VGH (airspeed, vertical acceleration, and altitude) data were recorded either on the RAE recorder or an oscillograph system. Brief descriptions of these and other systems, the methods of processing the data, and the means of separating the turbulence data from the maneuver data are given in Appendix A. More extensive treatments are given in Canadian, the United Kingdom, and the United States reports (References 19 and 23).

The VGH data were collected from operational aircraft, generally for the purpose of obtaining data for either damage calculations or design criteria. The processor, either subjectively or by the design of the instrument, set the thresholds for the vertical acceleration, separated the data into turbulence or maneuver categories, and counted the occurrences of accelerations in intervals. The threshold is that interval around the 1.0g line in which either measurements are not made or, if made, are not counted.

During the initial processing, additional parameters or constraints were added to the data. Among these were season, aircraft weight, fuel weight, mission segments (flight conditions), and flap position; but all of these were not common to all aircraft. Either parameters such as season and flight condition were coded directly, or a value was assigned to an interval and the interval was coded. Thus altitude code 1 could represent the interval of 0 to 1000 feet, vertical acceleration code 14 could represent the interval of 1.4g to 1.5g. Although the data from each flight were originally processed separately from all other flights, they must ultimately for statistical purposes be combined with the data from other flights. The individual flight data may or may not be preserved. In addition, the data might be preserved in the form of magnetic tapes, IBM cards, computer listings, etc. The coordinator received data from individual flights as well as combined data representing many flights and in all of the different forms. All in all, the coordinator received some 75 magnetic tapes of data, thousands of IBM cards, computer listings of data, and sundry small miscellaneous pages of data.

Some of the magnetic tapes contained data separated into maneuver and turbulence categories, the separation having already been made by the processor. Only the turbulence data were extracted from these tapes. For some flights in flight-by-flight data, the accelerations were processed only for certain mission phases such as low level. These flights were deleted in their entirety.

All of these magnetic tape data were written in different formats with different codes and intervals. Since one of the objectives of this program was to preserve the original data as far as possible, it was decided to rewrite all of the data in the same format but to preserve the original intervals wherever possible and to define the intervals for each set of data. However, some limit had to be set on the number of intervals for any parameter and this was chosen as twenty. In all but a few cases twenty was a safe limit. In the few cases where it was not, intervals in the original data were combined to reduce the number below 20. The only parameters affected were weight on one United States aircraft and airspeed and altitude on the U.K. data. The use of a single format required allocating space for each possible parameter. Thus, even though space has been left in the new format for all constraints, only those used by the original processor are entered. For any not used, the corresponding space is left blank. All data were kept separate by aircraft type and model. The preservation of the original intervals, and the variation in the number of constraints, require that the data for each aircraft type be preceded by a historical record defining these intervals and parameters. In each case the code identifies the interval or the lower limit of the interval.

The data received in tabular form, after keypunching, were combined with the other card data and written on tape. These tapes were then treated in the same manner as the tapes received originally.

VGH DATA FILES

After the VGH data were condensed, that is, similar data from different flights were combined, the accelerations were written as cumulative distributions - if they were not already in that form - for a given set of constraints, that is, constant values of weight, airspeed, altitude, season, etc. Any line in Figure 1-1 is one of these distributions and represents the data from many, many flights. During the processing two other forms of presentation were generated for each of these original distributions and inserted immediately following the appropriate original distribution. The first of these contained gust velocities in constant intervals - either 5 feet/second or 2 meters/second - with the original frequencies mathematically distributed over these intervals of gust velocity. These gust velocities are obtained by dividing Δn by \bar{A} , where Δn is the acceleration increment from the 1.0g condition, and \bar{A} is the gust response function considering either the rigid or flexible response. The second inserted distribution modified the gust velocity distribution to remove the effect of the aircraft on the assumed spectrum of the atmosphere. These processing methods are discussed in detail in Section 2. To allow easy combination of the data, none of the

distributions in the files have been divided by the distance. This division must be performed prior to printing as was done in Figure 1-3. Any line in Figure 1-2 or 1-3 represents the first and second of these inserted distributions, respectively. The total number of nautical miles is carried in each one of these distributions.

All of the original VGH data plus the two added presentations for each were compacted to be stored on the minimal number of magnetic tapes. The set of data for each aircraft and model was preceded by a historical record describing the data stored for that aircraft.

C-130 E FLAPS RETRACTED			CUMULATIVE FREQUENCY OF DELTA-N (G+S)															
SEASON	WINTER		-1.5	-1.0	-0.8	-0.6	-0.4	-0.3	-0.2	-0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.5
W-N-V	TIME (HR)	DIST (NM)																
020102	0.66	83.						1	5	55	74	10	1					
020103	0.13	21.								14	10							
020104	0.07	16.						5	27	74	85	34	5	1				
020202	2.27	300.						1	22	276	358	56	12					
020203	0.62	101.					1	3	19	104	111	39	17	2				
020204	0.29	65.					5	26	117	327	357	120	22	3				
020205	0.00	1.								2	2	1						
020302	3.41	467.					1	9	93	665	761	142	39	6				
020303	2.45	406.					1	11	47	320	357	82	17	10				
020304	0.44	104.					5	17	75	229	233	90	31	7				
020305	0.15	40.						2	11	57	47	14	1					
020402	2.80	387.						7	60	525	637	108	24	2				
020403	2.84	487.					2	21	120	702	846	207	42	10				
020404	1.30	296.					12	33	192	616	644	200	45	10	1			
020405	0.16	43.						4	25	78	87	31	10	1				
020502	4.26	597.					2	7	61	575	579	78	11	4				
020503	8.97	1570.					5	35	153	1359	1435	258	48	7				
020504	3.60	834.					15	77	333	1242	1195	348	79	22	1			
020505	0.32	86.					4	7	19	78	72	24	7					
020602	0.27	42.					1	1	3	18	29							
020603	1.09	205.					2	7	27	117	138	43	4					
020604	0.70	175.					1	3	15	64	61	9						
020605	0.28	76.							12	47	38	8	2	1				
020702	0.04	6.																
020703	0.64	123.						3	9	36	44	6	2	1				
020704	0.57	148.					1	1	4	27	40	6	2					
020705	0.84	237.					1	3	5	8	13	5	2					
020802	0.07	12.																
020803	0.45	95.								9	6	1						
020804	0.59	158.							2	12	16	5	3	1				
020805	0.32	95.							4	15	15	3						
020902	0.57	93.																
020903	0.71	154.								13	1							
020904	0.85	240.							2	19	20		2	2				
020905	1.67	517.							2	17	19	6	2	1				
021002	0.48	83.																
021003	2.80	446.							1	14	22							
021004	3.82	1040.							4	23	19	2						
021005	0.14	45.								4	4	1	1					
021102	0.07	15.								2	9	12	2	2				
021103	2.58	608.							13	81	79	15	2	1				
021104	4.77	1504.						2	7	37	39	4	1	1				
021203	0.01	3.								5	7	1						
021204	0.66	214.							3	19	104	103	12	1				
030102	3.83	500.								32	255	329	53	9				
030103	2.01	333.								27	224	345	73	14	3			
030104	1.78	410.					19	55	203	795	965	356	92	18	1			
030202	8.71	1176.						20	175	1099	1292	210	35	3	1			
030203	5.74	966.					2	15	107	698	681	238	56	12				
030204	4.09	943.					2	35	173	666	2425	2525	799	225	41	1		

Figure 1-1. Original Data

SAMPLES OF THE DATA

Samples of the two generated distributions previously discussed are shown in Figures 1-2 and 1-3, and a sample historical record is shown in Figure 1-4. The distributions have been listed with headings and spaced for legibility, and each figure illustrates only one distribution type with each printed line corresponding to one distribution. Note that the constraints appear in the first column and in the heading of each table. Since the frequencies (number of occurrences) from the original data were mathematically distributed over the gust velocity ranges, there was no need to maintain them as integers. They are in all cases carried as decimals but are rounded to integers for the presentation of the cumulative gust frequency. Decimals less than 0.5 correspond to blanks in Figures 1-2 and 1-3, and also explain why Figure 1-3 may have an entry but Figure 1-2 has a blank in the corresponding position. The first frequency in line 020502 illustrates this. The blank in Figure 1-2 indicates the frequency is less than 0.5, but multiplication by $N_0(IN)/N_0(OUT)$ makes the frequency greater than 0.5.

The interpolation routine uses an exponential fit to two consecutive points of the original data and interpolates for the frequencies corresponding to 5,10,15,... ft/sec, that occur in the interval bounded by the two points. Frequencies are not extrapolated, so that no frequencies are calculated for gust values less than the first observed value. The zero frequency after the last non-zero frequency is replaced by 0.1 and the interpolation carried out between the first observed value and the last. For example

if the first and last (frequency of 0.1) Δn give $\Delta n/\bar{X}$ values of 6.7 and 40.1, then frequencies are computed for $\Delta n/\bar{X}$ values of 10,15,20,....40.

C-130 E FLAPS RETRACTED

SEASON WINTER

W-H-V TIME (HR) DIST (NM)

CUMULATIVE GUST FREQUENCY OF DELTA-N/ABAR (FT/S)

			-40.	-35.	-30.	-25.	-20.	-15.	-10.	-5.	5.	10.	15.	20.	25.	30.	35.	40.
020102	0.66	83.						1	7			13	2					
020103	0.13	21.								3	3							
020104	0.07	18.							1	36	44	2						
020202	2.27	300.						4	43			93	21	2				
020203	0.62	101.						1	8	72	86	27	4					
020204	0.29	69.						1	19	176	187	19	1					
020205	0.00	1.									1							
020302	3.41	467.			2	9	49	251				332	103	40	9	2		
020303	2.45	406.						8	42	301	340	73	19	7				
020304	0.44	104.						4	24	149	181	39	5					
020305	0.15	40.							1	20	22							
020402	2.80	387.			1	11	31	231				321	99	33	8	1		
020403	2.84	487.					3	27	149			240	94	13	3			
020404	1.30	296.					2	14	73	448	469	89	12	3				
020405	0.14	43.							4	43	52	10						
020502	4.26	597.		1	4	12	54	252				274	71	18	7	3	1	
020503	8.97	1570.				1	8	48	249			324	67	11	2			
020504	3.60	834.					2	22	138	878	868	164	30	4				
020505	0.32	86.						2	7	40	42	7						
020602	0.27	42.		1	1	1	1	3	9			6						
020603	1.09	205.					3	9	30			51	7					
020604	0.70	175.						1	6	43	39	2						
020605	0.28	78.								24	18	2						
020702	0.04	6.																
020703	0.64	123.						4	11			9	2	1				
020704	0.57	148.						1	2	18	26	3						
020705	0.84	237.							3	6	9	2						
020802	0.07	12.																
020803	0.45	95.										1						
020804	0.59	158.								8	13	6	1					
020805	0.32	95.								9	9							
020902	0.57	93.																
020903	0.71	154.																
020904	0.85	240.							1	14	17	4	2					
020905	1.67	517.								10	11	1	1					
021002	0.48	83.																
021003	2.80	646.							2			1						
021004	3.82	1080.							2	20	16	1						
021005	0.14	45.								1	2	1						
021102	0.07	15.					1	3	7			9	3	2	2			
021103	2.58	608.						3	29			31	7	1	1			
021104	4.77	1504.							2	7		4	1	1	1			
021203	0.01	3.										2						
021204	0.66	214.							4	25		17	1					
030102	3.83	500.							2	56		87	19	2				
030103	2.01	333.								12	146	254	37	9	1			
030104	1.78	410.							3	43	340	526	64	5				
030202	8.71	1176.					7	67	356			421	95	20	2	1	1	
030203	5.74	966.					1	7	65	597	751	148	32	5	1			

Figure 1-2. Cumulative Gust Velocity Distribution

C-130 E FLAPS RETRACTED

SEASON WINTER

W-H-V TIME (HR) DIST (NM)

CUMULATIVE GUST FREQUENCY X NO(INI)/NO(OUT) OF DELTA-N/ABAR (FT/S)

			-40.	-35.	-30.	-25.	-20.	-15.	-10.	-5.	5.	10.	15.	20.	25.	30.	35.	40.
020102	0.66	83.						1	6			12	1					
020103	0.13	21.								4	3							
020104	0.07	18.								33	41	2						
020202	2.27	300.						4	43			96	22	2				
020203	0.62	101.						1	8	75	90	28	4					
020204	0.29	69.						1	20	187	198	16	1					
020205	0.00	1.									1							
020302	3.41	467.			2	11	59	302				399	124	48	11	3	1	
020303	2.45	406.					1	10	51	366	413	89	19	9	1			
020304	0.44	104.						5	30	186	201	49	7					
020305	0.15	40.							1	24	27							
020402	2.80	387.			2	15	69	308				428	131	46	11	2	1	
020403	2.84	487.					1	4	36	193		322	72	18	4	1		
020404	1.30	296.						3	20	100	611	640	122	17	4			
020405	0.14	43.								9	58	70	13					
020502	4.26	597.		1	2	9	18	81	375			408	106	27	10	5	2	1
020503	8.97	1570.				2	13	72	375			486	100	16	4	1		
020504	3.60	834.					3	35	241	1361	1327	231	46	7	1			
020505	0.32	86.						3	11	61	64	11						
020602	0.27	42.		1	1	2	4	13				9						
020603	1.09	205.				1	4	14	50			77	11					
020604	0.70	175.						2	9	64	52	3						
020605	0.28	78.								39	28	3	1					
020702	0.04	6.																
020703	0.64	123.						6	17			13	4	1				
020704	0.57	148.						1	3	28	40	5						
020705	0.84	237.						1	5	10	13	3						
020802	0.07	12.																
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020902	0.57	93.																
020903	0.71	154.								1								
020904	0.85	240.							1	21	25	6	2	1				
020905	1.67	517.							1	14	16	4	1					
021002	0.48	83.																
021003	2.80	646.							3			2						
021004	3.82	1080.							3	29	23	2						
021005	0.14	45.								1	3	1						
021102	0.07	15.					1	4	10			13	4	2	2	1		
021103	2.58	608.						4	40			43	10	2	1			
021104	4.77	1504.						3	10			6	1	1	1			
021203	0.01	3.										3						
021204	0.66	214.							6	33		23	2					
030102	3.83	500.							2	48		75	16	1				
030103	2.01	333.								10	127	221	32	5	1			
030104	1.78	410.							2	37	299	463	56	4				
030202	8.71	1176.					7	67	369			412	93	19	2	1	1	
030203	5.74	966.					1	7	64	550	741	165	31	5	1			

Figure 1-3. Modified Gust Frequency

AIRCRAFT TYPE	C-130, MODELS B AND E				
COUNTRY OF ORIGIN	UNITED STATES OF AMERICA				
TOTAL TIME	7650 HOURS				
TOTAL DISTANCE	1851200 NAUTICAL MILES				
GEOGRAPHY	SOUTH-EAST ASIA				
INSTRUMENTATION	OSCILLOGRAPH				
COUNTING METHOD	PRIMARY PEAKS				
SYSTEM OF UNITS	FOOT-POUND-SECOND				
DATE OF COLLECTION	1964-1969				
ABARS AND NZEROS	FROM LOCKHEED (8 D.O.F.), CHECKED AT LOW LEVEL				
EXTREME VALUES	AVAILABLE FOR ALL FLIGHTS				
FLAPS POSITION	1= FLAPS EXTENDED, 0= FLAPS RETRACTED				
RANGES OF VALUES	ACCELERATION (G)	AIRSPPEED (KEAS)	ALTITUDE (FT)	WEIGHT (LB)	FUEL (LR)
1		LESS	0	73000	0
2			100	85000	5000
3	LESS	150	1000	95000	10000
4	-0.5 - 0.0	200	1500	105000	15000
5	0.0 - 0.2	250	2000	115000	20000
6	0.2 - 0.4	300	4000	125000	30000
7	0.4 - 0.6	350	6000	135000	40000
8	0.6 - 0.7		8000	145000	50000
9	0.7 - 0.8		10000	155000	60000
10	0.8 - 0.9		15000	165000	
11	1.1 - 1.2		20000	175000	
12	1.2 - 1.3		25000		
13	1.3 - 1.4		30000		
14	1.4 - 1.6				
15	1.6 - 1.8				
16	1.8 - 2.0				
17	2.0 - 2.5				
18	2.5 - 3.0				
19	MORE				
FLIGHTS SEGMENTS	<ol style="list-style-type: none"> 1. INITIAL ASCENT 2. OTHER ASCENT 3. FIRST CRUISE 4. OTHER CRUISE 5. OTHER DESCENT 6. FINAL DESCENT TO LANDING 7. LOW LEVEL NAVIGATION 8. LOW LEVEL PRIOR TO AIRDROP 9. AIRDROP 10. LOW LEVEL POSTERIOR TO AIRDROP 11. PRACTICE LANDING 19. ASSAULT LANDING 				

Figure 1-4. Historical Record

Since not all countries use the same units, tapes using both the English and the International (SI) units were prepared. The original data were not changed; the only records affected are the distributions of gust velocities and the modified frequency distributions. The data in both units were not combined onto a single set of tapes since the computer time for any future work would be increased.

The units used to measure the various parameters in both systems are defined below.

<u>Parameter</u>	<u>English</u>	<u>International</u>
Weight	Pounds	Kilograms
Altitude	Feet	Meters
Airspeed	Knots	Knots
Acceleration	g's	g's
Gust Velocity	Feet/Second (interval- 5 ft/sec)	Meters/Second (interval- 2 meters/sec)

EXTREME VALUE FILES

Wherever individual flights were available, the maximum and minimum accelerations due to turbulence were extracted and written on tape as two individual occurrences. Each extreme value is identified by the coincident values of airspeed, altitude, weight, and so on. Since these data came from the same source as the VGH data, the historical records are applicable to both but are repeated for the convenience of the user. These data are also separated by aircraft type and model. A sample of this data is shown in Figure 1-5.

C-130 - MINIMUM AND MAXIMUM GUSTS PER FLIGHT

S	YBA	LBA	MOD	HOURS	MILTS	FS	F	GMT	FMT	ALT	A/S	LOD	FS	F	GMT	FMT	ALT	A/S	MIN
1	123	7A	E	0.323	73.1														
1	7A	159	E	0.395	149.1	3	100000	17500	9000	275	-0.1	3	100000	17500	9000	275		0.1	
1	159	7A	F	0.432	159.0	1	100000	17500	750	175	-0.1	4	90000	12500	1750	175		0.1	
1	7A	159	F	0.437	171.5	4	120000	25000	750	125	-0.1	1	120000	25000	750	175		0.1	
1	159	1	F	0.452	109.5	4	100000	25000	1250	175	-0.2	4	100000	25000	5000	225		0.2	
1	1	105	F	0.313	65.0	1	130000	25000	3000	175	-0.2	1	130000	25000	3000	175		0.2	
1	105	123	F	1.384	347.7	1	100000	17500	3000	175	-0.2	1	100000	17500	1750	175		0.2	
1	?	1	F	1.037	250.9	1	130000	25000	750	125	-0.1	4	120000	25000	9000	175		0.1	
1	1	104	E	0.245	53.2	1	120000	17500	7000	175	-0.1	1	120000	17500	7000	225		0.1	
1	105	119	F	0.266	61.4	4	120000	17500	1250	125	-0.2	1	120000	17500	750	175		0.1	
1	119	105	F	0.253	59.9	4	130000	25000	1750	225	-0.2	4	130000	25000	3000	225		0.3	
1	109	127	E	0.335	72.3	1	130000	25000	500	175	-0.2	1	130000	25000	500	125		0.2	
1	127	90	E	0.310	69.8	1	120000	17500	3000	225	-0.2	4	120000	17500	5000	275		0.4	
1	90	?	E	0.610	143.8	1	100000	17500	5000	175	-0.2	1	100000	17500	3000	175		0.3	
2	?	?	E	0.054	8.5														
2	?	?	F	1.815	380.1														
2	124	7A	E	0.483	109.2	1	100000	12500	3000	175	-0.2	1	100000	12500	1750	175		0.2	
2	7A	104	E	0.383	84.1	1	140000	25000	750	175	-0.1	1	140000	25000	1250	125		0.2	
2	104	7A	F	0.405	89.1	4	110000	25000	750	175	-0.1	4	110000	25000	3000	275		0.1	
2	7A	104	F	0.335	74.3	1	110000	25000	1750	175	-0.1	1	110000	25000	1750	175		0.1	
2	103	?	F	1.128	283.9	1	110000	25000	750	175	-0.1	1	110000	25000	750	175		0.3	
2	127	125	E	1.005	454.3	1	110000	17500	750	175	-0.1	1	110000	17500	750	175		0.2	
2	7A	132	E	0.754	203.9	4	120000	25000	750	125	-0.1	4	120000	25000	1250	175		0.1	
2	132	103	E	0.678	149.8	1	100000	25000	900	175	-0.1	1	100000	25000	500	175		0.1	
2	1	272	F	0.281	57.2	3	120000	25000	5000	175	-0.1	1	130000	25000	750	175		0.1	
2	272	1	B	0.300	66.8	3	100000	17500	5000	225	-0.1	4	100000	17500	1250	125		0.1	
2	1	272	B	0.295	62.1	1	120000	17500	750	175	-0.2	4	120000	17500	1250	275		0.3	
2	272	1	E	0.305	61.0	1	100000	12500	1250	175	-0.1	1	100000	12500	500	125		0.1	
2	272	1	F	0.310	61.6	4	100000	17500	3000	225	-0.2	4	100000	17500	7000	225		0.2	
2	1	272	B	0.463	88.7	1	120000	17500	3000	175	-0.2	1	120000	17500	500	125		0.2	
2	250	250	B	1.143	221.5	1	120000	25000	3000	175	-0.3	1	120000	25000	3000	175		0.3	
2	1	119	F	0.335	91.4														
2	119	1	B	0.357	120.7	3	100000	17500	7000	225	-0.1								
2	1	119	F	0.342	74.1	4	120000	12500	3000	225	-0.2								
2	119	1	B	0.470	105.5	1	90000	12500	5000	125	-0.1	1	90000	12500	3000	175		0.1	
2	1	102	B	0.427	97.5														
2	102	1	B	0.445	104.2	4	100000	17500	750	125	-0.1	4	100000	17500	3000	225		0.2	
2	1	273	B	0.332	70.8	1	130000	25000	5000	175	-0.1	1	130000	25000	5000	175		0.1	
2	273	273	B	0.320	70.8	1	100000	25000	750	175	-0.1	4	100000	25000	3000	225		0.2	
2	273	123	B	0.338	68.5	1	130000	17500	5000	225	-0.3	1	130000	17500	5000	175		0.4	
2	123	1	B	0.253	48.6	1	100000	17500	3000	175	-0.3	4	90000	17500	3000	225		0.3	
4	3	5	F	1.575	433.0	1	120000	35000	750	175	-0.1	1	120000	35000	750	175		0.2	
4	3	220	F	1.742	494.7	1	110000	25000	500	175	-0.1	1	110000	25000	500	175		0.1	
4	220	3	E	0.265	67.5	1	100000	17500	750	175	-0.1								
4	3	77	F	3.717	1026.8	4	120000	25000	12500	225	-0.4	4	120000	25000	12500	225		0.4	
4	77	222	F	2.102	557.9	1	120000	35000	750	125	-0.1	1	120000	35000	750	125		0.1	
4	222	26	E	1.007	265.3														
4	26	25	E	0.423	91.3	1	120000	35000	1750	175	-0.1	1	120000	35000	1750	175		0.1	
4	25	299	F	0.337	121.7														
4	299	24	F	0.344	122.9	4	110000	25000	750	125	-0.1	4	110000	25000	750	125		0.1	

Figure 1-5. Sample of Extreme Values

TRUE GUST VELOCITY

As mentioned previously, since the true gust velocity data were of short-time duration and collected for continuous analysis purposes only, they cannot be used in statistical work. Each set of true gust velocity data was collected for a specific program, and the description of each program was summarized on magnetic tape. These same data are also presented in the summary data report. This listing is probably not complete, but does reflect recent work. Once it was concluded that there was no way to use these data in conjunction with the VGH data, all positive efforts to obtain this type of data were halted. The example in Figure 1-6, printed directly from the data file, illustrates the information available.

TAPE DESCRIPTION

Two sets of tapes - one in the English and one in the International set of units - have been sent to each of the countries involved in the program. The representative in each country that received the sets is listed in Appendix B along with his address. All correspondence should be directed to the appropriate representative.

A description of the tapes is given in Appendix C.

Copies of these tapes can be made easily and quickly with the user's computer by using programs that are available at his site. All five tapes are physically labelled and the data contained on each tape are further identified on a magnetic label.

COMPUTER PROGRAMS

Along with each set of tapes, a series of programs were delivered. Written in Fortran IV, these programs are on the tapes themselves, and with minor modifications should be easily convertible to the user's computer. One of these programs can generate a copy of a summary data report, described later in this report. Others can generate sets of data that are usually requested.

TRUE GUST VELOCITY

PROGRAM NAME HICAT

AIRCRAFT U-2

REPORT NAME PROJECT HICAT, HIGH ALTITUDE CLEAR AIR TURBULENCE MEASUREMENT AND METEOROLOGICAL CORRELATIONS

REPORT NUMBER AFFDL-TR-68-127, VOL. I AND II
NOVEMBER 1968
AIR FORCE FLIGHT DYNAMICS LABORATORY (FDTE)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433 U.S.A.

AUTHORS W.M. CROOKS, ET AL
LOCKHEED-CALIFORNIA COMPANY

GEOGRAPHIC LOCATION
BEDFORD, ENGLAND
BARKSDALE AFB, SHREVEPORT, LOUISIANA, USA
LORING AFB, LIMESTONE, MAINE, USA
ALBROOK AFB, BALBOA, CANAL ZONE, PANAMA
PATRICK AFB, COCOA, FLORIDA, USA
EDWARDS AFB, EDWARDS, CALIFORNIA, USA

ALTITUDE FLOWN 45000 TO 70000 FEET

INSTRUMENTATION FIXED VANE GUST PROBE NOSE BOOM

PROCESSING FILTERS LOW-PASS MARTIN-GRAHAM WITH CUT-OFF AT 1, 2, 3, 5 HZ
HIGH-PASS CUT-OFF AT 0.1 HZ
PREWHITENING

SAMPLING RATE 12.5 SAMPLES PER SECOND

INTEGRATING TIME VARIED FROM 1.3 TO 13.3 MINUTES

DATA PLOTS OF GUST VELOCITY POWER SPECTRA, DATA AFTER 13 MARCH 67

Figure 1-6. True Gust Velocity

SUMMARY DATA REPORT

A copy of a summary data report has been made available to each of the participating countries and other copies can be made by each country from the five tapes. The summary report will contain all data on the tapes except the extreme values which would require an additional 1000 pages. The historical record which will be part of the summary report will identify those aircraft for which extreme values are available.

The format of the files points out that a single record will not fit on a line of paper. Hence, some editing must be done to make the summary report readable. Since only sixteen intervals can be listed (because of paper width), the deleted intervals - the first and last two - will have their data combined with the data in the first and last interval printed.

The summary report is prepared primarily for persons who will use the tapes so that they may see what and how much data are available. The data will be presented in the finest breakdown possible and will contain all of the original data. In this form the data can be used for manual calculations, but much effort would be required to combine the fine breakdowns into coarser but more useable groupings. The number of people who can use these very fine breakdowns is generally limited to people who process data. This and the size of the summary report are the only reasons that the distribution is limited. The summary report contains, therefore, in addition to a listing of all programs, and a description of the contents of all tape reels, the following:

1. Listing of all of the original cumulative acceleration distributions with the associated time and distance versus weight, altitude, and airspeed ranges by aircraft type and model for each season and further separated by flaps in or out and flight segments if this information is available. Each listing by aircraft is preceded by the historical record.
2. Bivariate distribution of the cumulative gust frequency per mile by altitude and season for each set of data by aircraft type. Normally there is one set of data for each aircraft type. However, the addition of parameters or finer parameter intervals during the course of the data collection resulted in three distinct sets of data for the C-130 and two for the B-52. These sets of data correspond to the plots shown in Section 3 of this report and are derived from the VGH data files.

3. Direct copy of part of each tape. This is commonly referred to as a dump by programmers and is useful only to them.
4. Description of each program submitted concerning what it will do and how it can be used.

SUMMARY OF ALL DATA

A summary of the data available from either the tape or the summary report is given in Table 1-1. The characteristics of the aircraft on which the data was recorded are given in Table 1-2.

The summary represents only that data that could be used and does not reflect over 25,000 hours of data made available by the Netherlands, and a similar amount made available by France. Both sets of data were recorded on counting accelerometers and included both ground and flight data. Even if some means were found to isolate the flight data, and to further separate the turbulence data from the maneuver data, the absence of the corresponding airspeed, altitude, and weight would still make the data unuseable. Some three thousand hours of German data will not be ready until next year. Italy had some extreme values that were very interesting and potentially useful, but were reluctantly omitted from the summary since only exceedances over a certain limit were reported, in great detail, and no knowledge was available on the size or number of the extreme values below these limits on the other flights.

TABLE 1-1
Summary of Available Data

Model	Data Hours	Distance N.M.	Altitude Range(ft)	Geographic Location	Extreme Value(hrs)	Additional Constraints	Source
C-130A,B,E	9,340	2,312,000	0-35,000	CONUS	8,403	S	U.S.A.
C-130B,E	7,650	1,851,000	0-35,000	SEA	7,651	FW,F,S,FC	U.S.A.
C-130A,B,E	11,210	2,626,000	0-35,000	CONUS,TRATL TRPAC	12,047	FW,F,S,FC	U.S.A.
C-141	39,200	14,580,000	0-40,000	CONUS,TRATL TRPAC	37,831	S,FC	U.S.A.
B-52B,F	12,503	4,851,900	0-50,000	CONUS	--	FC	U.S.A.
B-52C,H	14,297	5,167,000	0-50,000	CONUS,TRPAC	--	F,FC,S	U.S.A.
B-58	5,770	2,881,000	0-50,000	CONUS	--	FC	U.S.A.
B-26	2,076	424,000	0-20,000	CONUS	2,076	S	U.S.A.
F-4	2,950	1,180,000	0-50,000	CONUS	2,142	S	U.S.A.
T-38	2,876	1,080,000	0-40,000	CONUS	1,706	S	U.S.A.
OV-1	204	36,200	0-15,000	CONUS	204	S	U.S.A.
707-220	1,154	495,800	0-35,000	CONUS	--	--	U.S.A.
707-320	2,830	1,266,870	0-40,000	CONUS	--	--	U.S.A.
707-420	4,152	1,838,300	0-40,000	CONUS,TRATL	--	--	U.S.A.
DC-8-30	500	218,350	0-40,000	CONUS	--	--	U.S.A.
CV-880	3,766	1,661,390	0-40,000	CONUS	--	--	U.S.A.
Caravelle	723	242,580	0-35,000	CONUS	--	--	U.S.A.
727-200	994	401,560	0-35,000	CONUS	--	--	U.S.A.
DC-7C	1,728	428,960	0-20,000	CONUS	--	--	U.S.A.
BAC-111	1,156	389,140	0-35,000	CONUS	--	--	U.S.A.
CL-44 Cargo	1,179	373,580	0-30,000	CONUS	--	--	U.S.A.
300-LR	186	56,300	0-35,000	Canada,TRPAC	--	--	Canada
DC-4M	85	10,130	0-20,000	Canada	--	--	Canada
C-119	65	11,000	0-10,000	Canada,Greenland	--	--	Canada
680-E	25	4,170	0-10,000	Canada	--	--	Canada
D-18-S	137	18,200	0-10,000	Canada	--	--	Canada
SA-16B	62	8,290	0-10,000	Canada	--	--	Canada
CL-44	3,056	929,660	0-35,000	N.A.,TRATL,TRPAC	--	--	Canada
Transall	84	21,500	0-5,000	France	84	--	France
Ambassador	893	178,000	0-21,000	EUR	--	S,FC	Germany U.K.
Britannia	1,228	363,000	0-27,000	I.O.,AFR,EUR,M.F.E.	--	S,FC	U.K.
Comet 1	1,809	610,000	0-44,000	EUR,AFR	--	S,FC	U.K.
Comet 4	1,185	477,500	0-41,000	EUR,AFR,M.F.E.,AUS	--	S,FC	U.K.
Bristol	1,346	189,400	0-11,000	EUR,AFR,AUS	--	S,FC	U.K.
Hermes 4,4A	4,601	1,029,900	0-22,000	EUR,AFR,M.F.E.	--	S,FC	U.K.
Stratocruiser	3,378	765,000	0-25,000	TRATL,N.A.	--	S,FC	U.K.
Superconstellation	3,766	904,500	0-22,000	EUR,AFR, M.F.E.,TRPAC	--	S,FC	U.K.
Viking	1,324	230,000	0-14,000	EUR,AFR	--	S,FC	U.K.
Viscount	3,390	946,900	0-28,500	EUR,AFR	--	S,FC	U.K.
707	2,240	975,100	0-40,000	EUR,AFR,M.F.E., AUS,TRATL	--	S,FC	U.K.

Geography Code

CONUS	Continental United States
SEA	Southeast Asia
TRATL	Trans-Atlantic
TRPAC	Trans-Pacific
N.A.	North America
EUR	Europe
M.F.E.	Mid- and Far-East
AFR	Africa
AUS	Australia
I.O.	Indian Ocean

Constraint Code

F	Flaps
S	Season
FC	Flight Condition
FW	Fuel Weight
W	Weight
H	Altitude
A	Airspeed

NOTE: W,H,A apply to all aircraft.

TABLE 1-2
Aircraft Characteristics

Model	Maximum Gross Weight (lb)	Wing Area (ft ²)	Mean Chord (ft)	Span (ft)	A & N ₀ Basis
C-130	135,000-155,000	1745	13.7	132.6	8 DOF
C-141	318,000	3228	22.17	159.9	6 DOF
B-52	460,000-500,000	4000	22.96	185.0	16-30 DOF
B-58	175,000	1542	36.17	56.8	6 DOF
B-26	41,000	540	7.72	71.5	1 DOF
F-4	56,000	530	16.05	38.4	1 DOF
T-38	11,700	170	7.73	25.2	1 DOF
OV-1	15,000	330	8.16	42.0	1 DOF
707-220	248,000	2433	20.1	130.8	1 DOF
707-320	312,000	2892	22.69	142.4	1 DOF
707-420	312,000	2892	22.69	142.4	1 DOF
DC-8-30	310,000	2773	22.1	142.4	1 DOF
CV-880	185,000	2000	18.98	120.0	1 DOF
Caravelle	110,230	1579	14.03	112.5	1 DOF
727-200	152,000	1650	14.4	108.0	1 DOF
DC-7C	143,000	1637	13.7	127.5	1 DOF
BAC-111	76,500	980	11.08	88.5	1 DOF
CL-44 Cargo	210,000	2075	16.07	142.3	1 DOF
300LR	140,000	2075	14.67	--	1 DOF
DC-4M	73,000	1457	13.64	117.5	1 DOF
C-119	64,000	1447	14.02	109.3	1 DOF
680-E	8,000	255	5.84	49.5	1 DOF
D-18-S	8,000	374	13.61	46.0	1 DOF
SA-16-B	40,000	1035	11.46	96.7	1 DOF
CL-44	205,000	2075	16.07	142.3	1 DOF
Transall	98,600	1723	13.7	131.2	1 DOF
Ambassador	61,800	1200	10.42	114.8	1 DOF
Britannia	176,400	1205	10.52	114.2	1 DOF
Comet 1	110,200	2315	17.50	114.8	1 DOF
Comet 4	162,000	2120	18.45	114.8	1 DOF
Bristol	45,200	1487	13.78	107.9	1 DOF
Hermes 4, 4A	99,200	1408	12.46	112.8	1 DOF
Stratocruiser	160,000	1769	12.50	141.1	1 DOF
Superconstellation	137,500	1650	14.67	123.0	1 DOF
Viking	35,200	882	9.89	89.2	1 DOF
Viscount	64,500	963	10.22	94.2	1 DOF
707	316,000	2890	22.69	142.4	1 DOF

SECTION 2

During the past few years, advances have been made in the analysis of airplane behavior in rough air through the application of the theory of random processes and the techniques of generalized harmonic analysis (References 3 to 9). The application of these techniques is based upon the representation of atmospheric turbulence as a continuous random disturbance characterized by power-spectral-density (PSD) functions and certain probability distributions (Reference 2). The power spectrum of atmospheric turbulence shows the contribution of different frequencies of turbulent air flow to the mean square velocity of the turbulence. The total area under the curve is the mean square velocity (Reference 32). The power spectrum of the turbulence is then used along with the airplane response characteristics to determine the power spectra and other statistical characteristics of the airplane loads or motions in rough air. The application of this approach to the problem of calculating load and other histories for operational flight requires detailed information on the spectrum of turbulence in the atmosphere (Reference 2).

The Lo-Locat program is establishing a definition of atmospheric turbulence near the ground for use in aircraft design criteria. Twenty-mile segments of low-altitude turbulence have been found to be isotropic and homogeneous with statistically independent gust velocity components. Lo-Locat has shown that gust velocity spectra are closely represented by the Von Karman expressions (Reference 10). Members of the advising committee, on the basis of their own or related work, also recommended this expression.

The Von Karman expression (Reference 31), or the isotropic turbulence equation, is

$$\phi(\Omega) = \sigma_w^2 \cdot \frac{L}{\pi} \cdot \frac{1 + 8/3(1.339L\Omega)^2}{[1 + (1.339L\Omega)^2]^{11/6}} \quad (1)$$

where

- $\Omega = 2\pi/\lambda = \omega/V$ and
- λ = wave length ~ feet
- ω = frequency ~ radians/second
- V = aircraft velocity ~ feet/second
- L = scale length ~ feet
- σ_w = root-mean-square (RMS) of the gust velocity
- w = wind speed ~ feet/second

A graph of the model is shown in Figure 2-1.

For large Ω , $\phi(\Omega)$ decays with a slope of $-5/3$ which decay is supported by some data and by Kolmogoroff's similarity theory (Reference 33).

L , the scale of turbulence, is dependent on altitude, and has been defined variously by different investigators. Two of these are as follows: L can be considered proportional to the eddy size (Reference 2), and L defines the frequency at which the bend in the spectrum occurs (approximately $\Omega L = 1$). This latter definition can be found in many reports. For the processing of these data, the assumption that L equals altitude up to 2500 feet and is constant 2500 feet thereafter was made.

While the Von Karman spectrum has been assumed for this program, various other spectra have been developed by other investigators. Among these are J. L. Lumley and H. A. Panofsky (Reference 24), and H. L. Dryden (Reference 25). A more general description is given in Reference 12.

The spectral density varies with σ_w and L , that is, with the standard deviation or the root-mean-square of the gust velocity and the scale of turbulence. The square of σ_w in turn varies appreciably with weather conditions. The probability distribution of σ_w is not required for this program. A detailed development of this density function can be found in Reference 2.

The probabilities of encountering the various conditions of atmospheric turbulence can be derived from the data collected from the contributing NATO countries. These data have been obtained from airplane acceleration measurements in normal operations, and given in the form of the number of peak counts - or, in a few instances, level crossings - that exceed given values.

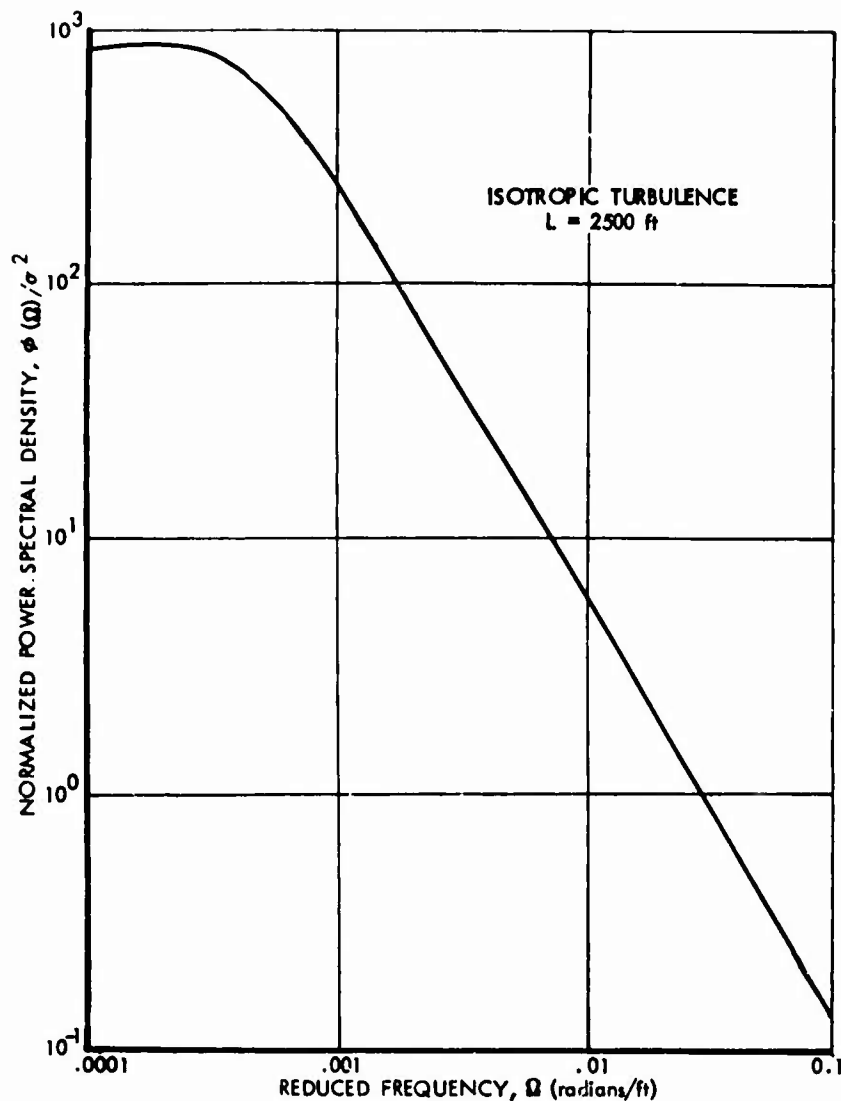


Figure 2-1. Gust Power Spectral Density Function

Fortunately, in the theory of random processes, relations have been derived (Reference 14) between level crossings which are related to peak counts (such as have been made for normal acceleration) and the associated power spectra. These relations apply to the case of a stationary Gaussian random process. A very brief summary of the statistical concepts involved is given, but more details can be found in any book on stochastic processes.

The power spectral density is the Fourier transform of the autocorrelation function, that is,

$$\phi(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R(\tau) e^{-i\omega\tau} d\tau$$

where ω is angular frequency in radians per second.

DERIVATION OF CONVERSION TECHNIQUES

In many recent studies of airplane behavior in rough air, atmospheric turbulence is generally considered a stationary Gaussian random process. The assumption that turbulence is a Gaussian random process appears warranted by the approximately Gaussian character of turbulent velocity fluctuations. However, for present purposes (in which the overall gust and load experiences of an airplane in operational flight are of concern), the process cannot be considered a simple stationary one, inasmuch as the turbulence characteristics of the atmosphere vary widely with weather conditions, particularly in regard to the intensity of the turbulence.

In order to account for the variations in atmospheric turbulence with weather conditions, it will be assumed that turbulence is only locally Gaussian and stationary; that is, its statistical characteristics are Gaussian and invariant in a given restricted region and for a short time, but vary, particularly in intensity, from time to time and place to place. This assumption implies that the region or time is small relative to the entire flight path or flight duration but large enough for statistical equilibrium. On this basis, the overall turbulence experienced by an airplane in given operations is taken to consist of the summation for appropriate exposure times to a series of elemental stationary Gaussian processes (Reference 2).

If the airplane response to turbulence is linear, as assumed in the present analysis, the response, such as the load history, to each elemental turbulence process, is likewise a Gaussian process, and the overall operational load history may in turn also be considered to consist of a summation of the loads for various elemental Gaussian turbulence disturbances. This scheme serves to yield a reasonable approximation of the actual airplane load history and, further, has the particular advantage for present purposes of permitting the use of relations between peak counts and spectra derived for the stationary Gaussian case in Reference 14. (Reference 2)

RELATIONS BETWEEN NUMBER OF PEAKS AND SPECTRA

The asymptotic relation between the average number of maximums per second exceeding a given value and the spectrum of a stationary Gaussian disturbance $y(t)$ has been derived in Reference 14 and is for large values of y given by

$$N(y) = \frac{1}{2\pi} \left\{ \frac{\int_0^{\infty} \omega^2 \phi(\omega) d\omega}{\int_0^{\infty} \phi(\omega) d\omega} \right\}^{1/2} e^{-y^2/2\sigma^2} \quad (2)$$

where

$N(y)$ = average number of maximums per second exceeding given values of y

ω = frequency ~ radians/second

$\phi(\omega)$ = power-spectral-density function of a random disturbance $y(t)$

$$\sigma^2 = \int_0^{\infty} \phi(\omega) d\omega \quad (2.1)$$

Equation (2) is the exact expression for the number of crossings per second with positive slope of given values of y , but is an approximate expression for the number of maximums above a given value of y .

Members of the advisory committee investigated the relationship between the number of peak-between-mean countings and the number of level crossings since practically all of the available data represent peak-between-mean readings. No useable relationship could be defined within the allowable time frame. Hence equation (2) is assumed to be an adequate approximation for the number of level crossings. The cumulative frequencies in the lower intervals of the gust velocity are therefore affected since they are underestimated. No general statement of this underestimation can be made since it is dependent upon the RMS (σ) value, the bandwidth, and the shape of the transfer function.

Given a function of time (or distance whose ordinate varies randomly in time), such as the example shown in Figure 2-2

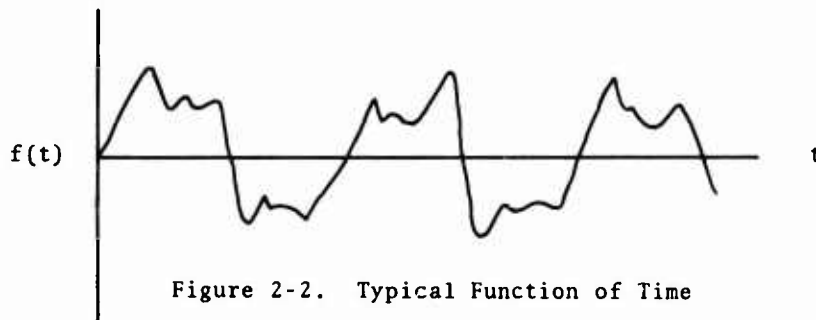


Figure 2-2. Typical Function of Time

Actually there exists an entire class of such functions $f_i(t)$; a value of i yields a representative of the family. A different value yields, of course, a completely different time history, the relation between the two being defined in a statistical sense.

Stationarity: The statistical properties of $f_i(t)$ do not vary with time, t ; that is, the statistical properties of the time history, such as its mean, its root-mean-square, its power spectral density, and so on, do not change with time.

Ergodicity: Averages over i are equivalent with averages over t .

Normality: Gaussian means the same. The distribution over i of $f_i(t)$ ordinates are governed by a normal distribution (single value of t and all joint distributions of t_1, t_2, \dots, t_k). With ergodicity, this distribution can be obtained from a single trace.

Autocorrelation: For stationary processes, the correlation between $f(t)$ values is a function only of the time lag, τ . If the process is ergodic, the autocorrelation $R(\tau)$ is

$$R(\tau) = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^{+T} f(t)f(t + \tau)dt$$

$$\sigma^2 = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^{+T} f^2(t)dt = R(0)$$

$$\text{mean of } f(t) = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^{+T} f(t)dt = \overline{f(t)}$$

Examination of equation (2) indicates that the number of peaks per second above given values depends upon σ^2 (the denominator), which is the area under the spectrum, and upon the second moment of the spectrum about the origin (the numerator).

From Reference 14, a second form of equation (2) is

$$N(y) = N_0 e^{-y^2/2\sigma^2} \quad (3)$$

which can also be obtained from equation (2) by letting $y = 0$. N_0 has the dimensions of a frequency and can be considered a characteristic frequency of the random disturbance $y(t)$.

CONVERSION OF ACCELERATION DATA TO ROOT-MEAN-SQUARE GUST VELOCITY

If the input (atmospheric turbulence) has the desired statistical properties and if the aircraft is a linear system, then the response of the aircraft (acceleration) has the same statistical properties. If it is assumed that the spectral shape of turbulence is invariant with weather conditions (as suggested by available measurements), and varies only in intensity or root-mean-square-velocity, the output spectrum, $\phi_n(\omega)$, for an acceleration, $n(t)$, for a given airplane, under given operating conditions (fixed speed, weight, altitude, etc.), is likewise invariant in shape. Then

$$n = \text{some constant} \cdot w = \bar{A} \cdot w \quad (4)$$

$$\sigma_n^2 = \bar{A}^2 \cdot \sigma_w^2 \quad (5)$$

where n is the vertical acceleration of the aircraft

w is the gust velocity.

Equation (3) may now be written as

$$N(w) = N_{0,w} e^{-w^2/2\sigma_w^2} \quad (6)$$

and for the response to w of n

$$N(n) = N_{0,n} e^{-n^2/2\sigma_n^2} \quad (6.1)$$

where $N_{0,w}$ is the characteristic frequency of the gust velocity

$N_{0,n}$ is the characteristic frequency of the aircraft response.

$$\frac{N(w)}{N(n)} = \frac{N_{0,w}}{N_{0,n}} \cdot \frac{e^{-w^2/2\alpha_w^2}}{e^{-n^2/2\alpha_n^2}}$$

Using equations (4) and (5), the exponential factors cancel resulting in

$$N(w) = \frac{N_{0,w}}{N_{0,n}} \cdot N(n) \quad (7)$$

Thus the number of positive slope crossings of any level of gust velocity, w , can be obtained from the number of positive slope crossings of the corresponding response, n , by multiplying the latter by the ratio of the characteristic frequency of the gust velocity to the characteristic frequency of the response of the aircraft. This method is valid even if the process is only locally stationary and Gaussian.

The root-mean-square gust acceleration in rough air is related to the turbulence spectrum and the airplane response characteristics by the following equation:

$$\alpha_n^2 = \int_0^{\infty} \phi_w(\omega) T^2(\omega) d\omega \quad (8)$$

$$= \int_0^{\infty} \phi_n(\omega) d\omega \quad (8.1)$$

where $\phi_w(\omega)$ is the power spectrum of vertical gust velocity

$\phi_n(\omega)$ is the power spectrum of airplane normal acceleration

$T(\omega)$ is the amplitude of airplane acceleration response to sinusoidal gusts of unit amplitude (transfer function). (Reference 2)

Equation (8.1) is the same as (2.1). Changing subscripts from n , acceleration, to w , gust velocity, yields

$$\alpha_w^2 = \int_0^{\infty} \phi_w(\omega) d\omega \quad (8.2)$$

Equation (8) is useful when the transfer function is known. When the transfer function is not known, the following simplification can be used.

As a preliminary effort in this direction, it will be assumed that:

- (1) The airplane is rigid.
- (2) The airplane is free to move vertically only (not pitch).
- (3) A spectrum of turbulence is assumed.

For the foregoing condition, a useful result obtained by Y. C. Fung (Reference 4) is that

$$\bar{z}^2 = \alpha_w^2 \frac{16V^2}{\bar{c}^2(1+K)^2} \cdot \frac{I(K,s)}{\pi} \quad (9)$$

where \bar{z}^2 = mean square acceleration

\bar{c} = mean aerodynamic chord

K = airplane mass parameter, $\frac{W}{g\rho S\bar{c}}$

s = ratio of the mean chord to the scale of turbulence, \bar{c}/L .

Since $K \gg 1$ in almost all cases of concern, and when m is substituted for 2π , equation (9) can be simplified to yield

$$\alpha_n = \frac{\sigma_w \rho V S m}{2W} \sqrt{\frac{I(K, s)}{\pi}} \tag{10}$$

and $\alpha_n = \bar{A} \alpha_w$ (11)

where $\bar{A} = \frac{\rho V S m}{2W} \sqrt{\frac{I(K, s)}{\pi}}$ (12)

and $\sqrt{\frac{I(K, s)}{\pi}}$ is an airplane gust-response factor. (Reference 2)

The derivation by Fung (Reference 4) of equation (9) was based on 2-dimensional strip theory, a Liepman approximation of the frequency response of the lift, a simplification of the frequency response of the airplane, and the Liepman gust spectrum. The influence of the gust spectrum is restricted to the evaluation of the gust response

factor $\sqrt{\frac{I(K, s)}{\pi}}$, commonly referred to as K_G . Thus, since the Von Karman spectrum is desired in the present work, a revised evaluation of K_G is needed from that used by Fung or Reference 2. Fortunately, such a presentation is made by Hoblit, et al., in Reference 13. These curves were used in the present program for K_G and are presented in Figure 2-3. A note should be made that the lift curve slope, m , in equations (10) and (12) is the three-dimensional slope for the wing only. Hoblit modified the wing lift slope by a factor of 1.15 in his derivation to account for the total airplane lift curve slope. The present work used actual airplane values where obtainable, or the one-dimensional NASA approximation for the wing airplane lift curve slope given by:

$$C_{L\alpha} = \frac{6A \cos \Lambda}{A + 2 \cos^2 \Lambda} \cdot \frac{A + 2 \cos \Lambda}{A \sqrt{1 - M^2 \cos^2 \Lambda + \cos \Lambda}}$$

- where A = wing aspect ratio
- Λ = wing sweep angle at 1/4 chord
- M = Mach number.

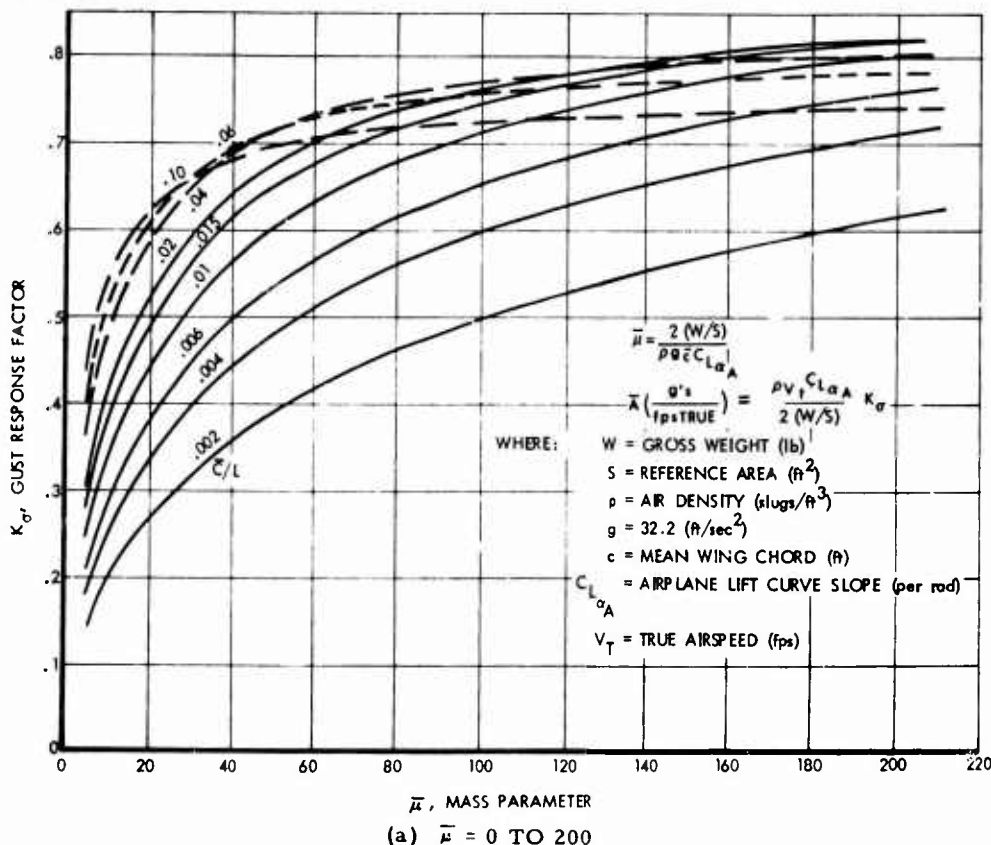


Figure 2-3. Gust Response Factor for Isotropic Turbulence Spectrum

Equation (11) is not restricted to the one-degree-of-freedom case and can be generalized by substituting equations (8) and (8.2) in equation (11) as follows:

$$\bar{A} = \sigma_n / \sigma_w$$

$$= \left\{ \frac{\int_0^{\infty} \phi(\omega) T^2(\omega) d\omega}{\int_0^{\infty} \phi(\omega) d\omega} \right\}^{1/2} \quad (13)$$

If Ω is used instead of ω , where $\Omega = \omega/V$, a more convenient form of the equation is obtained and one which agrees with the notation used to define the Von Karman spectrum at the beginning of this section. This new form gives

$$A = \left\{ \frac{\int_0^{\infty} \phi(\Omega) T^2(\Omega) d\Omega}{\int_0^{\infty} \phi(\Omega) d\Omega} \right\}^{1/2} \quad (14)$$

In a similar manner equation (2) can be expressed in terms of Ω for both the input spectrum and the response spectrum. The notation used is the same notation used in equations (6) and (7). Equation (2), evaluated at $y = 0$, for the input spectrum

$$N_w(0) = N_{0,w} = \frac{1}{2\pi} \left\{ \frac{\int_0^{\infty} \omega^2 \phi(\omega) d\omega}{\int_0^{\infty} \phi(\omega) d\omega} \right\}^{1/2}$$

$$= \frac{V}{2\pi} \left\{ \frac{\int_0^{\infty} \Omega^2 \phi(\Omega) d\Omega}{\int_0^{\infty} \phi(\Omega) d\Omega} \right\}^{1/2} \quad (15)$$

The response spectrum $\phi_n(\omega)$ can be expressed in terms of the input spectrum from equation (8) is

$$\phi_n(\omega) = T^2(\omega) \phi(\omega)$$

Then substituting $\Omega = \omega/V$ would yield

$$N_n(0) = N_{0,n} = \frac{V}{2\pi} \left\{ \frac{\int_0^{\infty} \Omega^2 \phi(\Omega) T^2(\Omega) d\Omega}{\int_0^{\infty} \phi(\Omega) T^2(\Omega) d\Omega} \right\}^{1/2} \quad (16)$$

where $\phi(\Omega)$ is the Von Karman spectrum

and $V =$ airspeed ~ feet/second

$$\Omega = 2\pi\lambda = \omega/V$$

$\omega =$ frequency ~ radians/second.

For the graphs presented in Section 3, true airspeed is used.

The methods used to process the acceleration data were based on the one-degree-of-freedom \bar{A} defined in equation (12) or the A generated from equation (13) if the transfer function was known.

The integration was done over a range of 0 to b for both spectra where b was defined by the bandwidth used in deriving the transfer function. This same limit was used to derive the characteristic frequencies defined in equations (15) and (16). For the characteristic frequency the integral is divergent as b increases without bound. Hence the characteristic frequency of the response function is highly sensitive to this chosen upper limit, which must be defined by the response characteristics of the aircraft.

The characteristic frequency of the response function is 1 for the one-degree-of-freedom case.

The difference between the one-degree-of-freedom \bar{A} and the multi-degree-of-freedom \bar{A} is illustrated in Figure 2-4 where \bar{A} values for various conditions of airspeed, altitude, and weight are generated for both eight and one degrees of freedom for one aircraft.

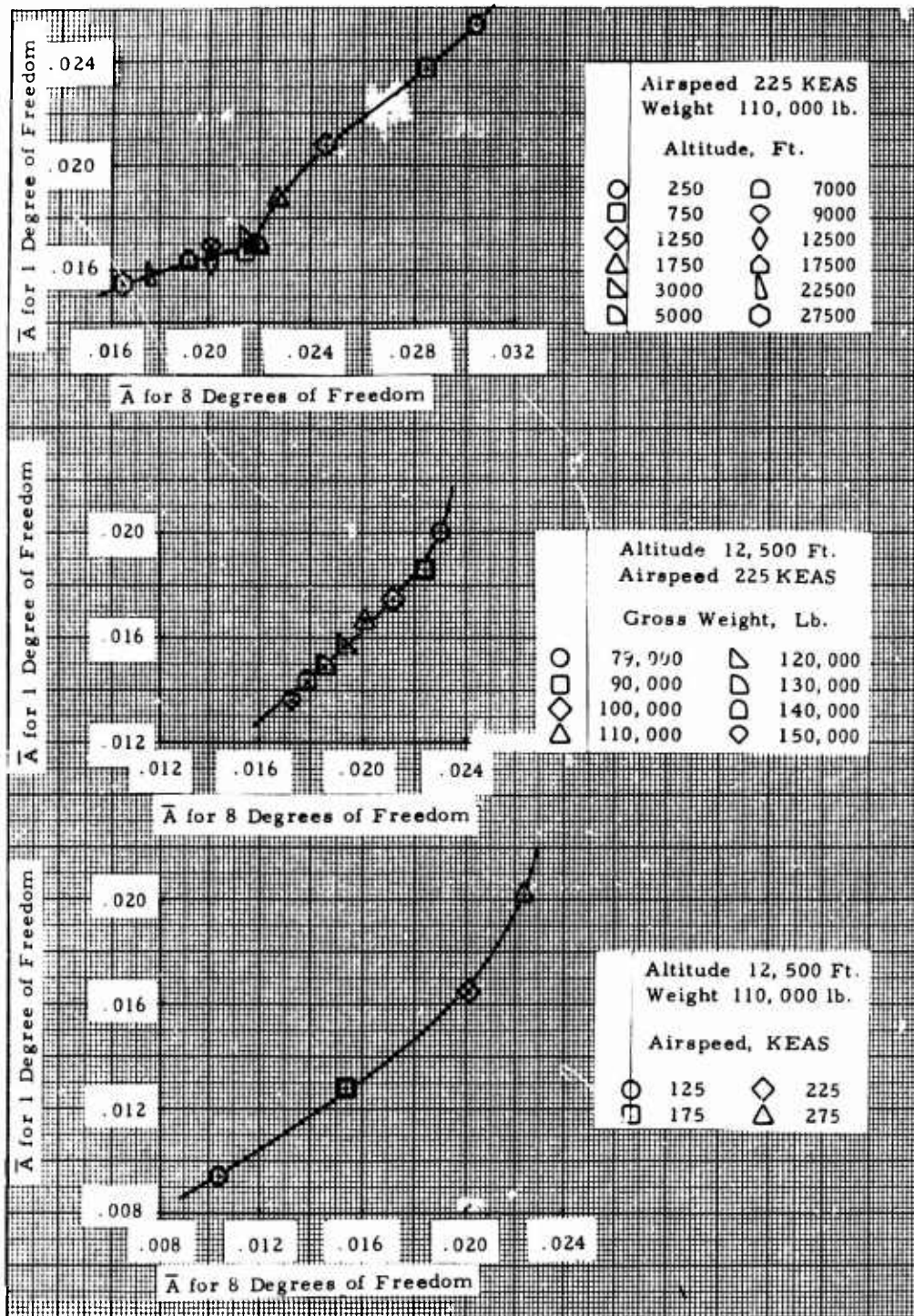


Figure 2-4. Comparison of \bar{A} Values Derived from 1 DOF and 8 DOF for C-130 Aircraft

SUMMARY OF THE PROCESSING OF THE ACCELERATION DATA

The original data are available as a cumulative distribution of the number of occurrences of Δn , the vertical acceleration minus lg , for sets of constant weight, altitude, and airspeed. Each of the last three parameters defines an interval, with the constant value being the lower limit of the interval. The Δn values also represent intervals.

Each Δn is divided by \bar{A} where \bar{A} is derived for the averages of each set of weight, altitude, and airspeed for each aircraft from

$$\bar{A} = \frac{\rho V S m}{2W} \cdot K_{\sigma}$$

or

$$\bar{A} = \left\{ \frac{\int_0^b \phi(\Omega) T^2(\Omega) d\Omega}{\int_0^b \phi(\Omega) d\Omega} \right\}^{1/2}$$

and $N_{0,n}$ from

$$N_{0,n} = \frac{V}{2\pi} \left\{ \frac{\int_0^b \Omega^2 \phi(\Omega) T^2(\Omega) d\Omega}{\int_0^b T^2(\Omega) \phi(\Omega) d\Omega} \right\}^{1/2}$$

and $N_{0,w}$ from

$$N_{0,w} = 1 \text{ for one degree of freedom}$$

$$N_{0,w} = \frac{V}{2\pi} \left\{ \frac{\int_0^b \Omega^2 \phi(\Omega) d(\Omega)}{\int_0^b \phi(\Omega) d\Omega} \right\}^{1/2}$$

where

$$\phi(\Omega) = \sigma_w^2 \frac{L}{\pi} \frac{1 + 8/3(1.339L\Omega)^2}{[1 + (1.339L\Omega)^2]^{1.5/6}}$$

and

\bar{A} = aircraft response

ρ = density

V = true airspeed ~ feet/second

S = wing area ~ feet²

m = slope of the lift curve per radian

W = weight of aircraft ~ pounds

K_{σ} = gust alleviation factor based on the Von Karman spectrum

b = cut-off frequency

Ω = $2\pi/\lambda = \omega/V$

$T(\Omega)$ = transfer function, amplitude of aircraft acceleration response to unit amplitude sinusoidal gusts

$N_{0,n}$ = characteristic frequency of the aircraft response per second. N_0 is used on the plots in Section 3.

$N_{0,w}$ = characteristic frequency of the Von Karman spectrum per second. N_0^1 is used on the plots in Section 3.

$\phi(\Omega)$ = Von Karman spectrum

ω = frequency ~ radians/second

λ = wave length

L = scale of turbulence L = h for $h \leq 2500'$
 L = 2500 for $h > 2500$
 h = altitude ~ feet.

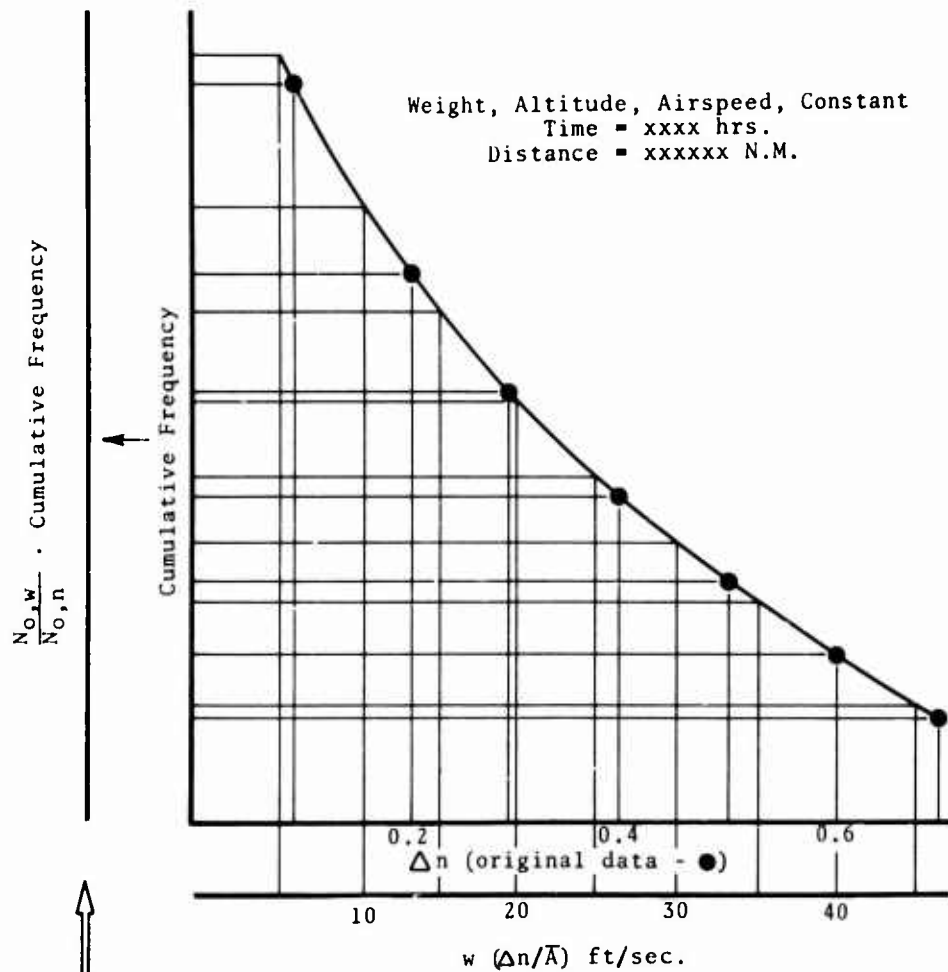
Since $\Delta n/\bar{A}$ is normally a decimal, new frequencies were derived corresponding to $\Delta n/\bar{A}$ at 5 feet/second intervals (or 2 meters/second).

These new frequencies were multiplied by $N_{0,w}/N_{0,n}$ (or $\frac{N_0'}{N_0}$).

These resultant frequencies are divided by the number of nautical miles the aircraft traveled for this set of data. This division is made just prior to printing the data, since the data on tape does not reflect it.

The graphic details of the transposition from acceleration frequencies to gust frequencies is shown in Figure 2-5.

Additional references that either expand on the derivations covered in Section 2 or discuss the applications of power spectral density techniques can be found in References 26 through 33.



These modified frequencies divided by total miles after the data is combined.

Figure 2-5. Graphical Representation of the Processing

SECTION 3

PRESENTATION OF THE DATAExtreme Values

Although no extreme values are listed in the summary report, one plot, taken from Dr. Buxbaum's paper (Reference 18) and derived by using only extreme values from C-130 data, is presented as Figure 3-1 in this section. This is inserted to show what information can be gained by using relatively little data. Extreme values of gust velocities encountered once per flight or flight segment by aircraft flying under different conditions, can be used to calculate the possible scatter of the cumulative frequency distributions. These same values are useful in predicting the occurrence of rare events such as upsets. The brevity in the treatment of this method results only from lack of time and funds and in no way results from lack of interest. References 16 and 17 treat the methods in detail and their reading is highly recommended. Since the extreme values are written on one tape, a listing of the set desired can be made easily from that tape.

Plots

Plots of vertical gust velocity are presented in graphical form at the end of this report. In general they represent frequency of occurrence per nautical mile versus gust velocity plotted for each altitude by season. For each set of data the total hours are given for that set, along with the number of nautical miles of data recorded for each subset of data. For example, for the C-130 data recorded in Southeast Asia operations, 195 hours of data were recorded in the altitude band of sea level to 500 feet. The number of miles recorded is separated by season as follows:

Winter	8195 nautical miles
Spring	4882 " "
Summer	5234 " "
Autumn	9040 " "

Where both positive and negative gust velocities are plotted, the original data identified the accelerations as positive and negative. Where only positive gust velocities are presented, the original data combined the positive and negative accelerations. However, during processing of the data into gust velocities, the frequencies were halved.

Where the frequencies are multiplied by N_0'/N_0 , transfer functions or A and N_0 values were available from the aircraft manufacturer and were used.

Where the frequencies are unweighted, a one-degree-of-freedom \bar{A} was used, and the recorded frequencies are unchanged.

If the original data were not identified by season, the gust velocities are presented only by altitude bands.

Where two seasons determined the same curve, only one curve is drawn and the legend modified to indicate that this occurred. Obvious differences in the data are represented as distinct curves, but as single curves when the data overlap.

The B-58 data are represented in the plots by only two altitudes, although data are available for all altitudes to 40,000 feet. Transfer functions are available only for the two altitudes represented. No attempt was made to extrapolate these data to higher altitudes.

The C-130 data are represented by three sets of data which resulted from earlier decisions. Initially a decision was made not to change any of the initial ranges of airspeed or altitude, and to preserve all of the coincident values of other parameters. Hence the C-130 data recorded from flights flown primarily in the United States could not be combined with Southeast Asia data since the altitude ranges were different. The C-130 data from Southeast Asia could not be combined with those from World-Wide flights because the elevator and flap positions were recorded on the aircraft in one area but not on those in the other.

The T-38 and F-4 data are not presented since the threshold of 0.5g in the original data is too great to yield any but the largest values of gust velocity.

C-130

Weight in lbs	Symbol	Sample Size N	Log. Mean μ_z	Log. Std. Dev. σ_z
85.000-95.000	————	58	0.378	± 0.167
95.000-105.000	- - - - -	176	0.330	± 0.188
105.000-115.000	- · - · -	198	0.291	± 0.189
115.000-125.000	- · · - -	138	0.251	± 0.185
125.000-135.000	————	75	0.248	± 0.188
135.000	- - - - -	87	0.223	± 0.328

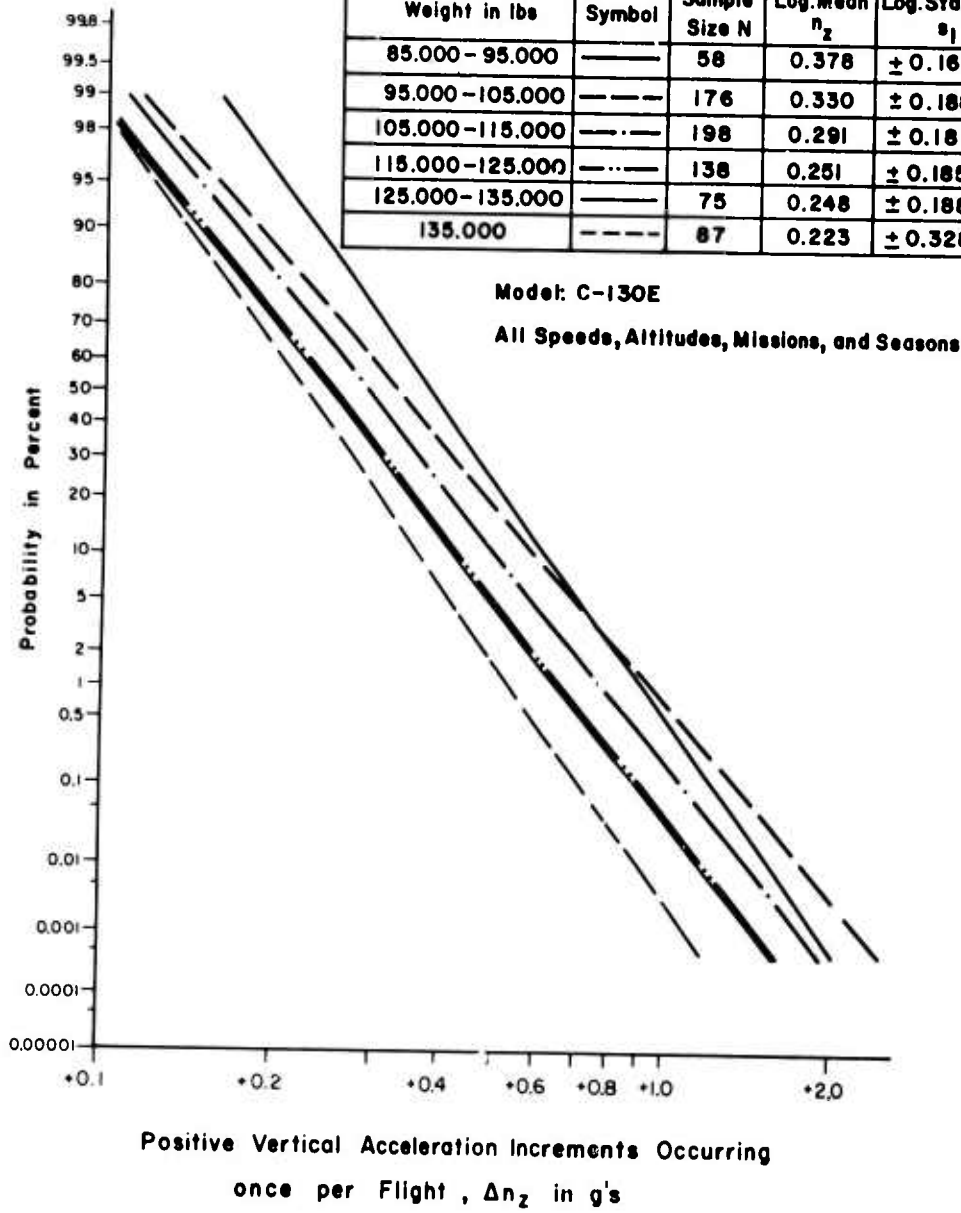
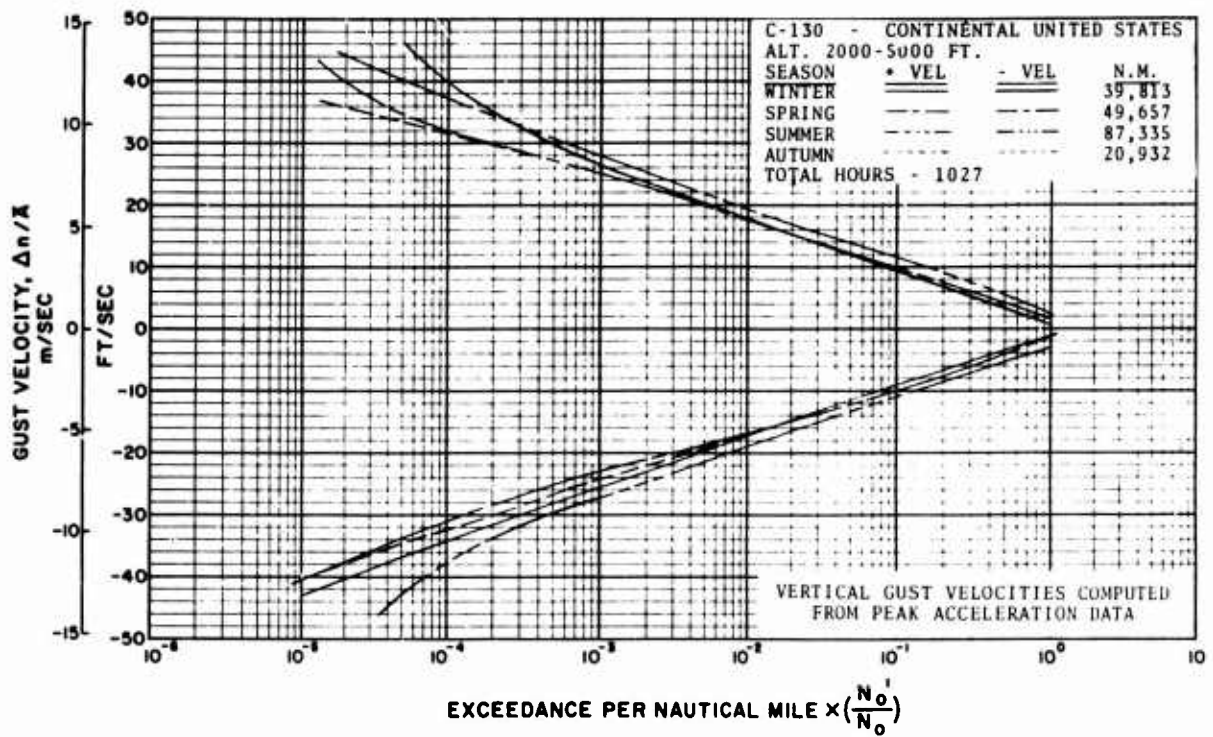
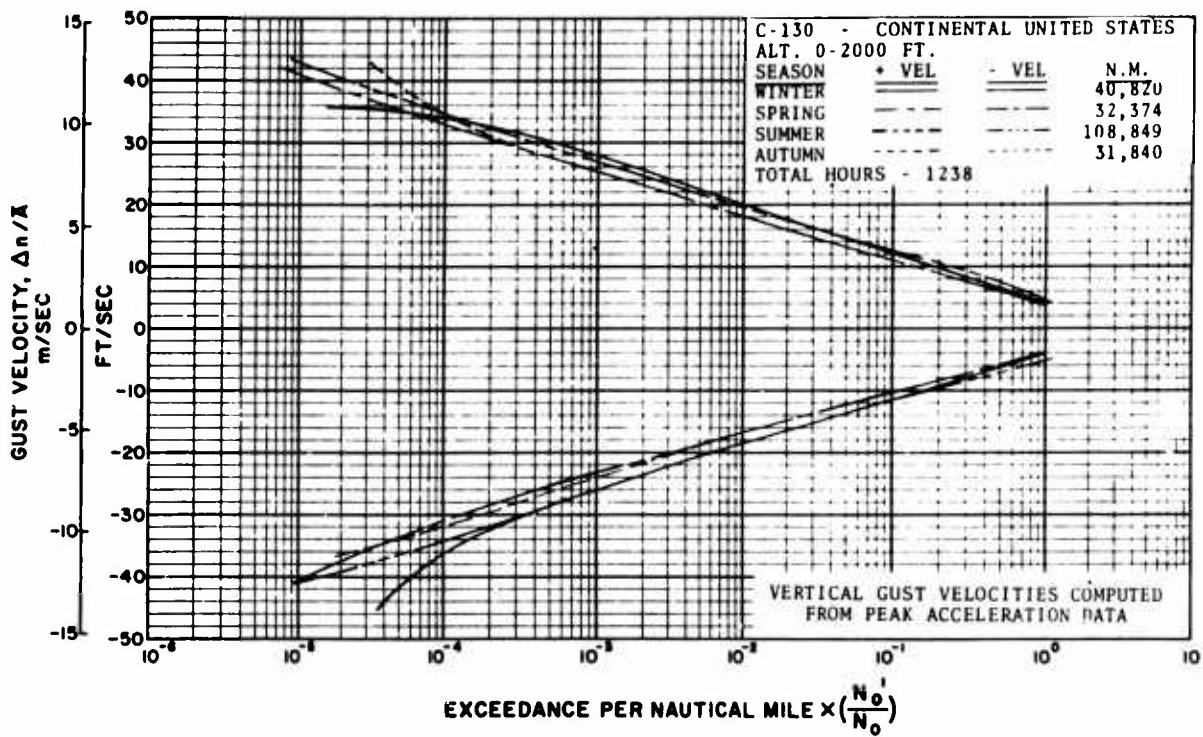
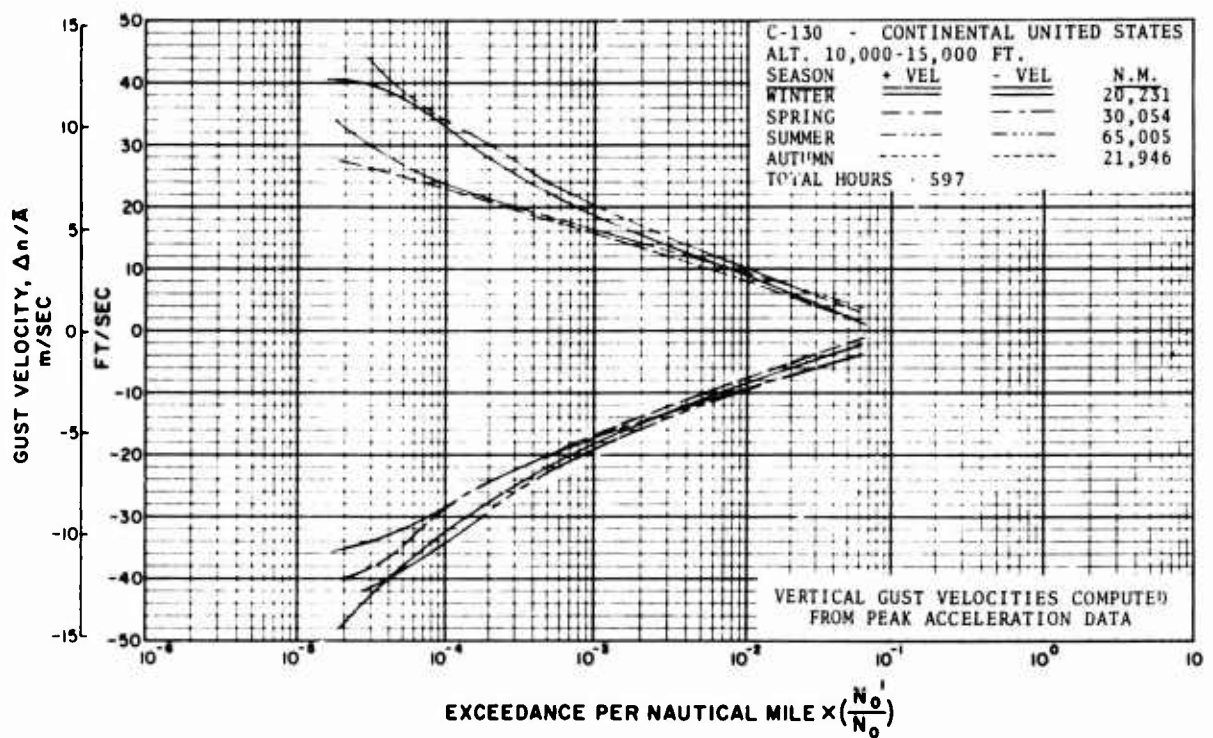
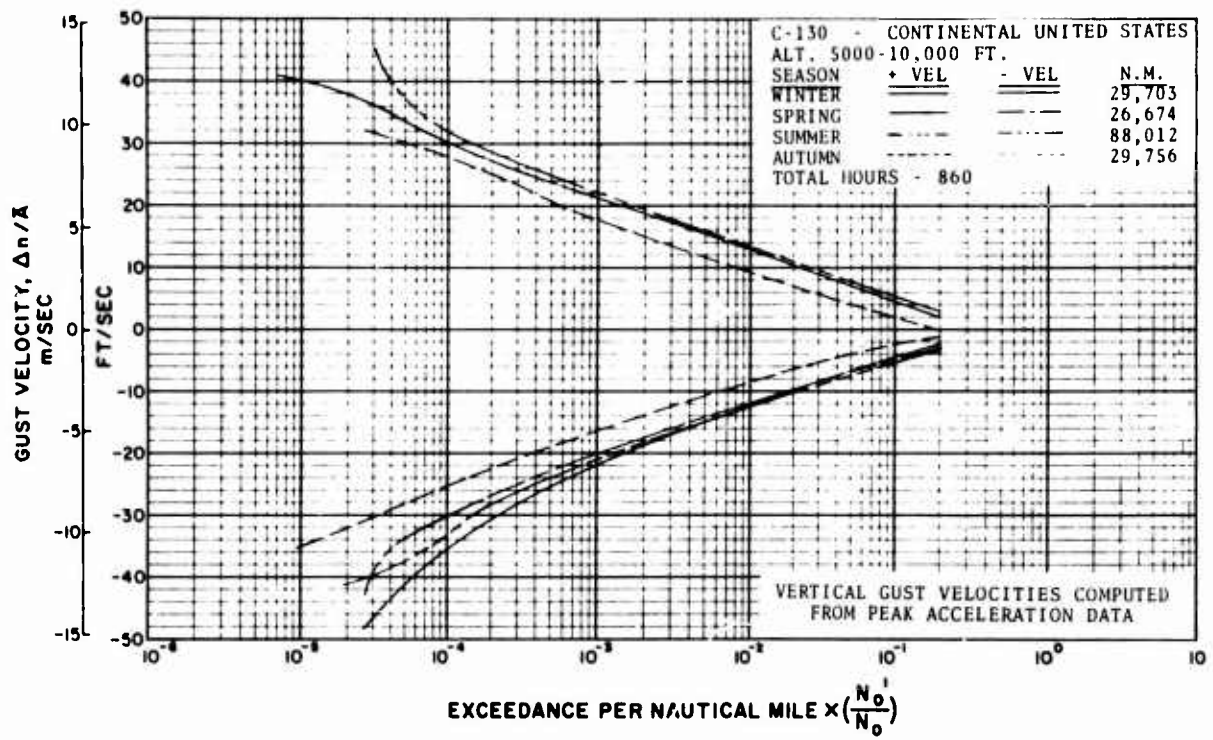
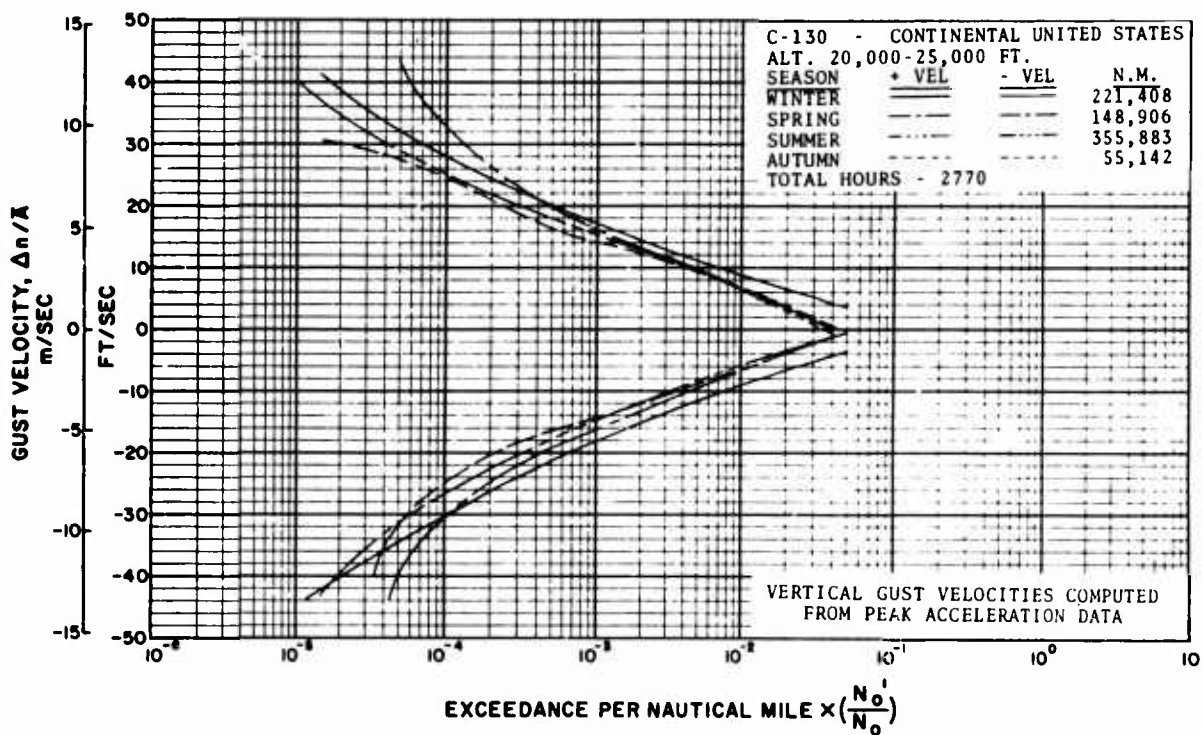
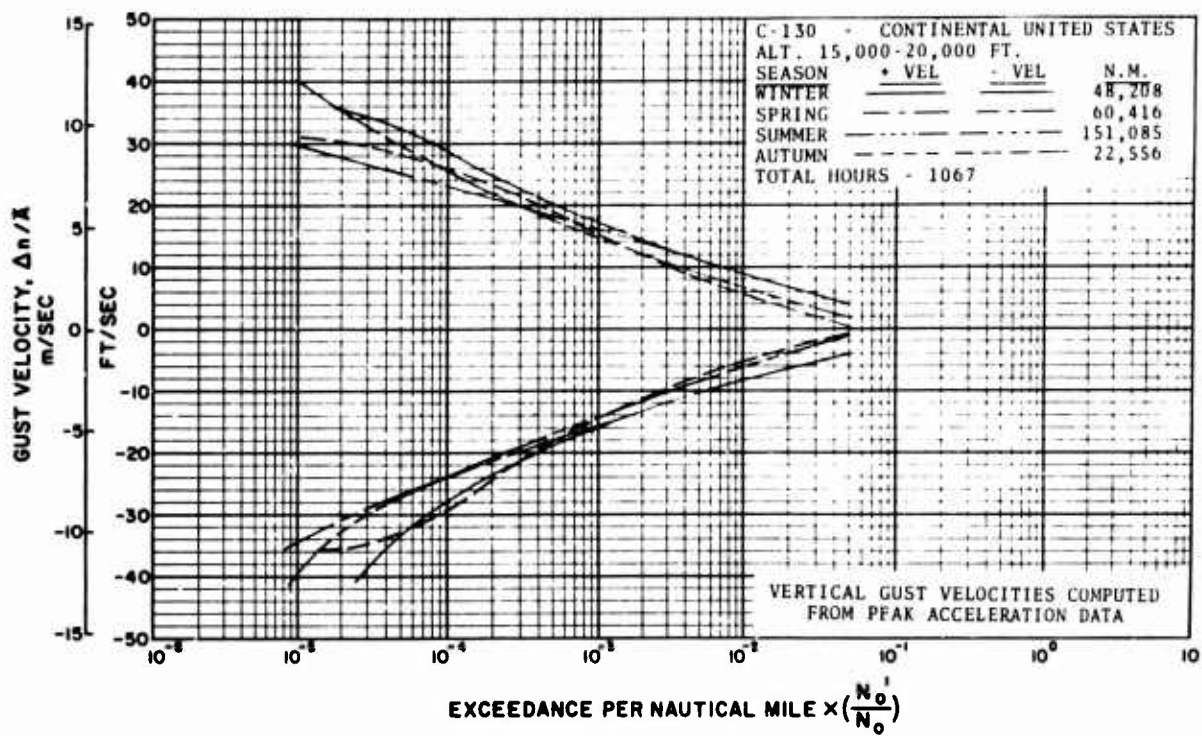
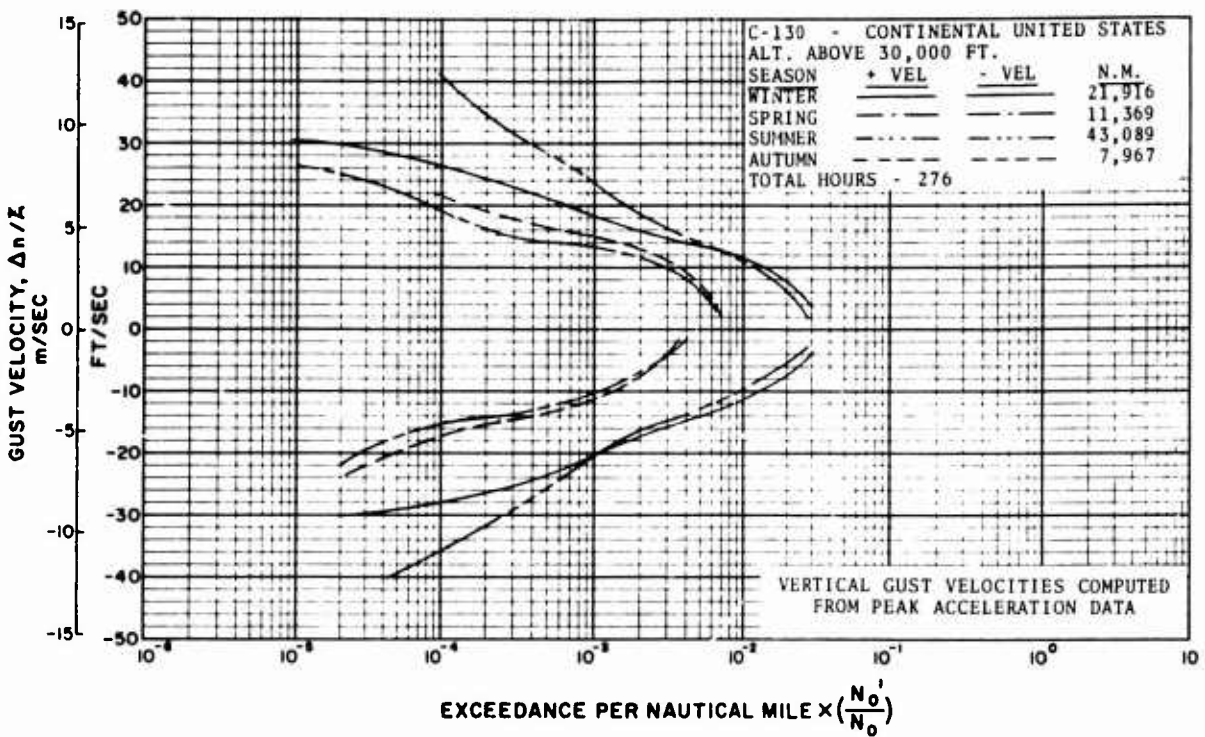
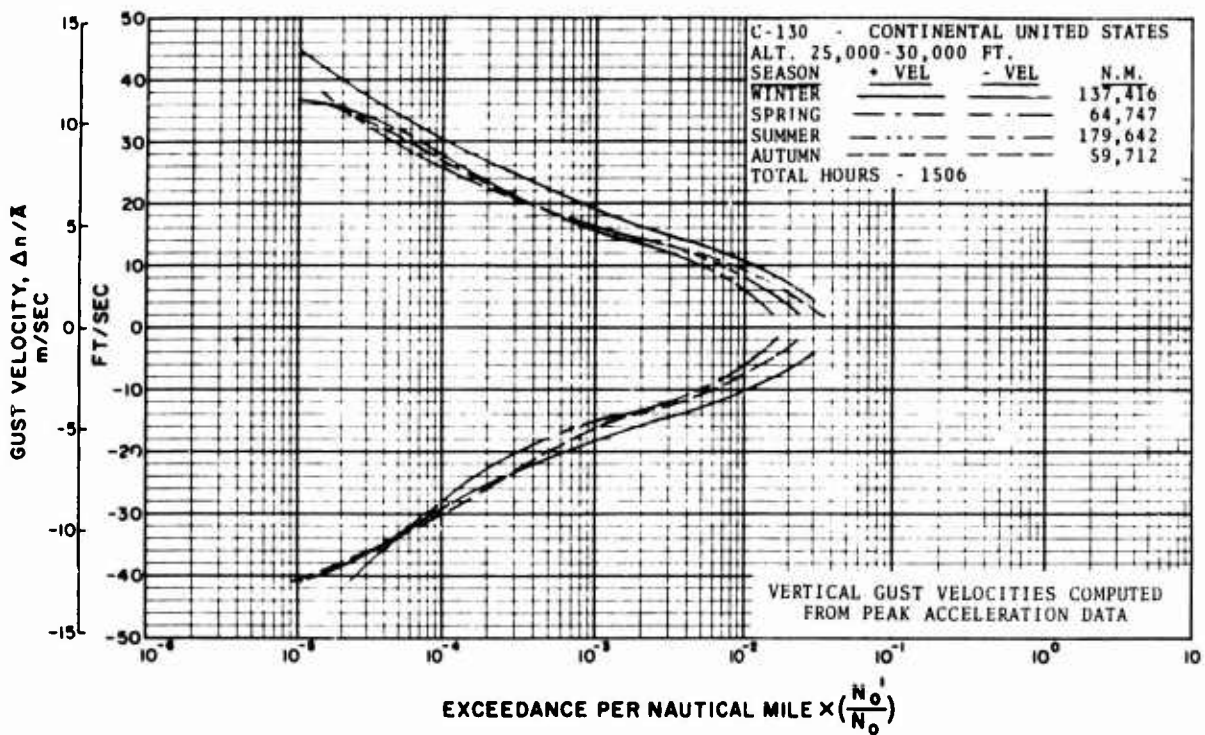


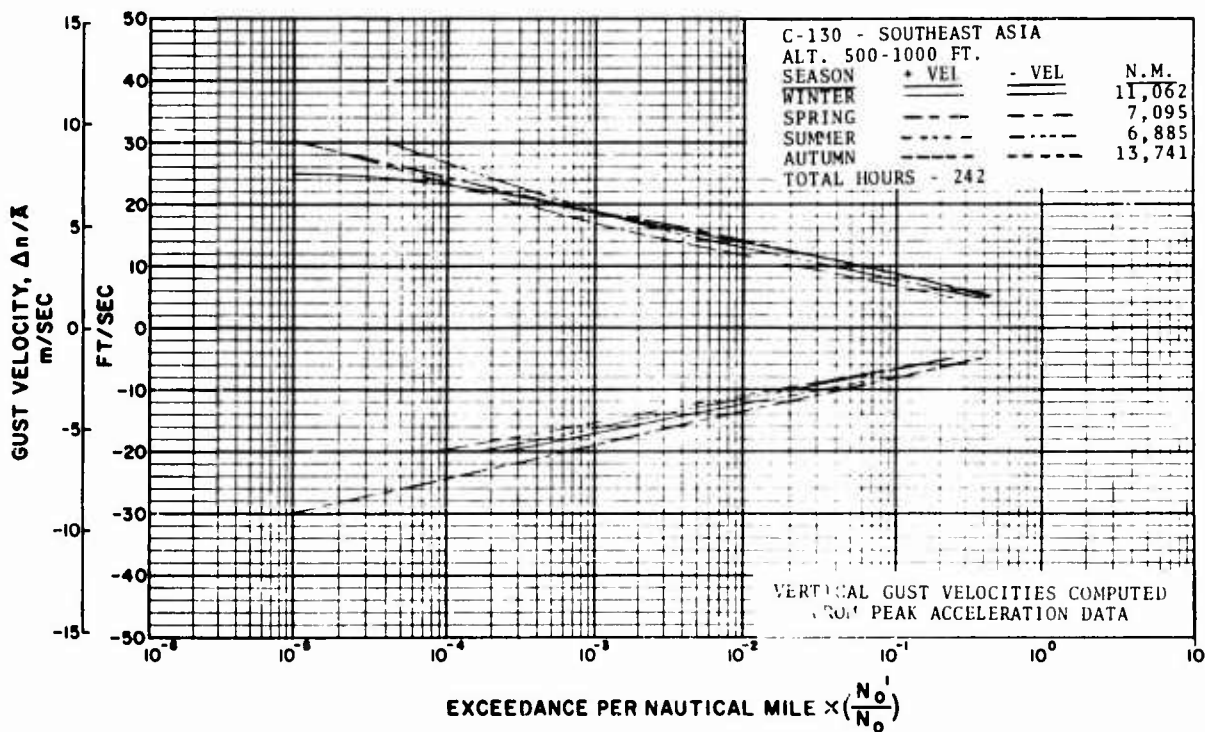
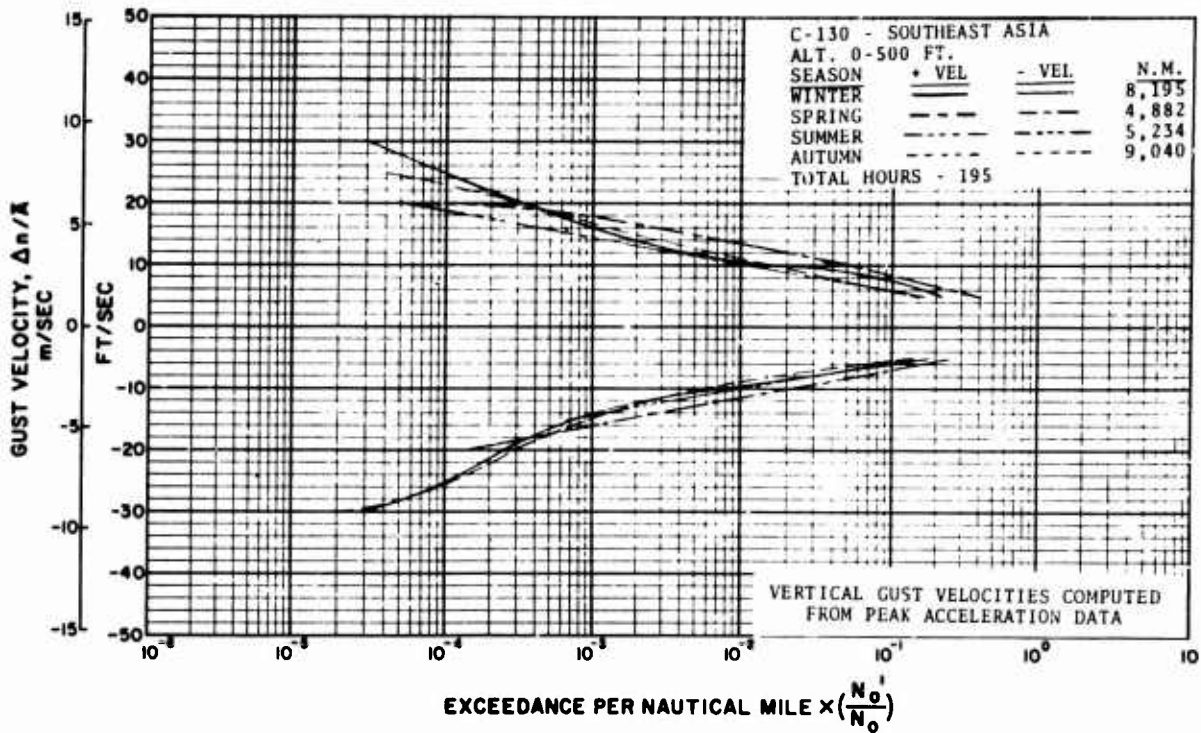
Figure 3-1. Extreme Value Distribution (Log Normal): Effect of Weights

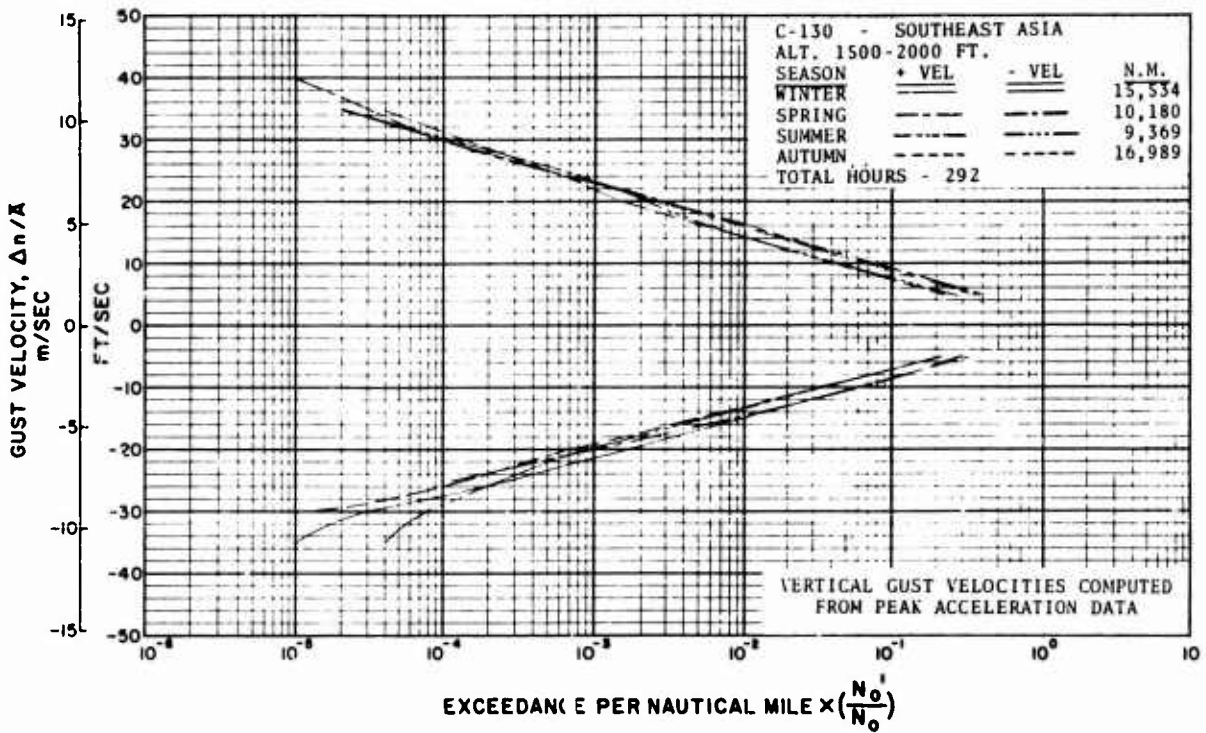
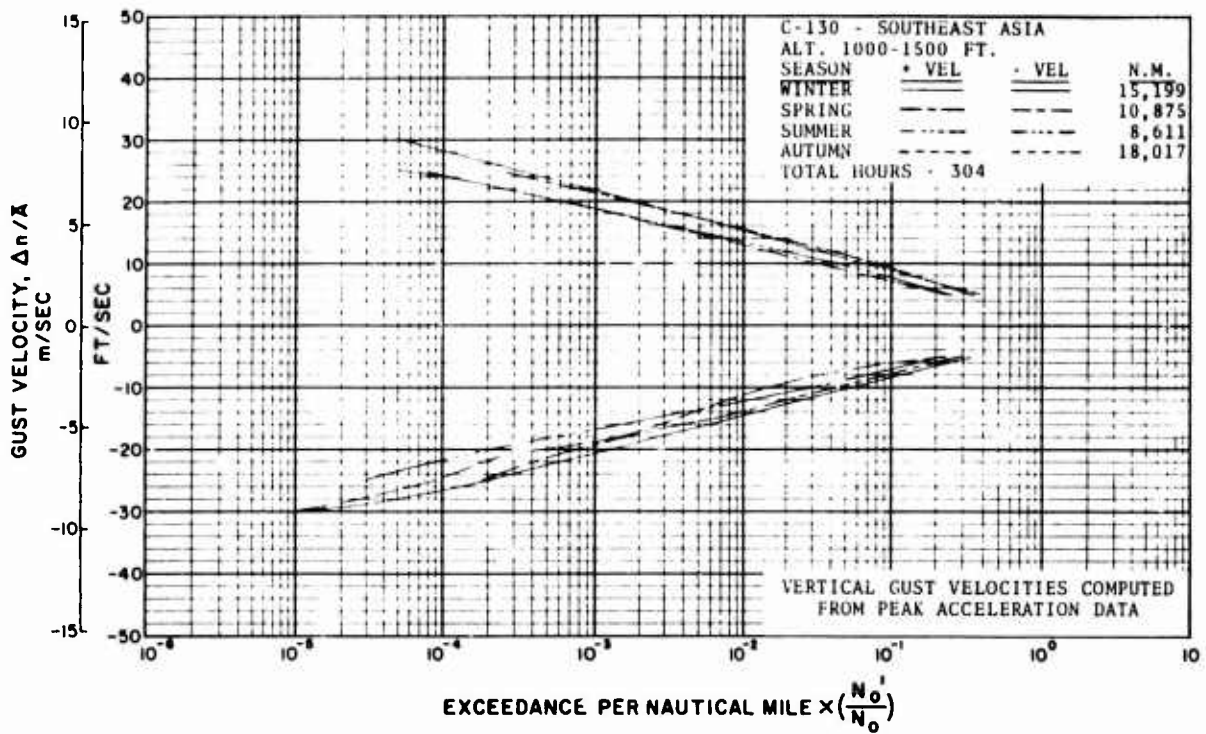


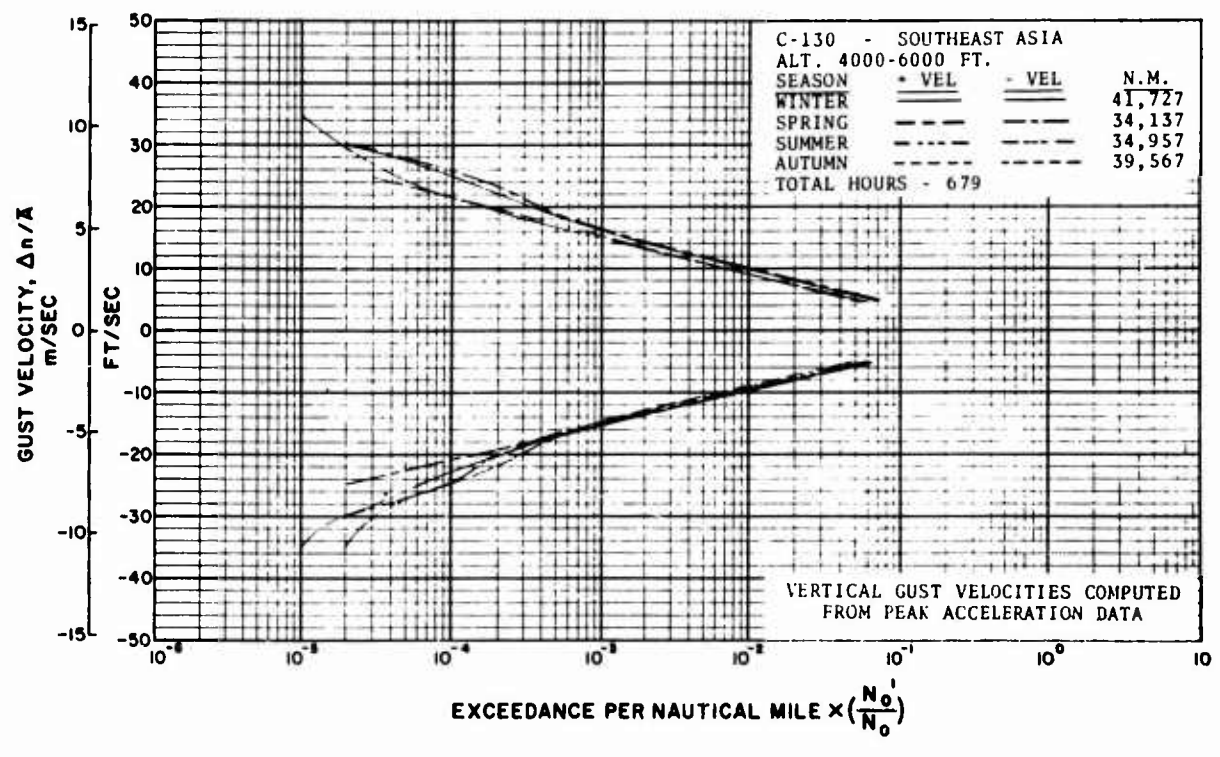
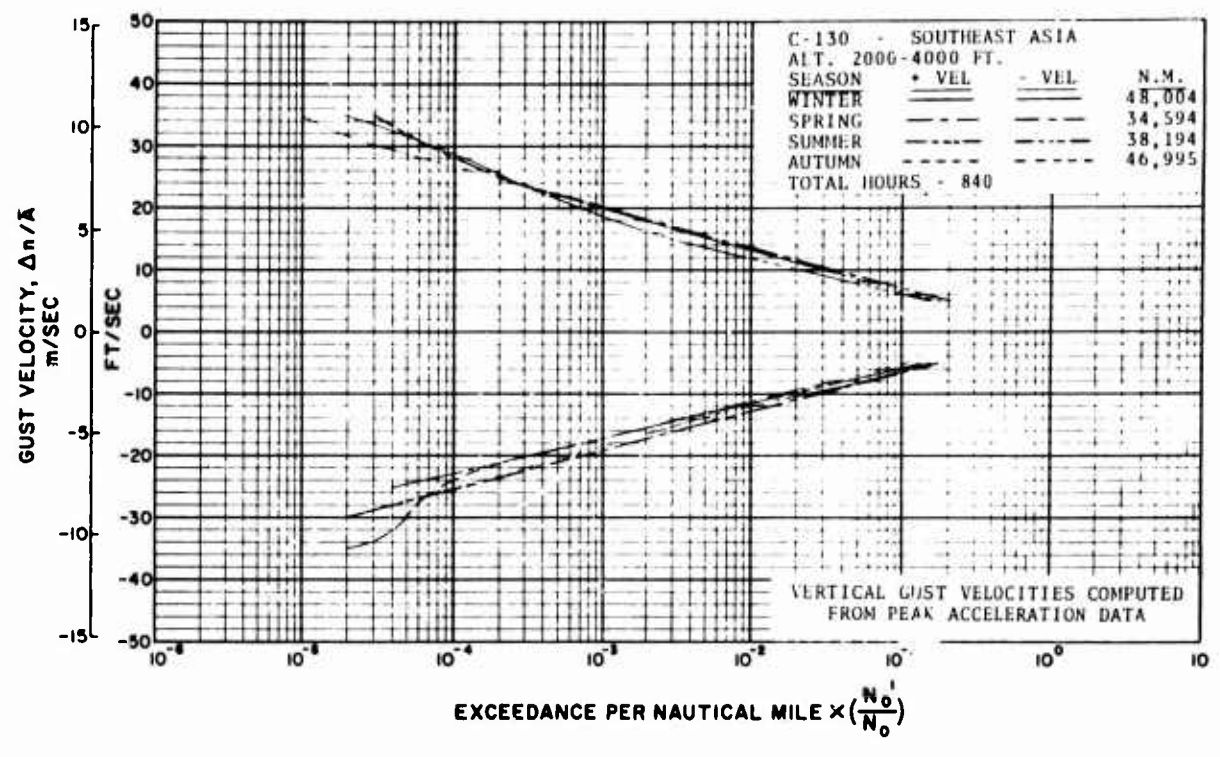


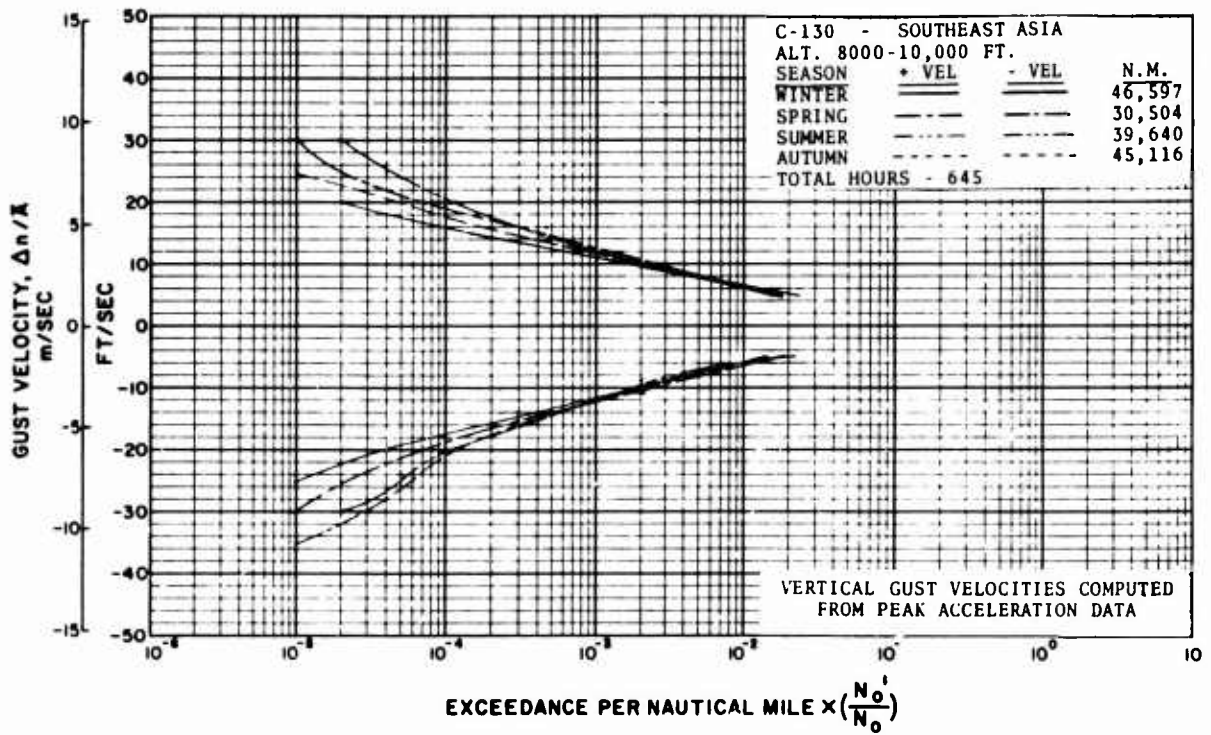
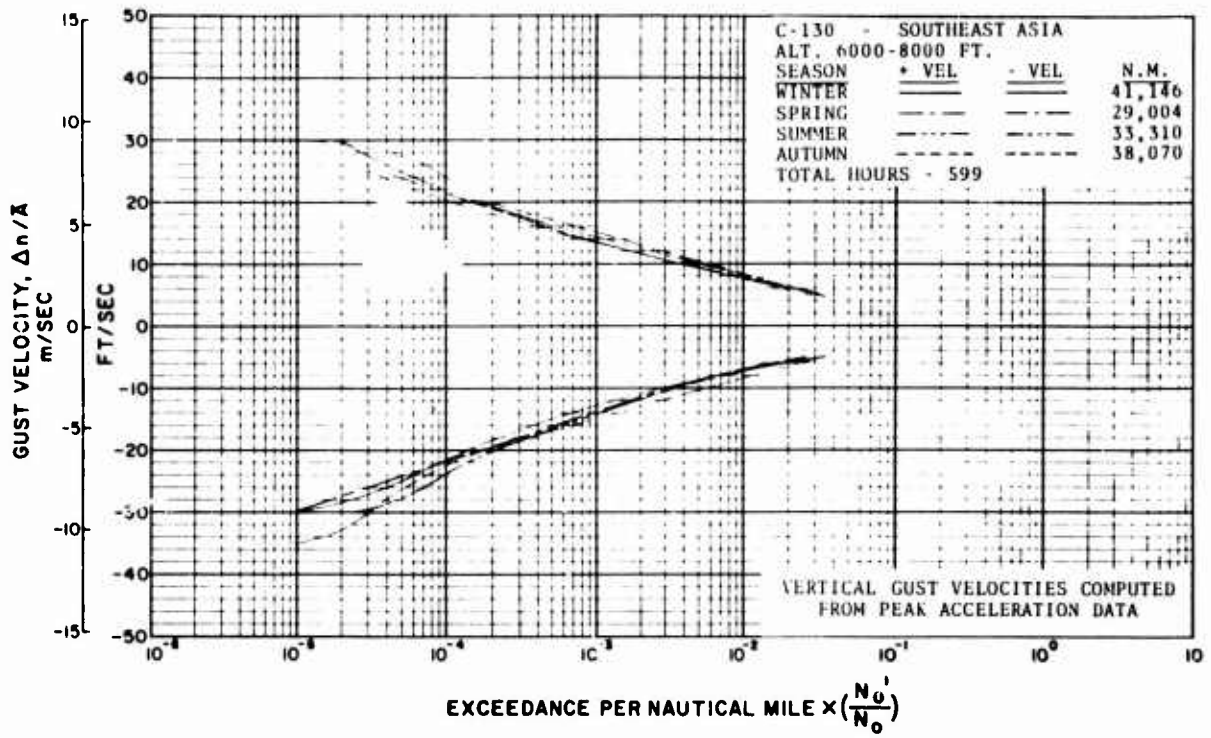


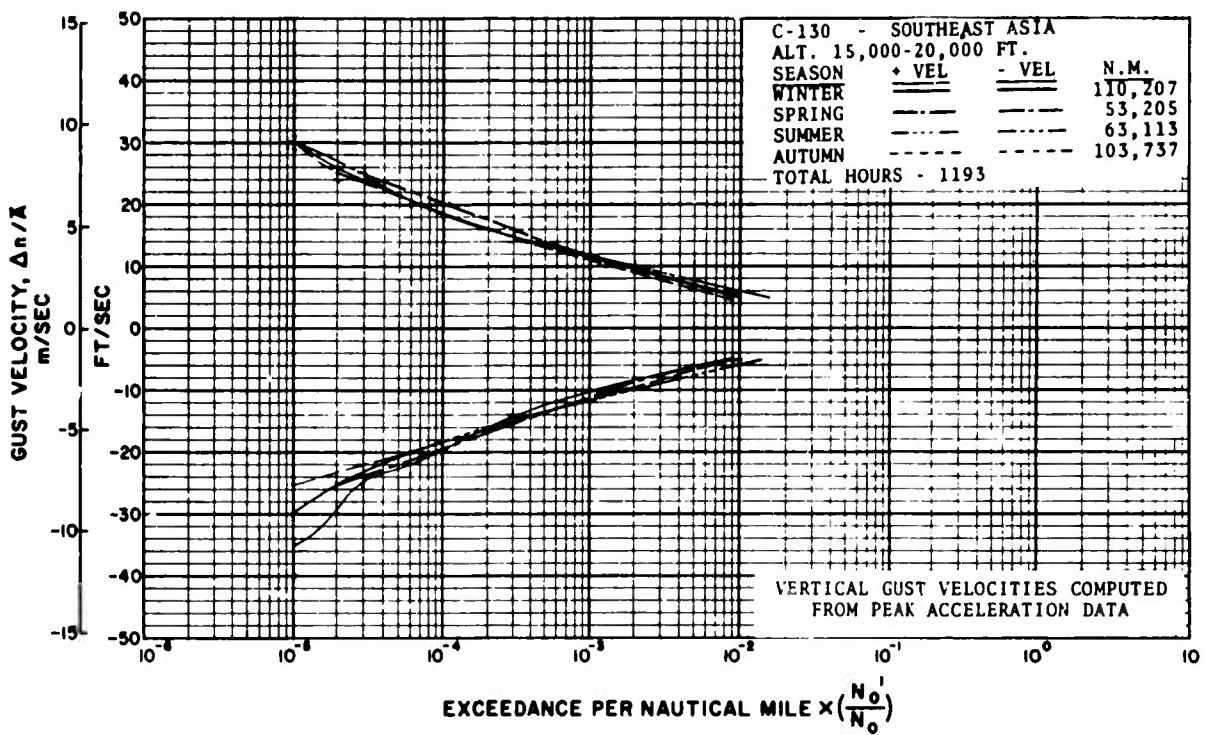
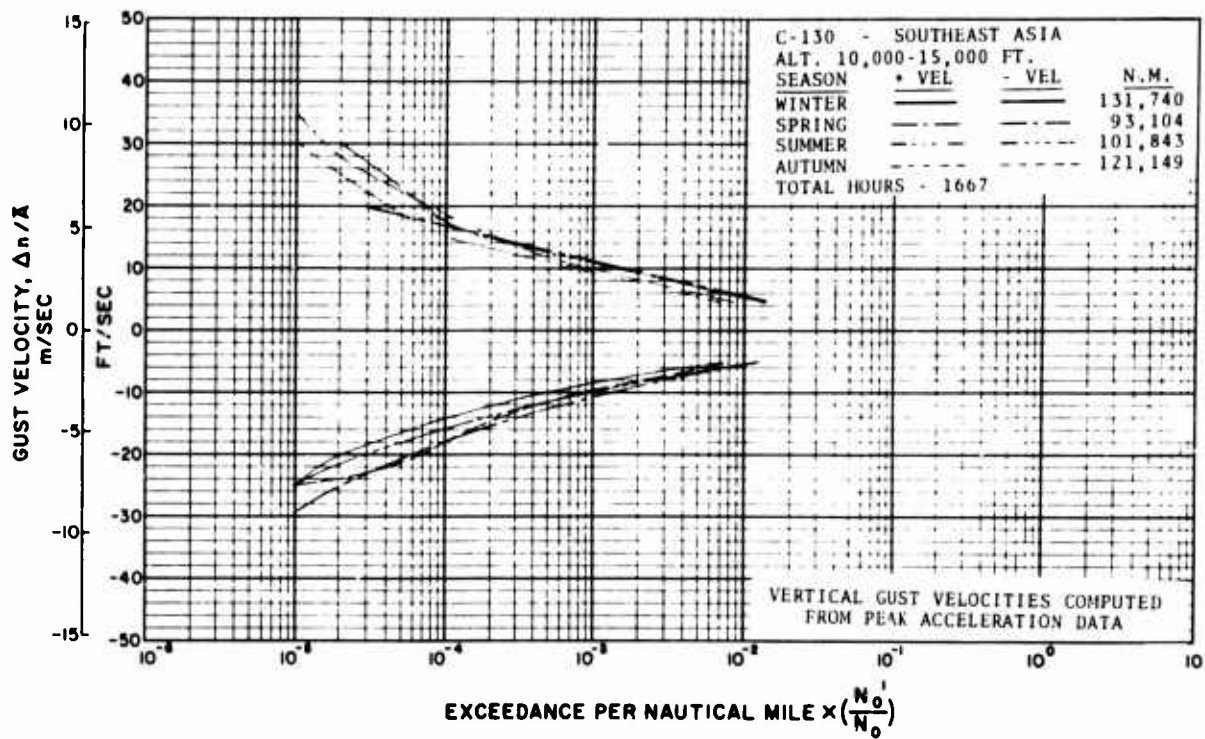


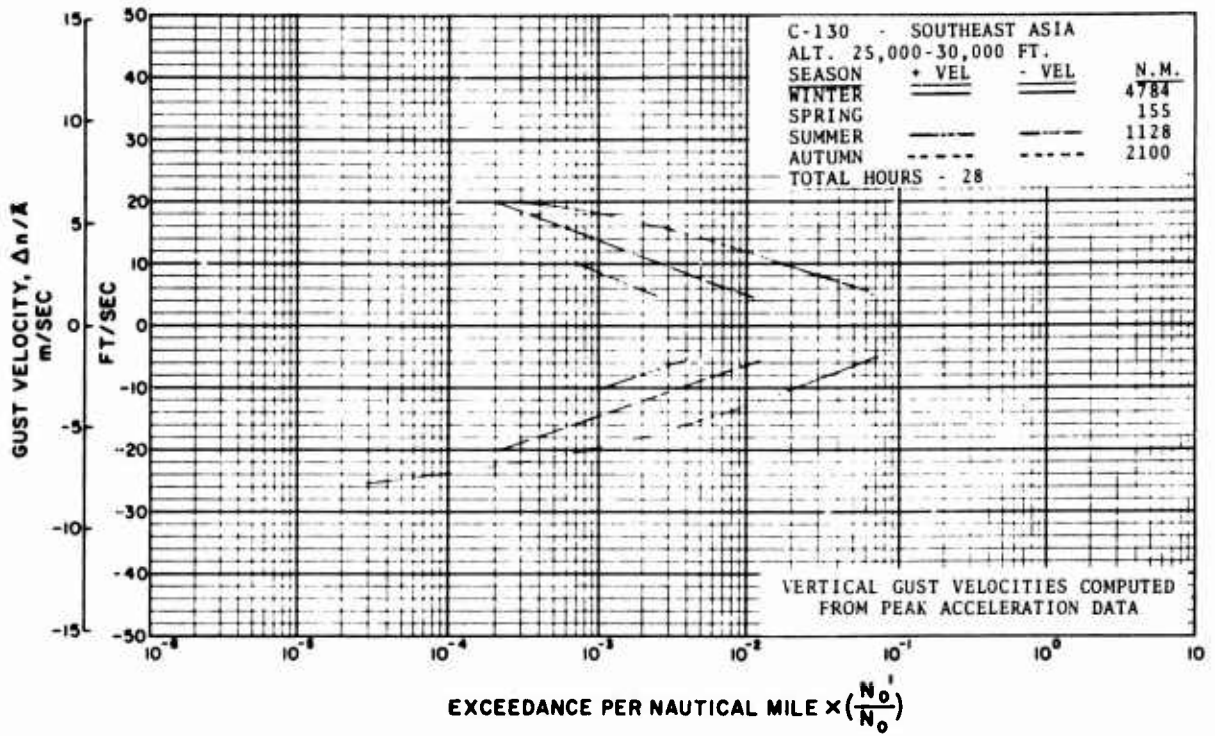
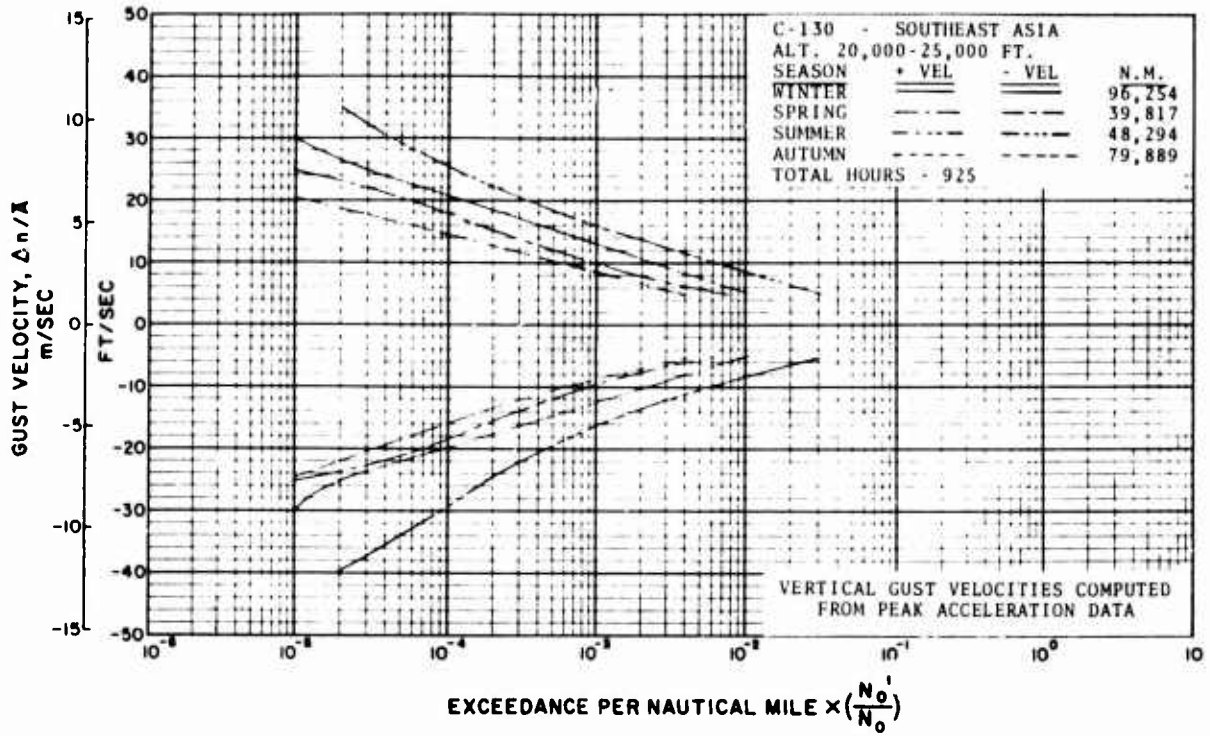


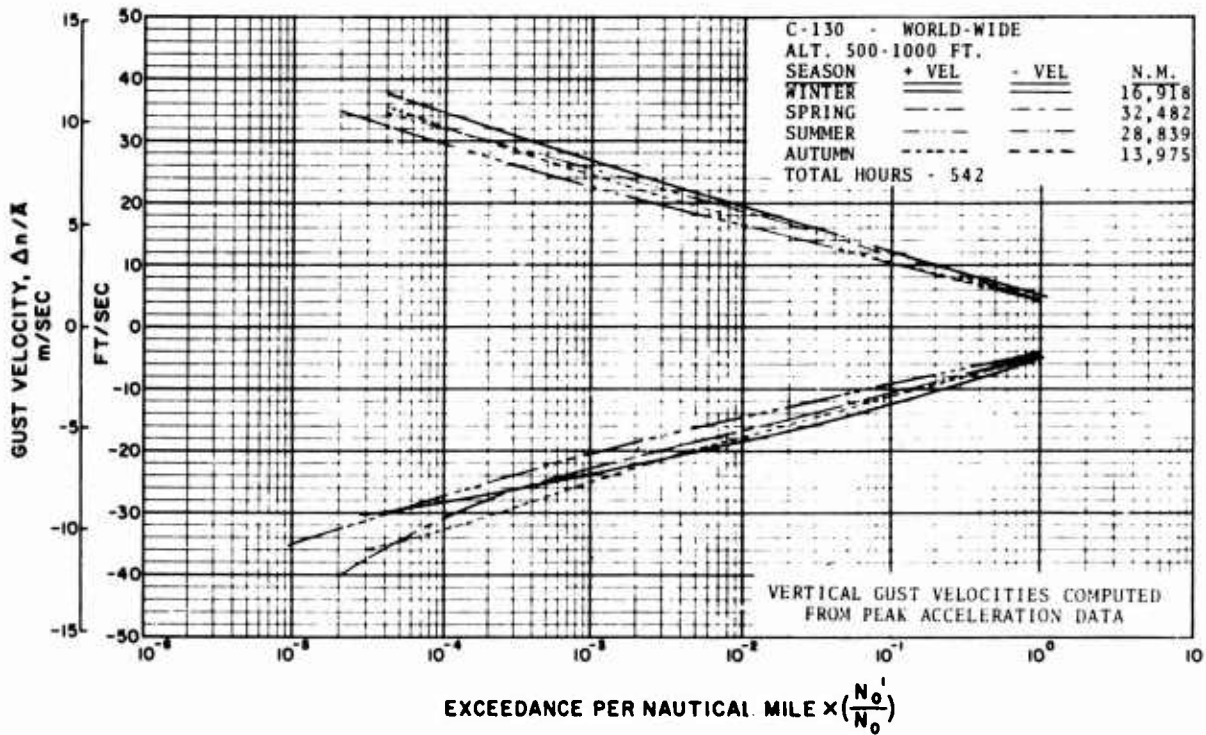
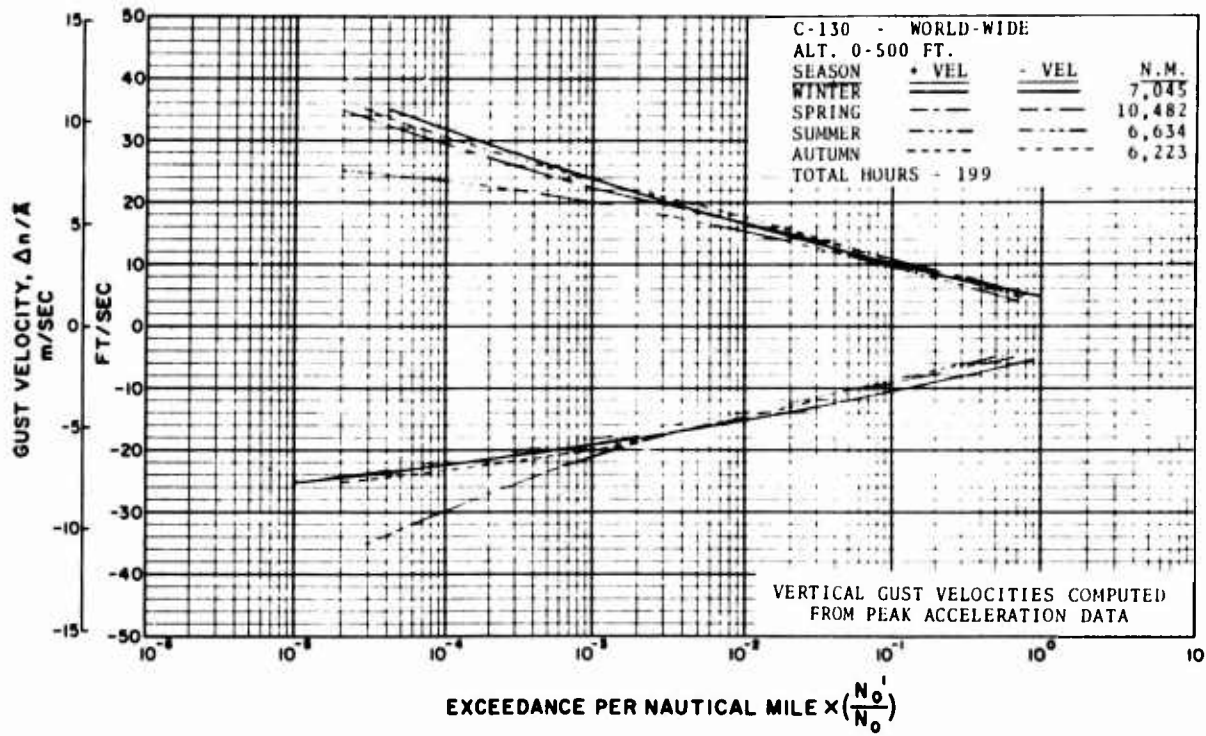


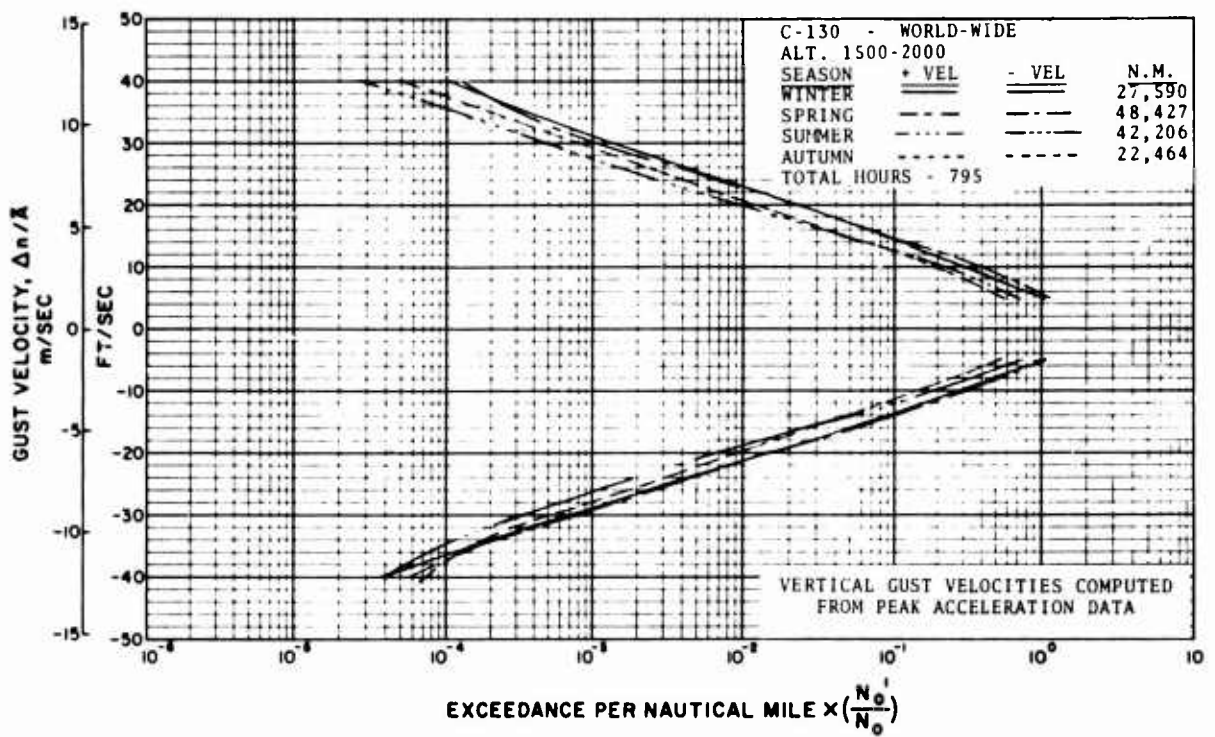
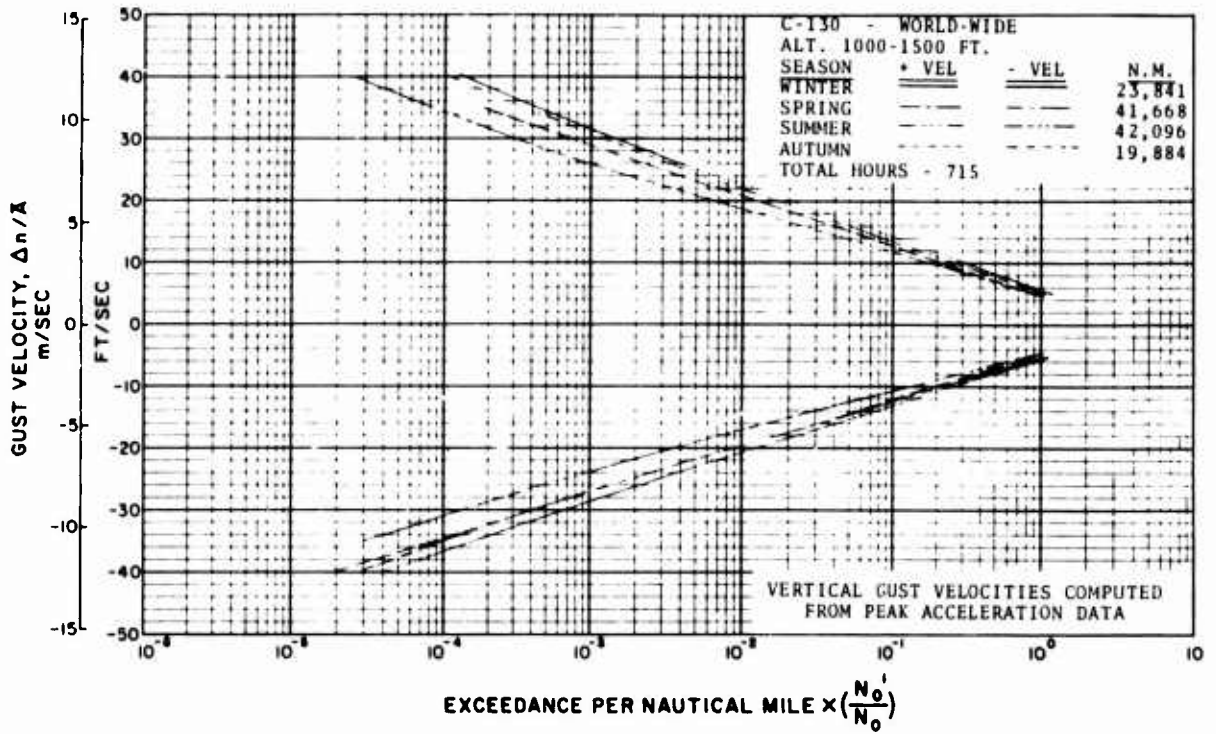


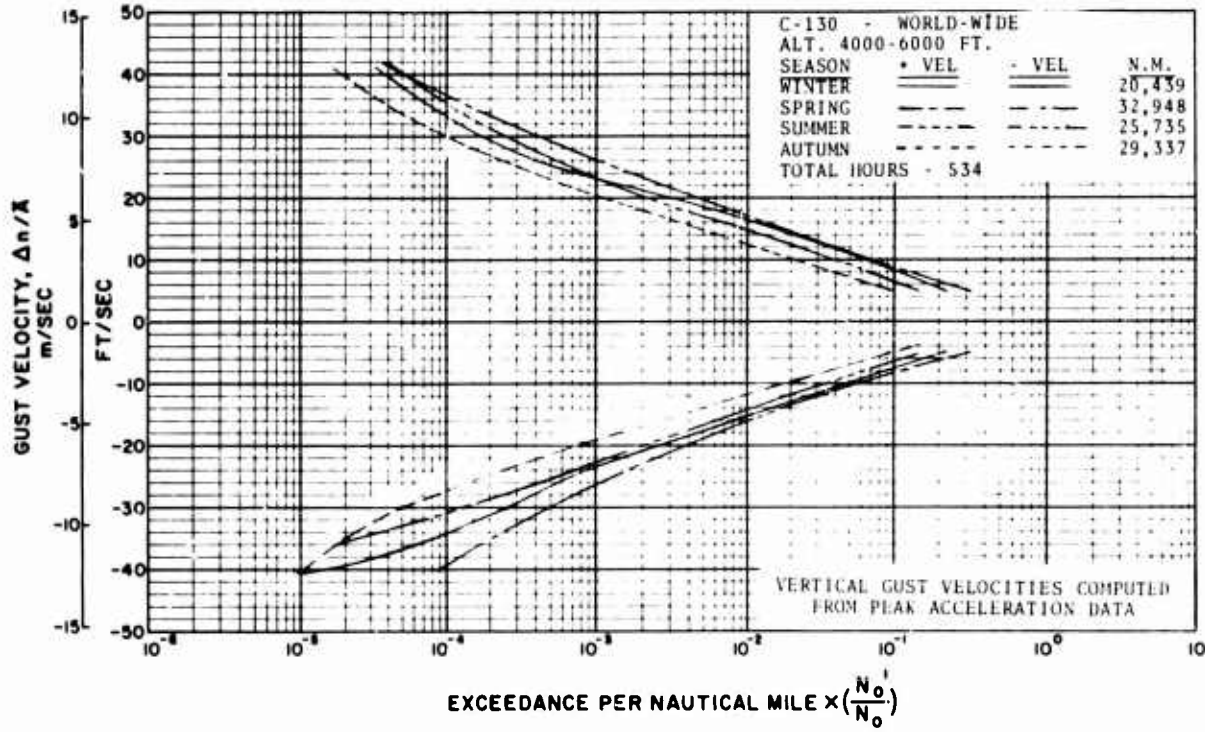
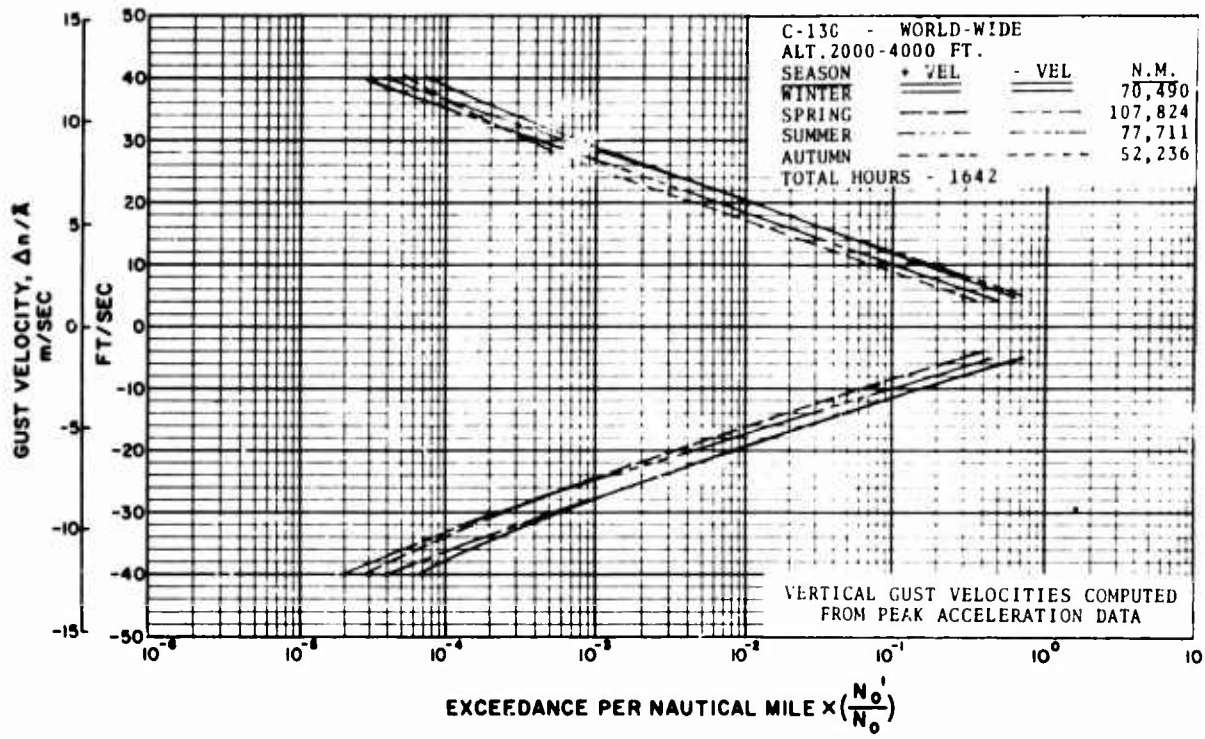


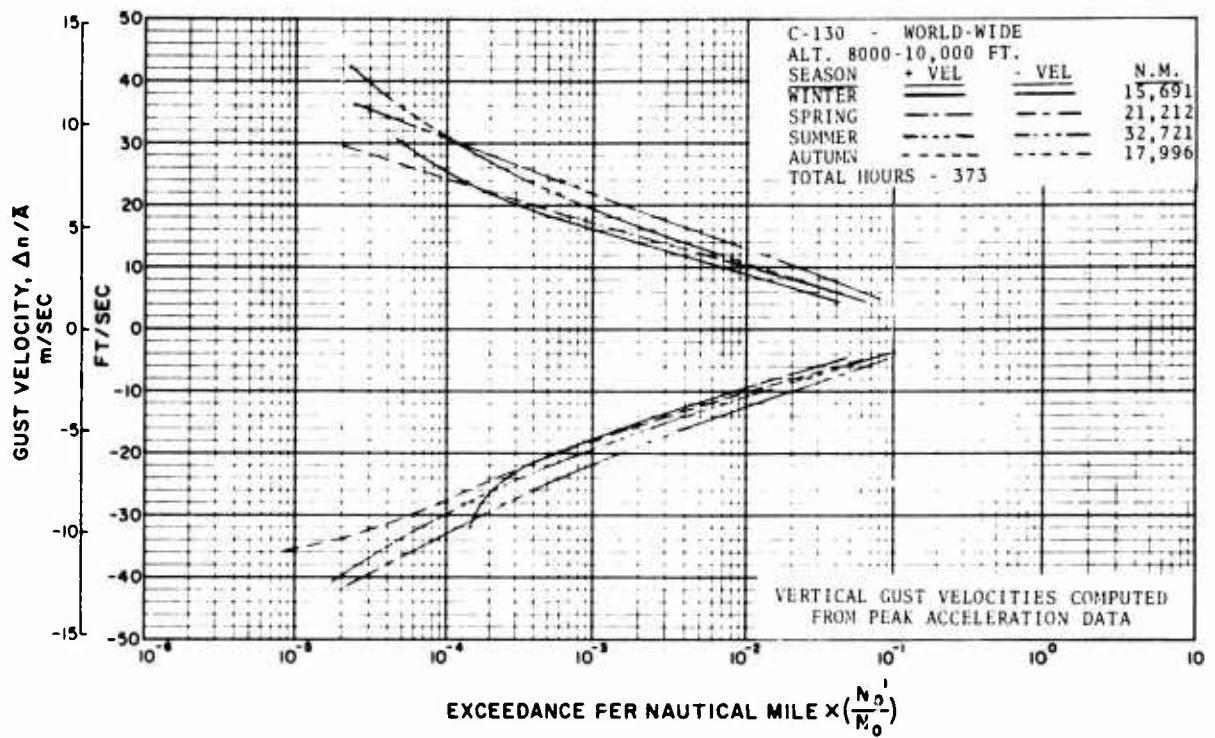
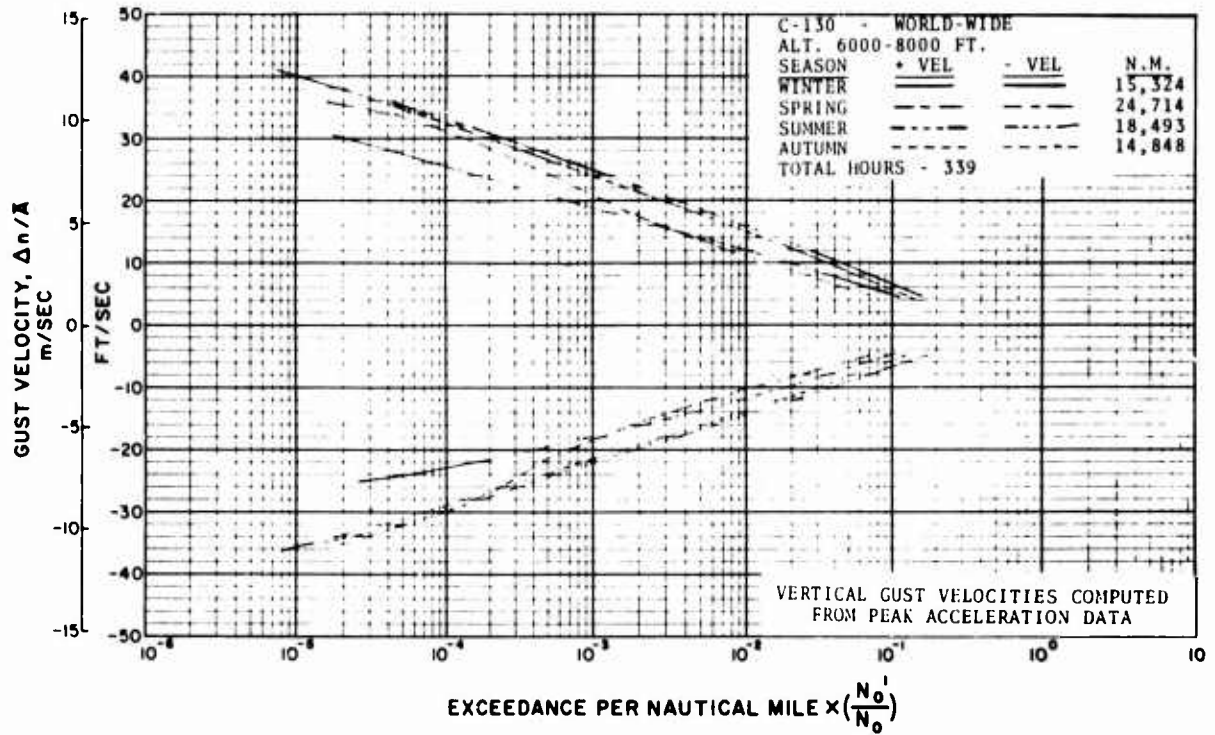


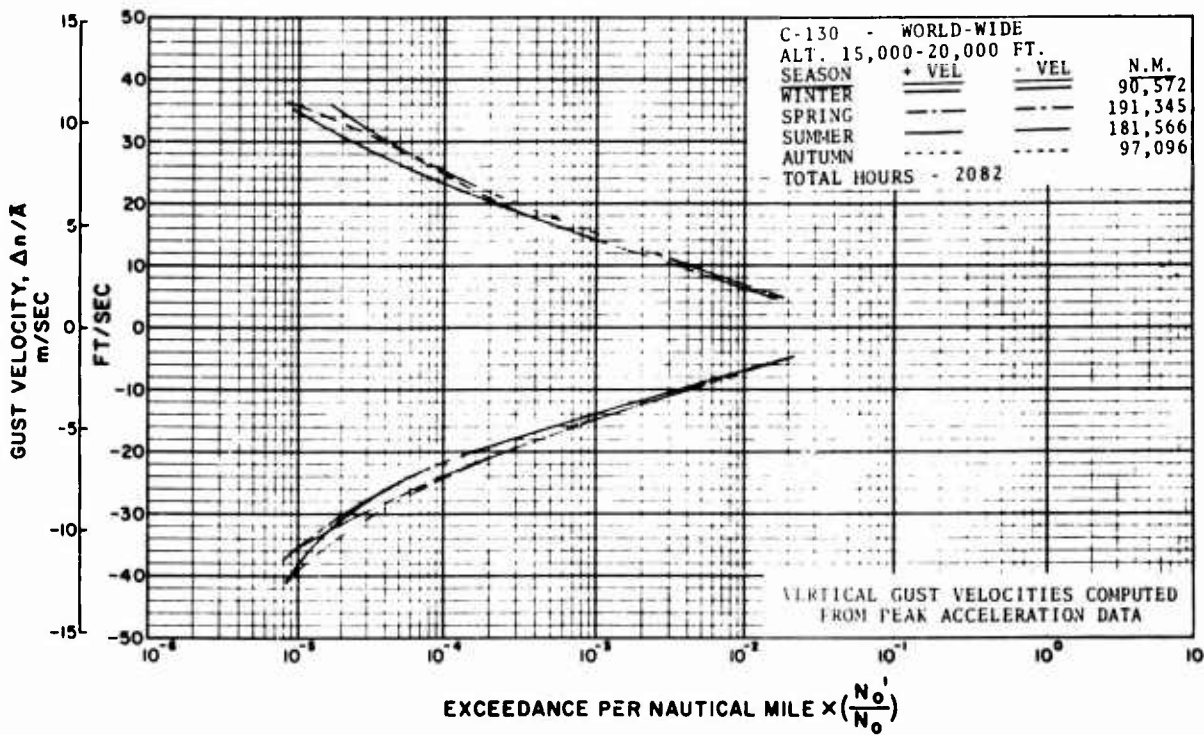
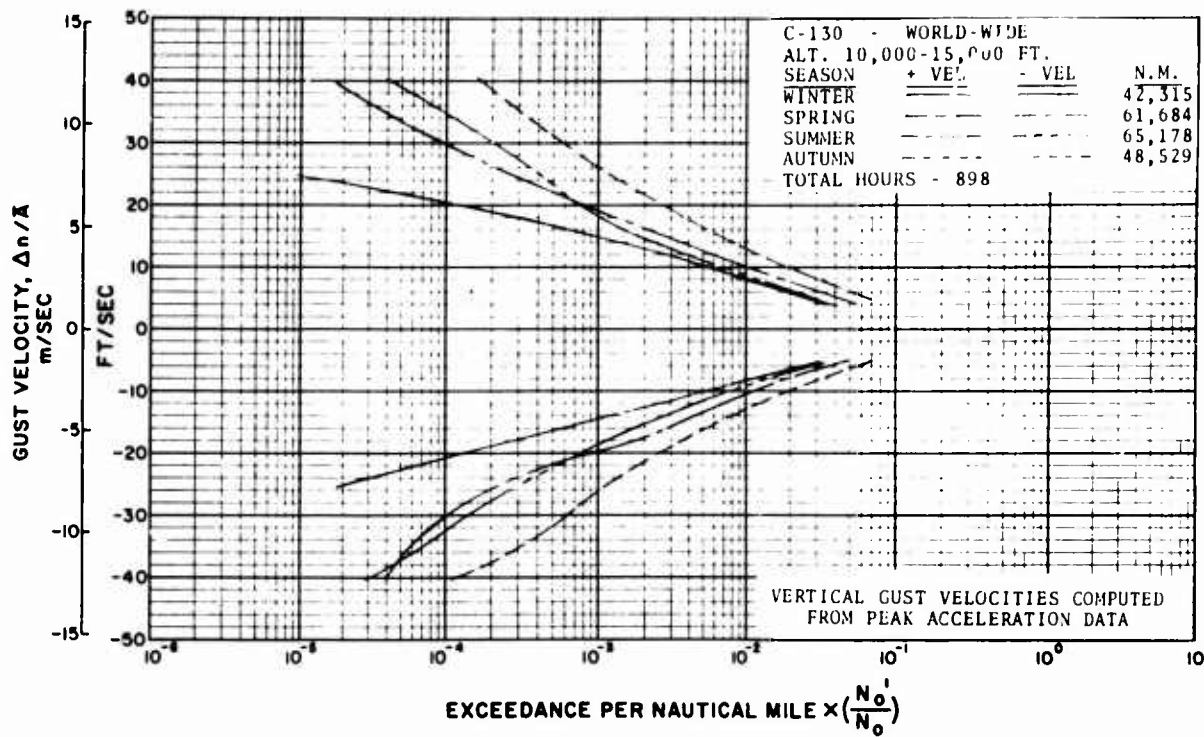


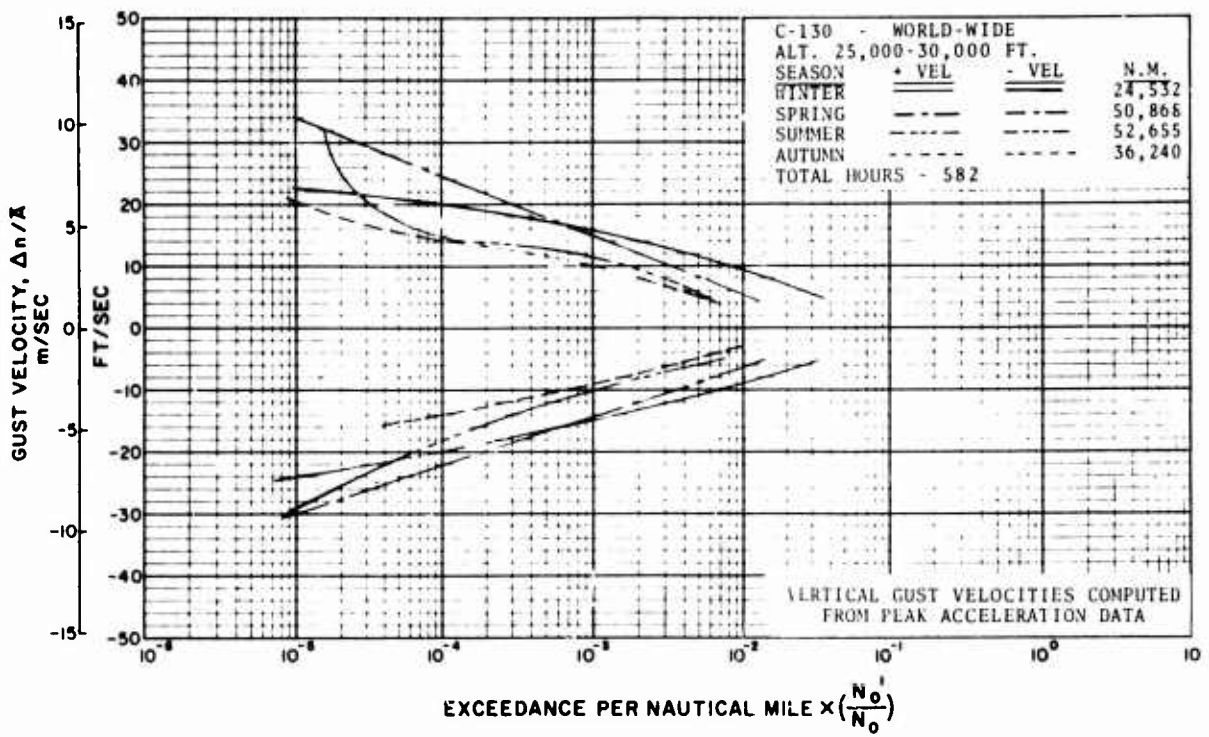
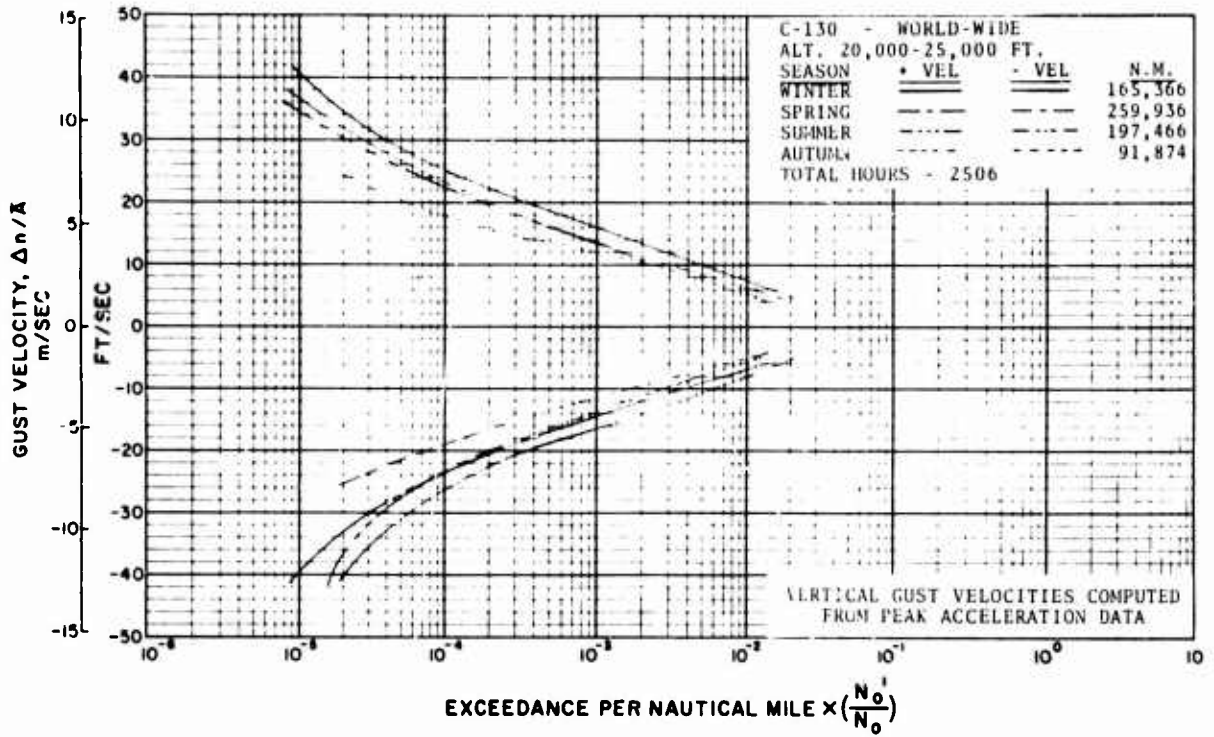


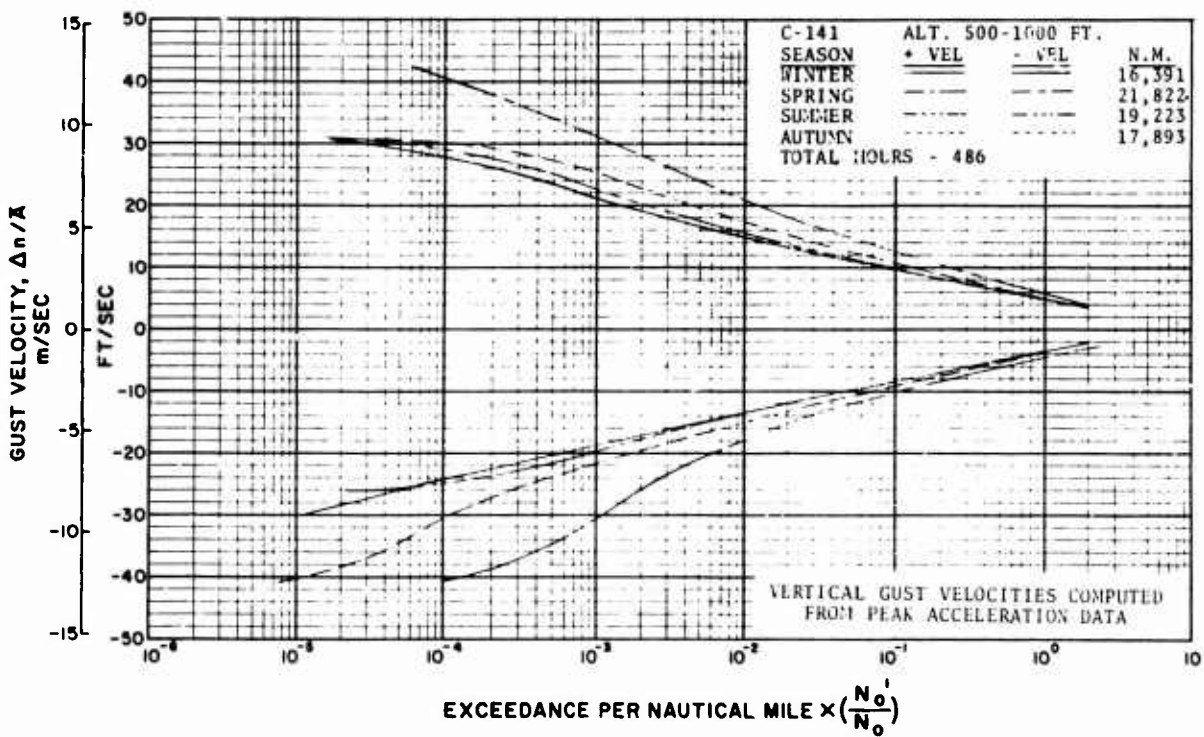
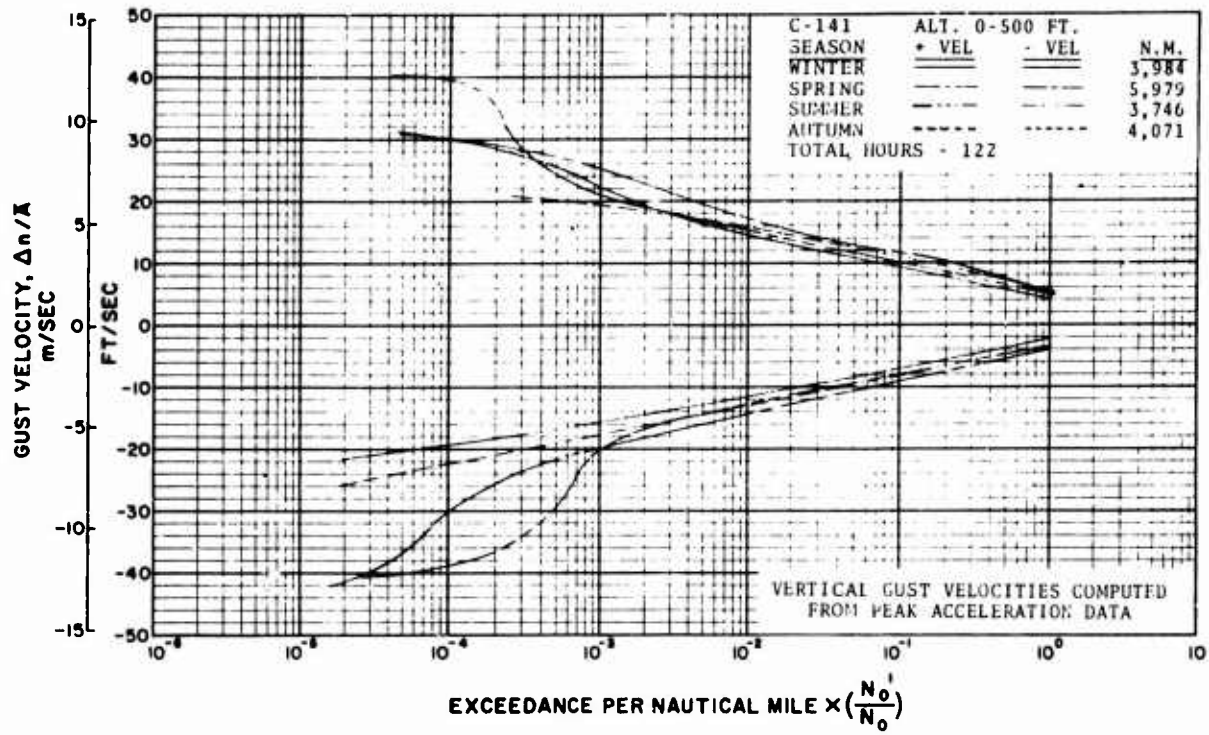


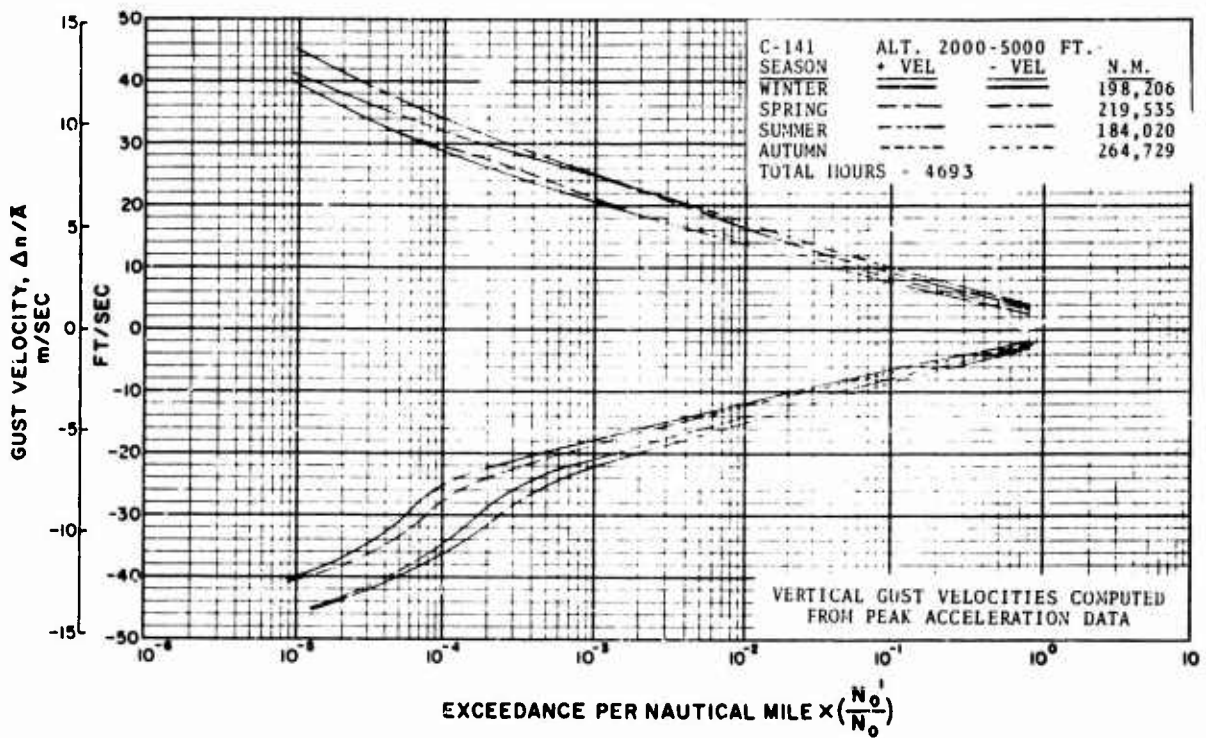
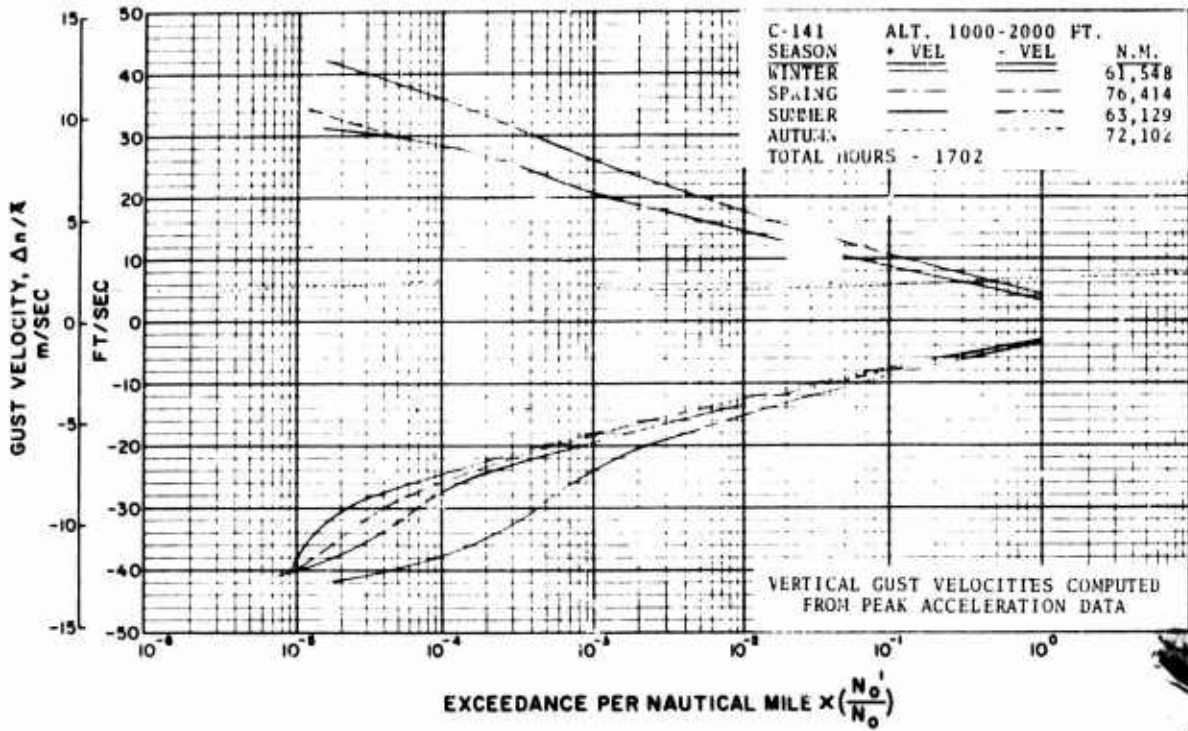


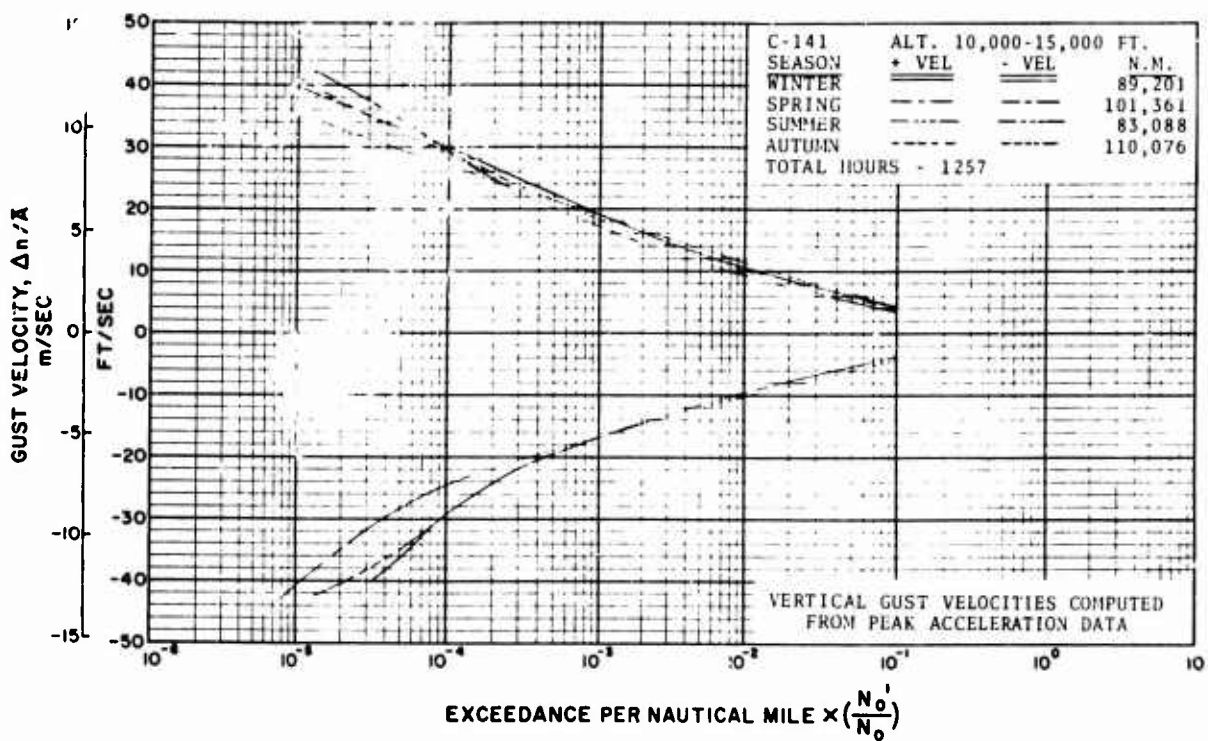
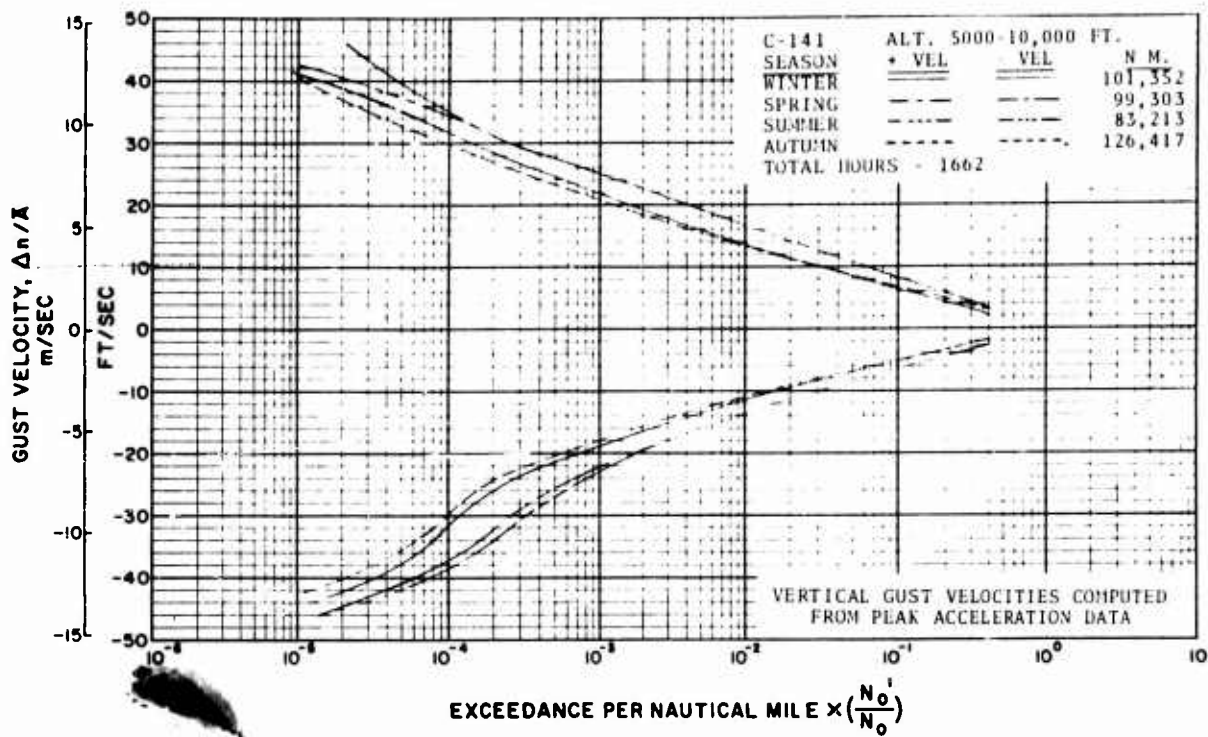


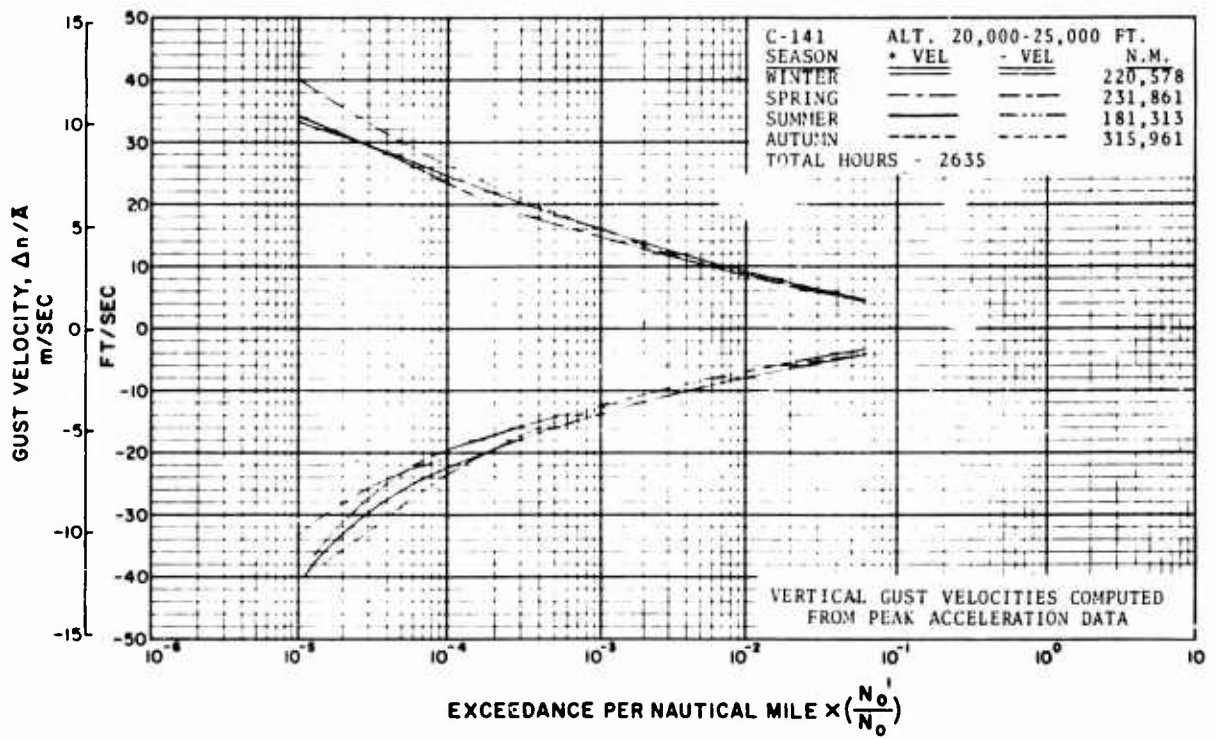
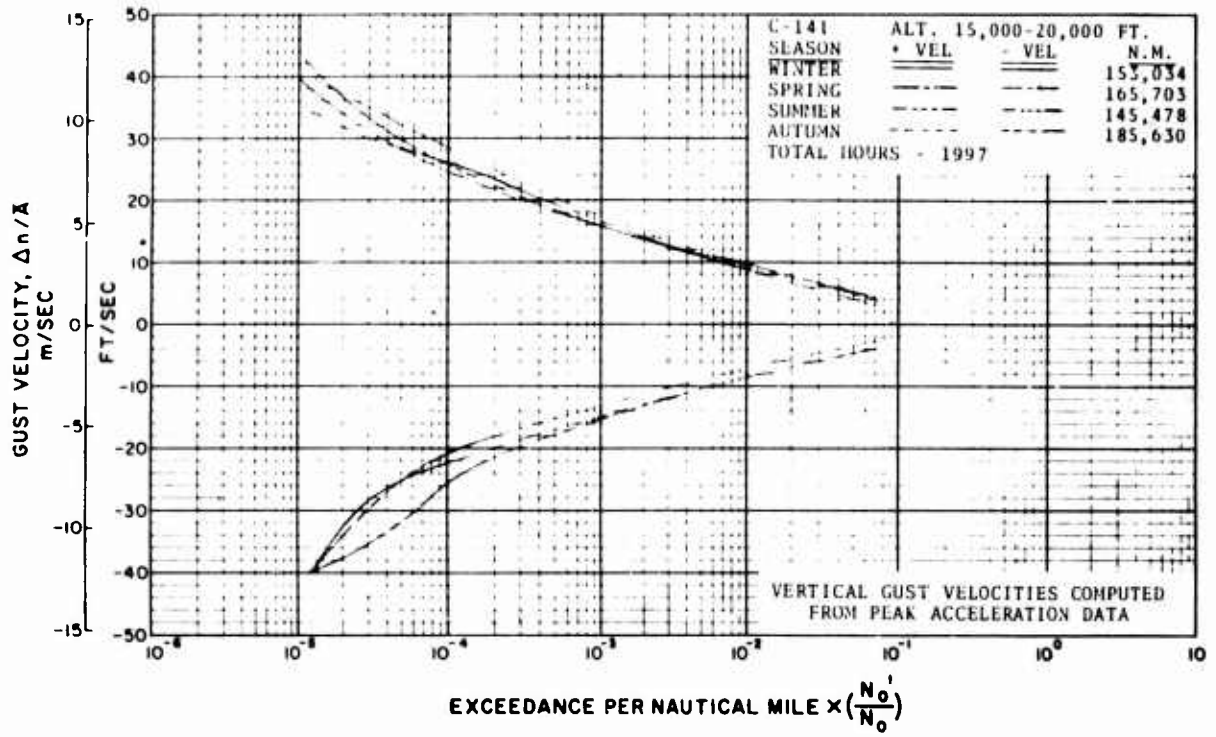


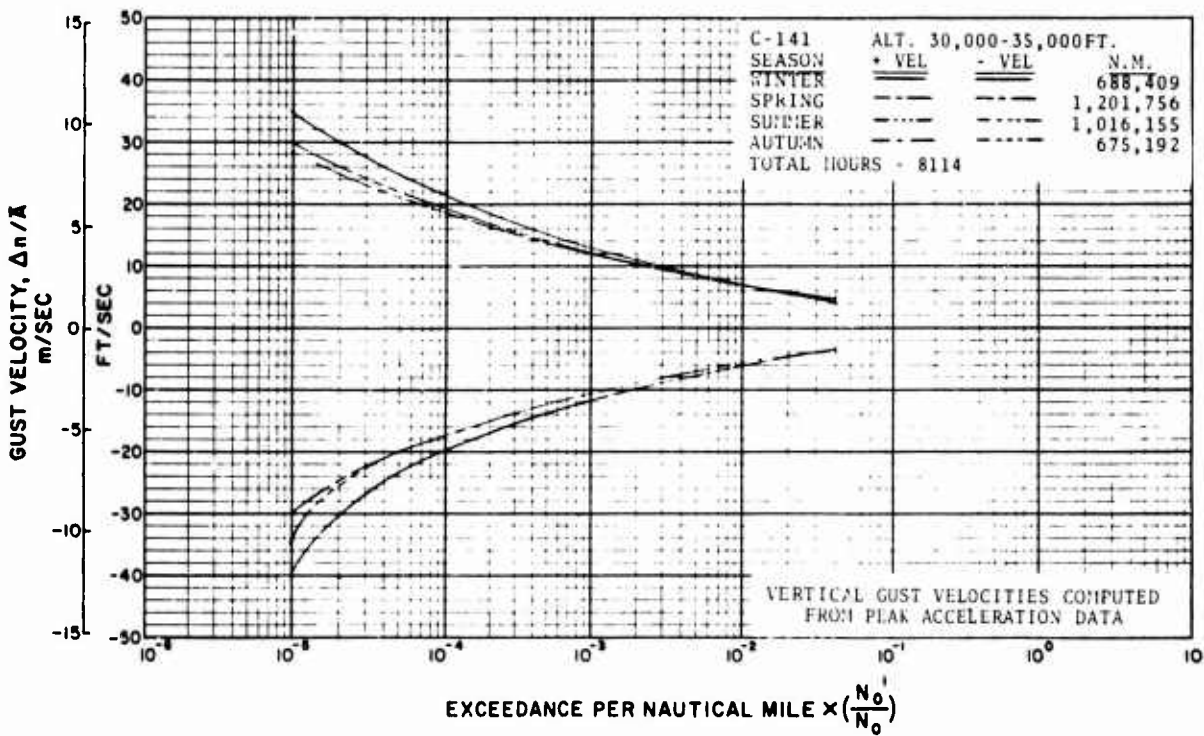
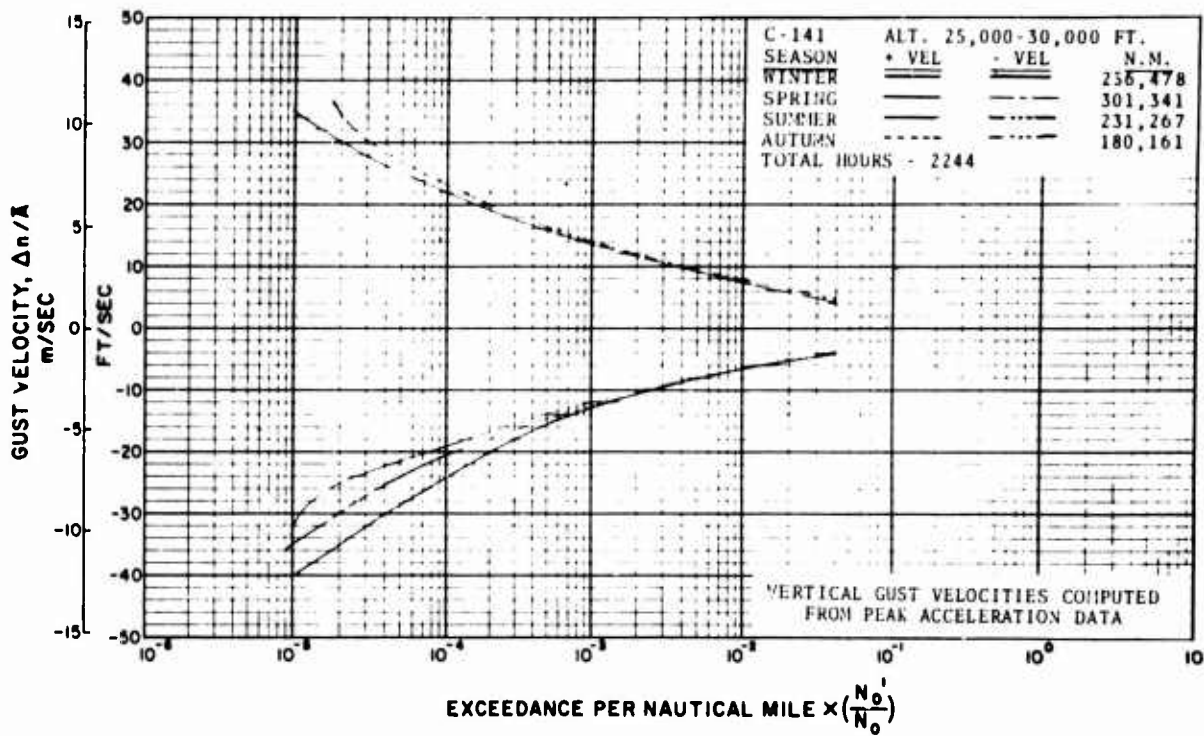


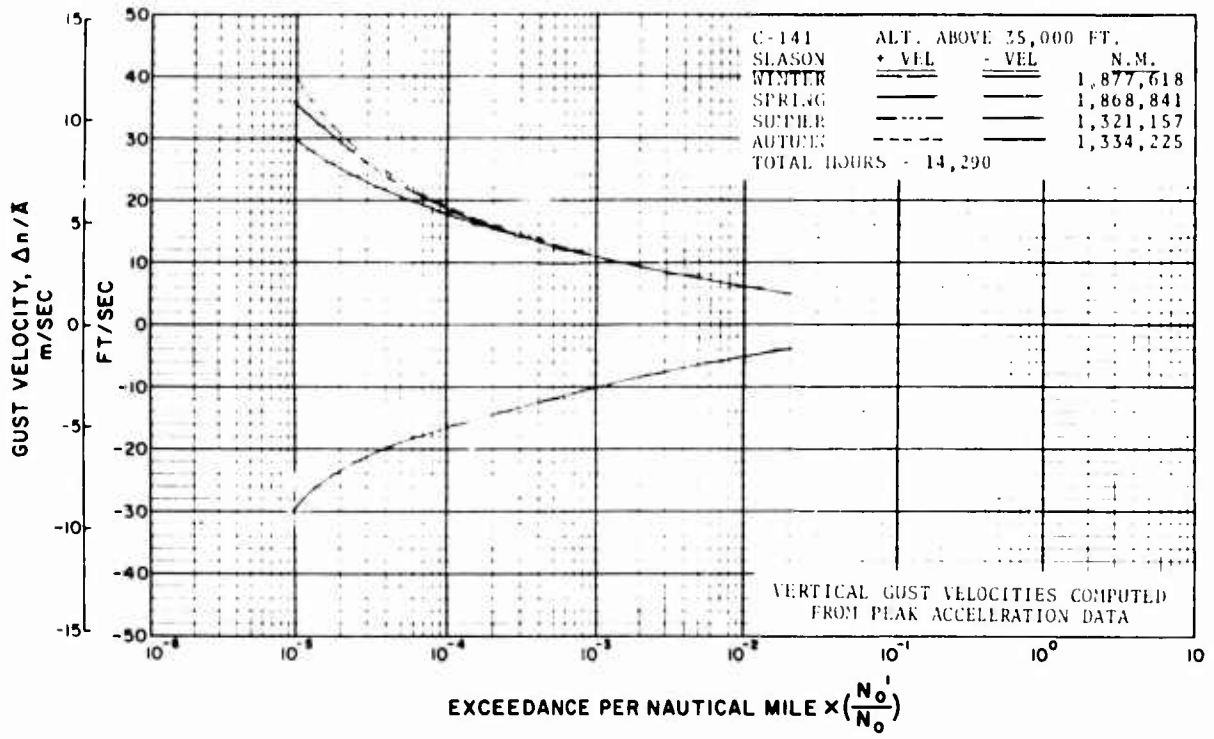


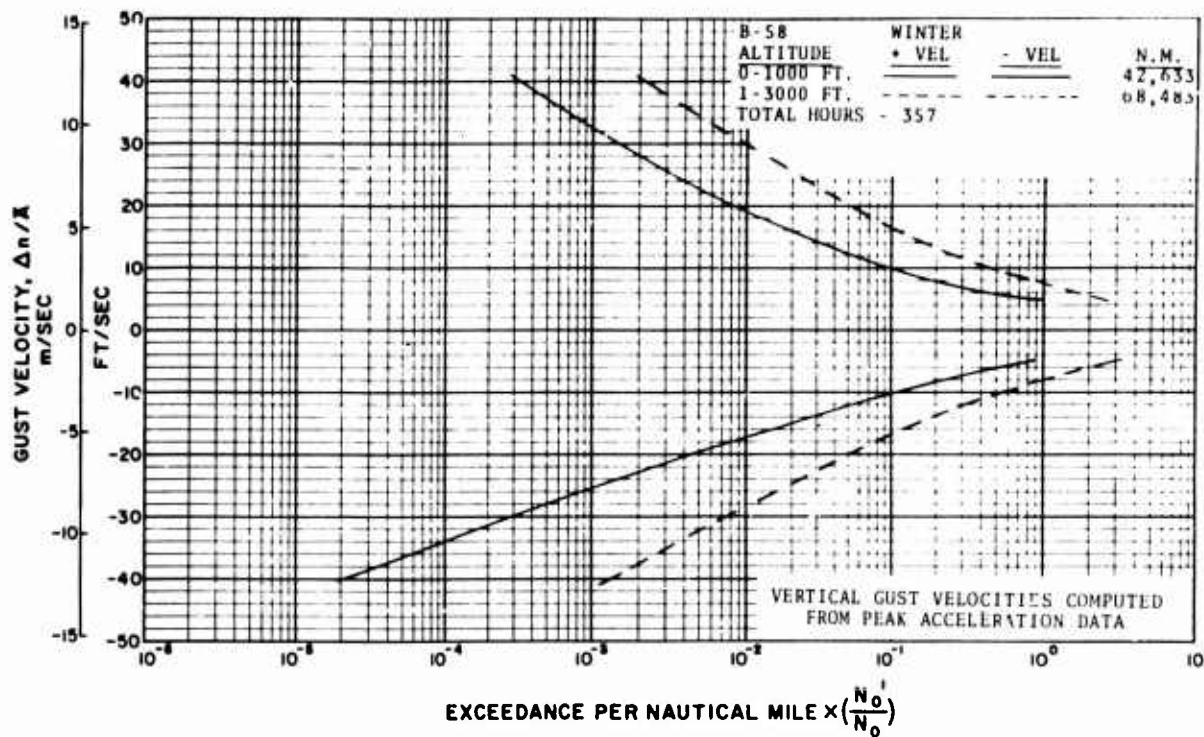


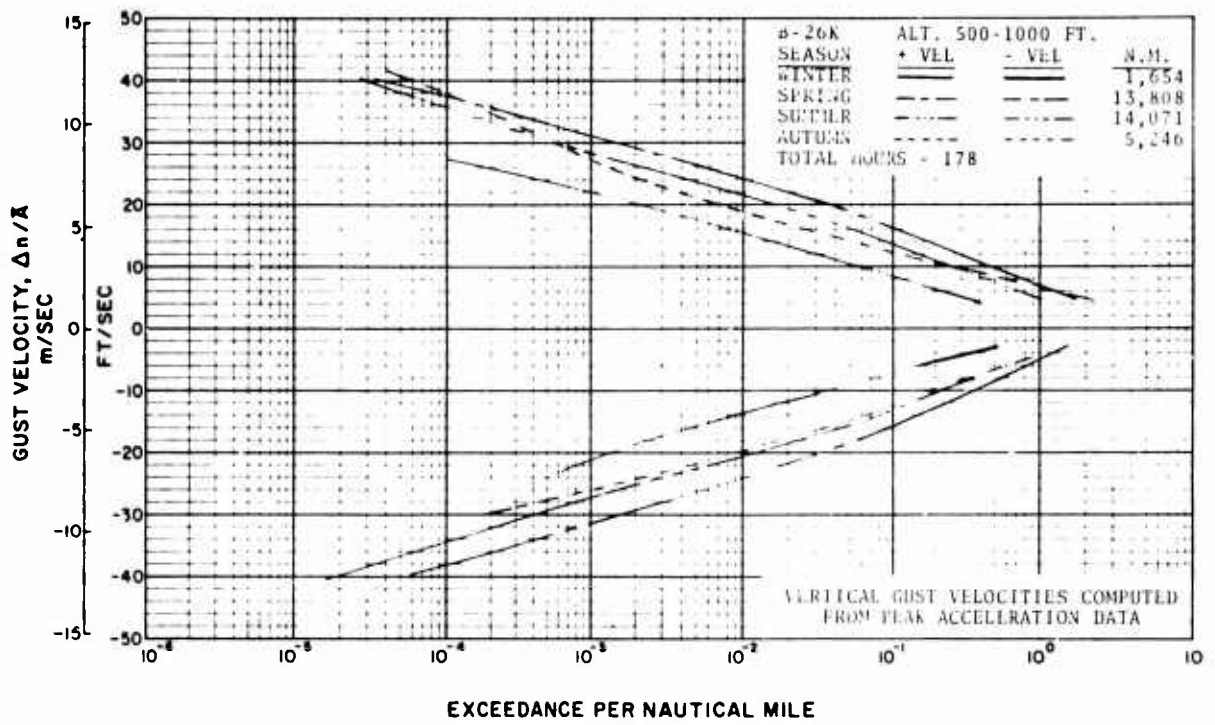
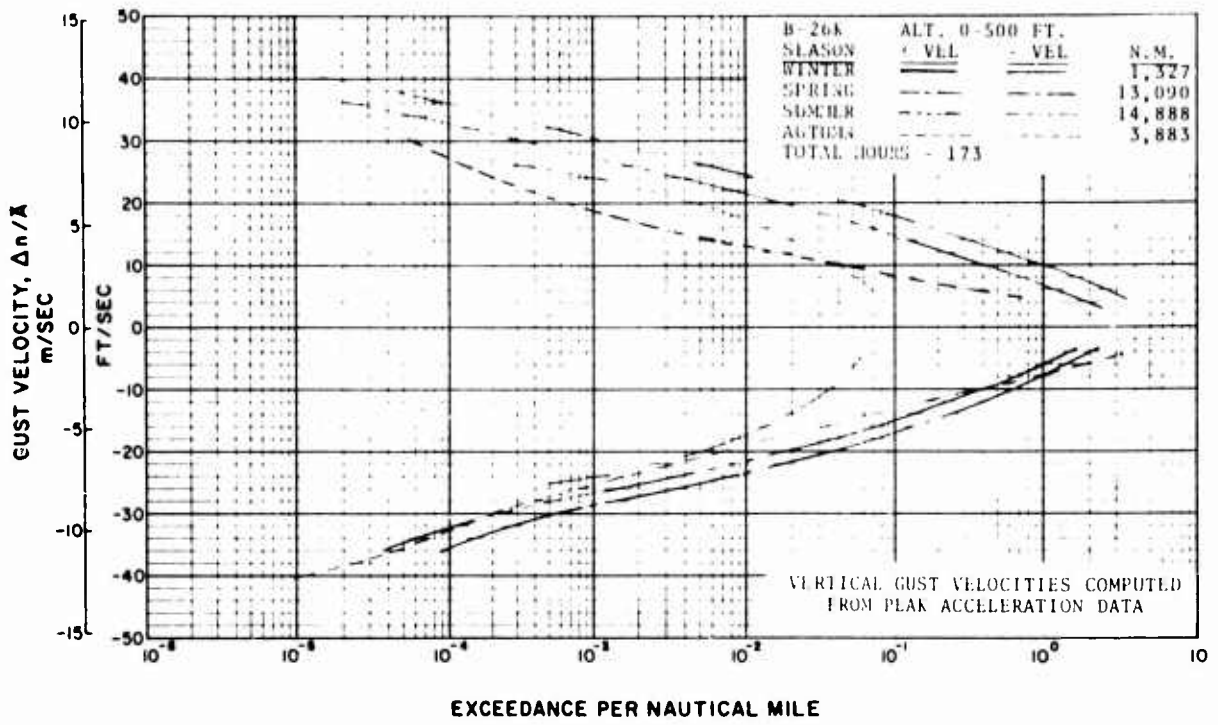


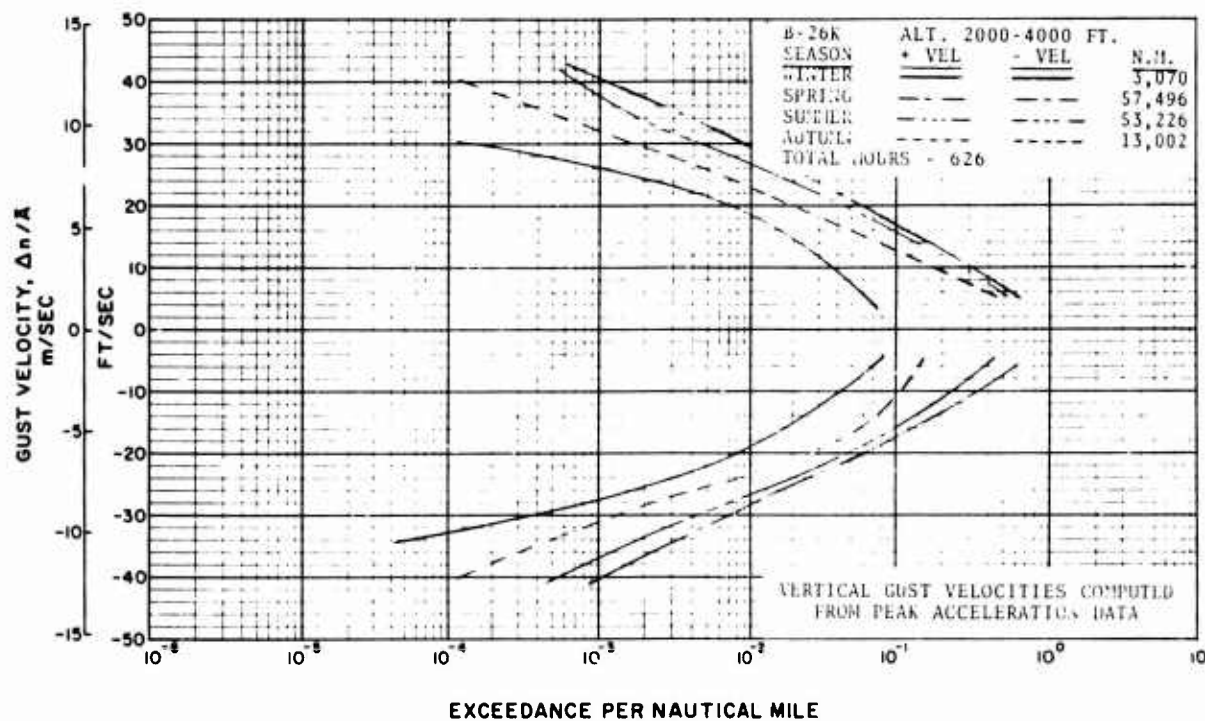
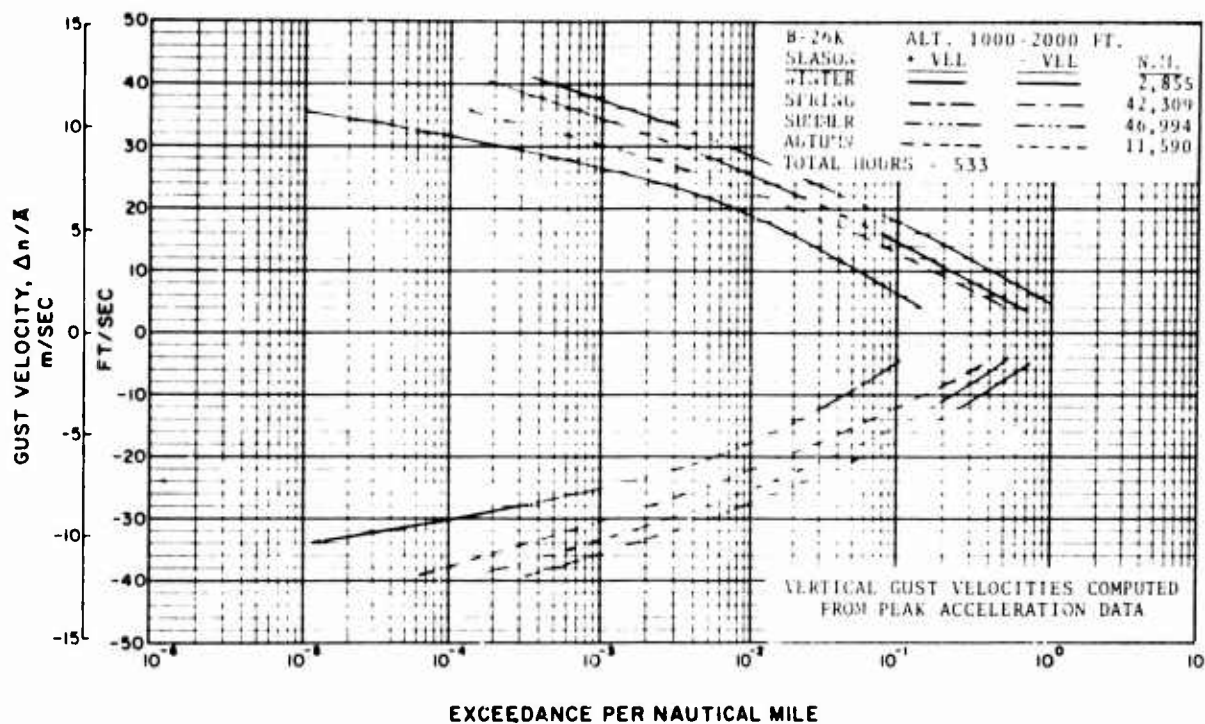


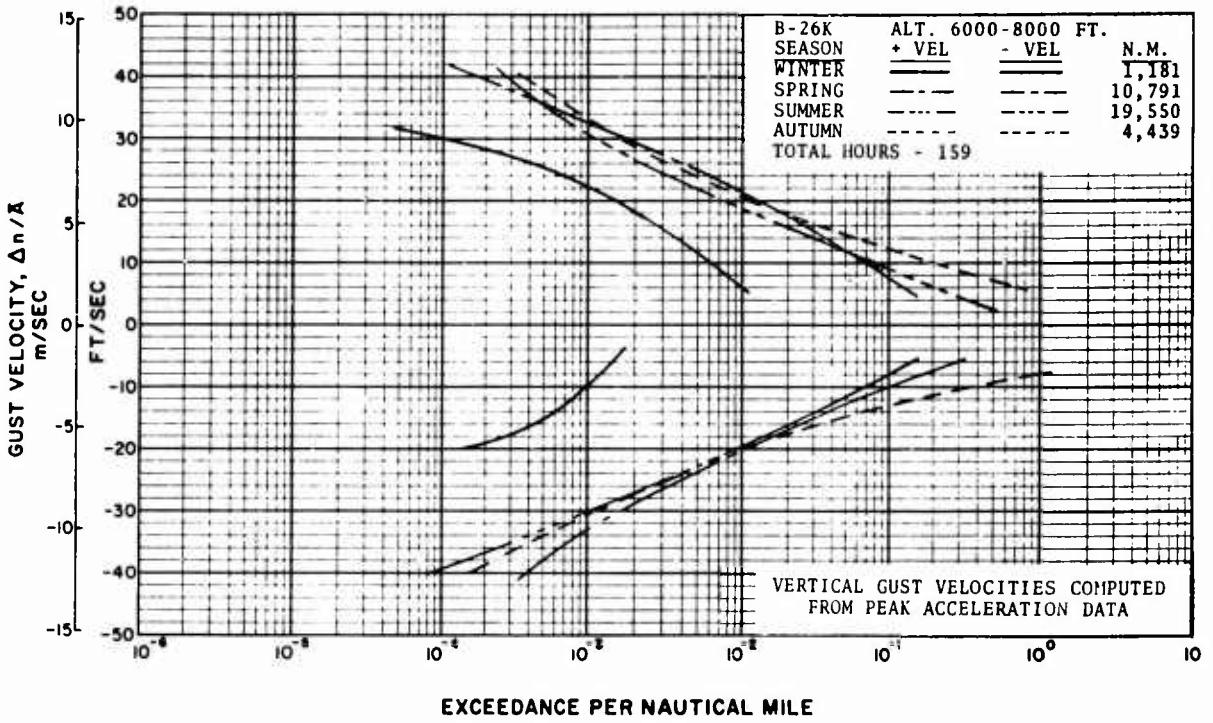
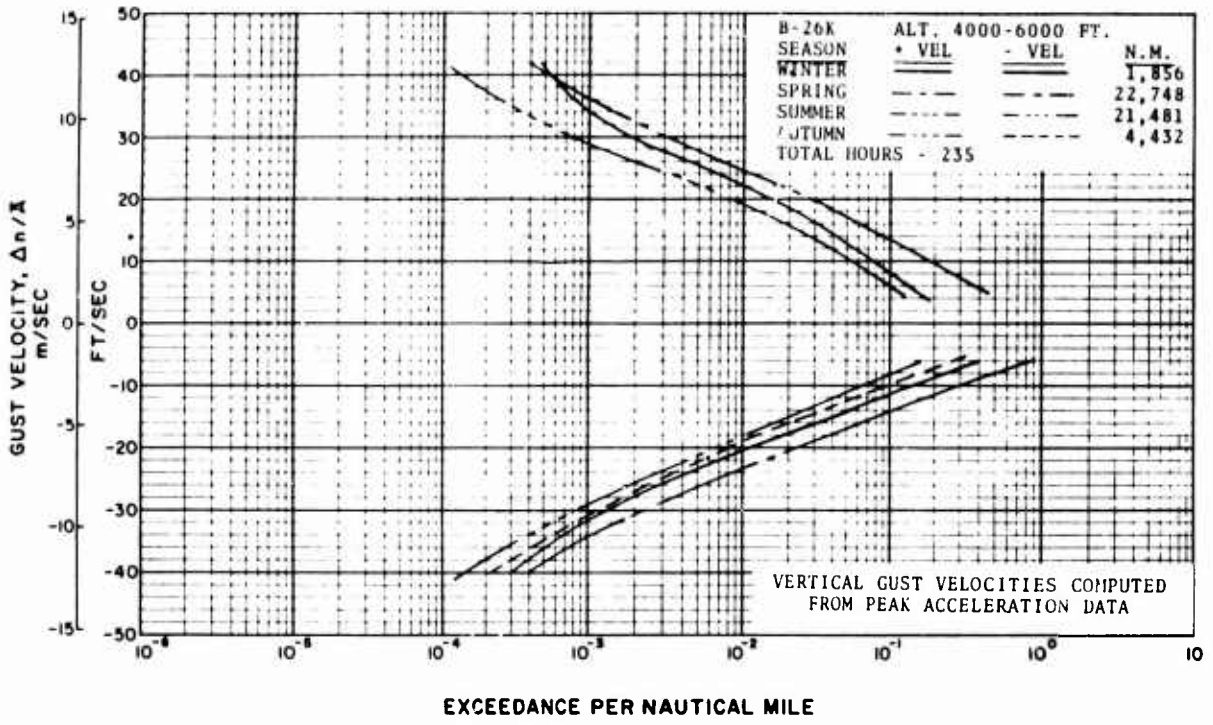


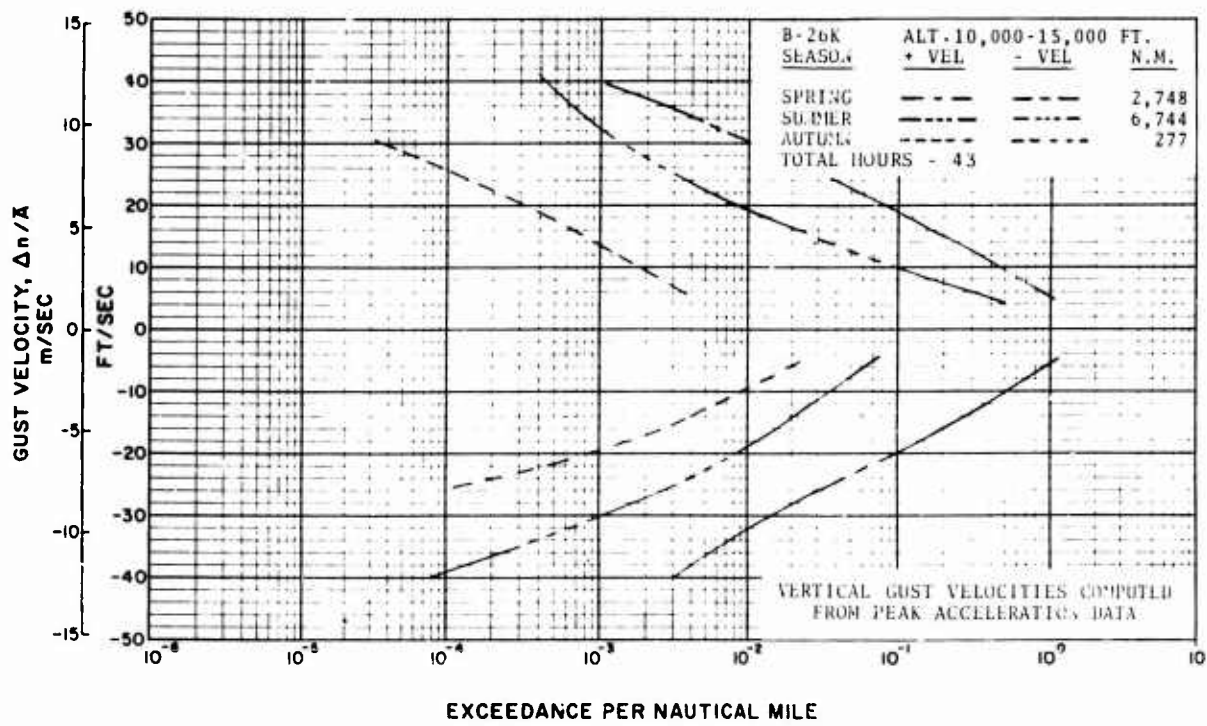
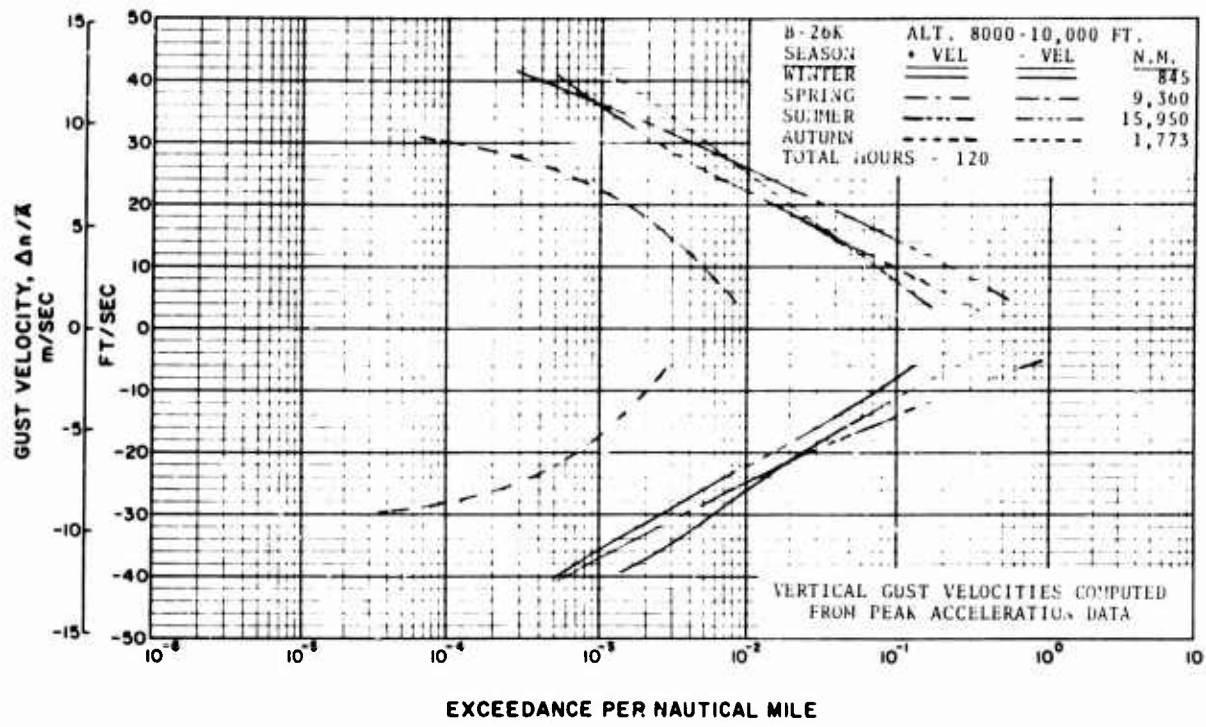


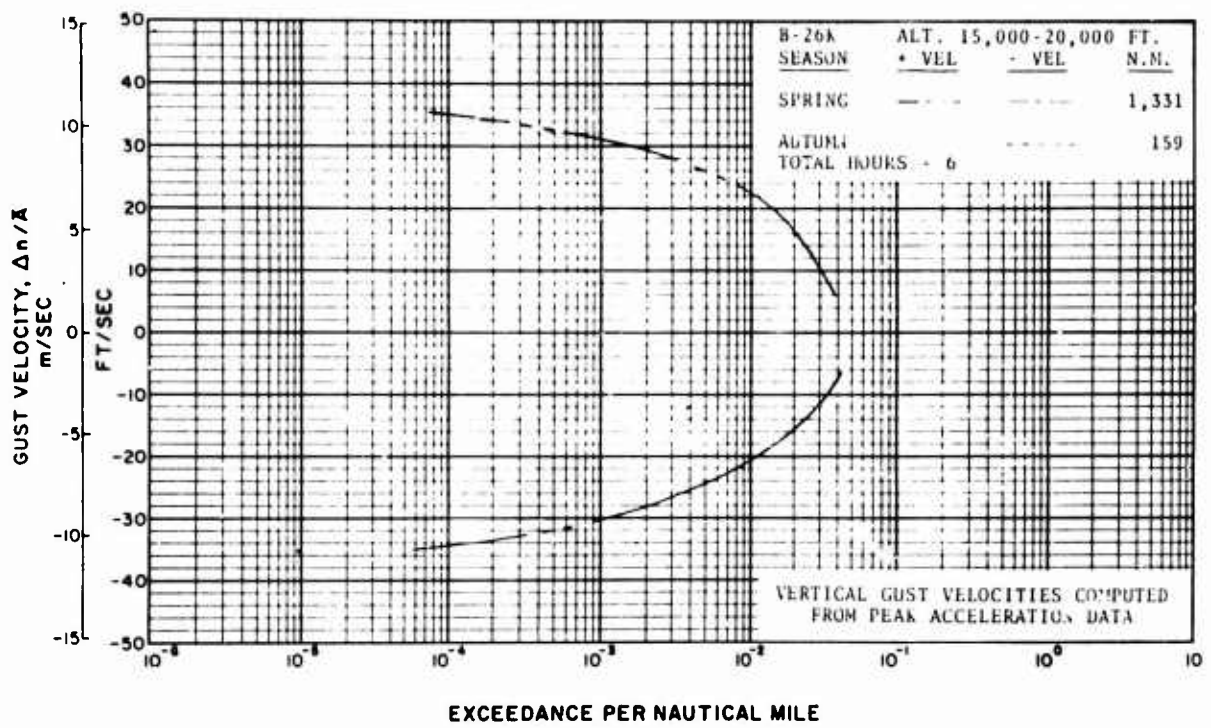


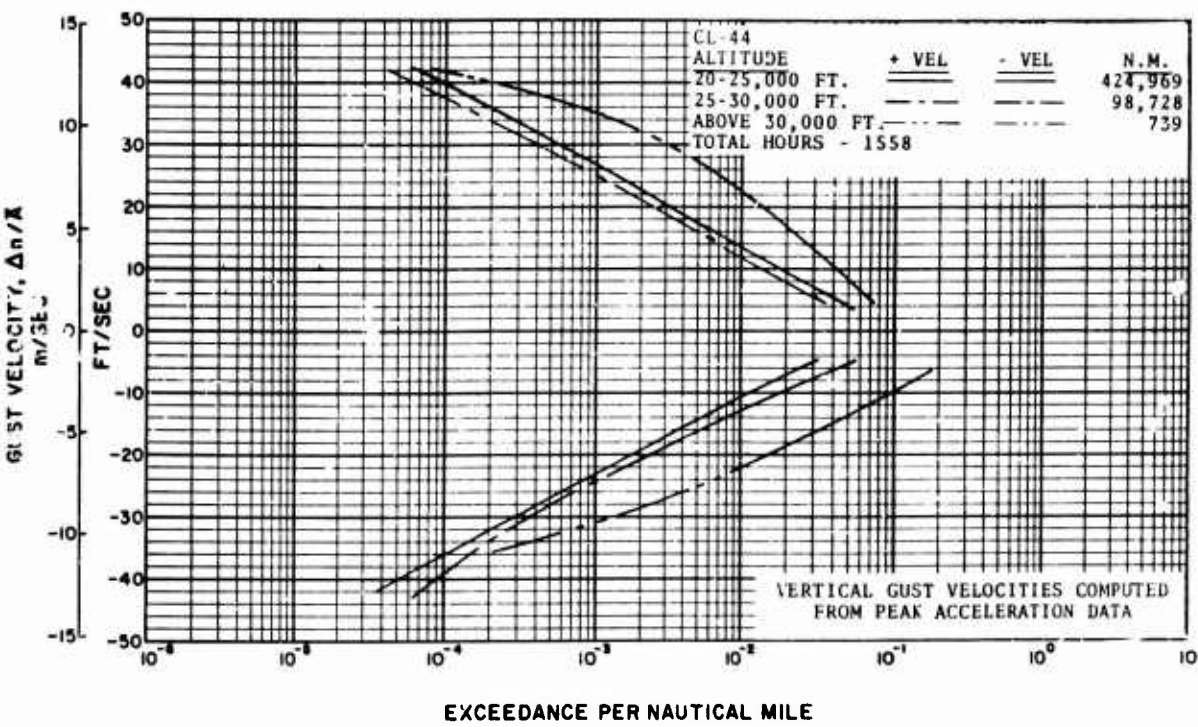
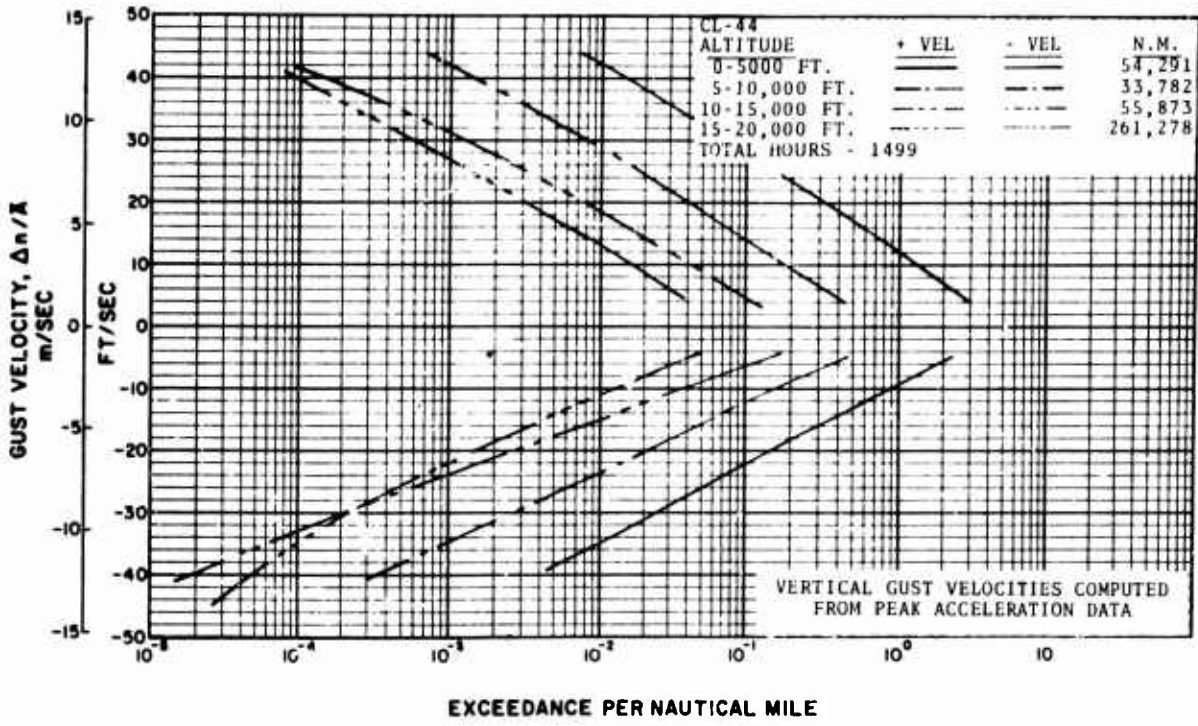


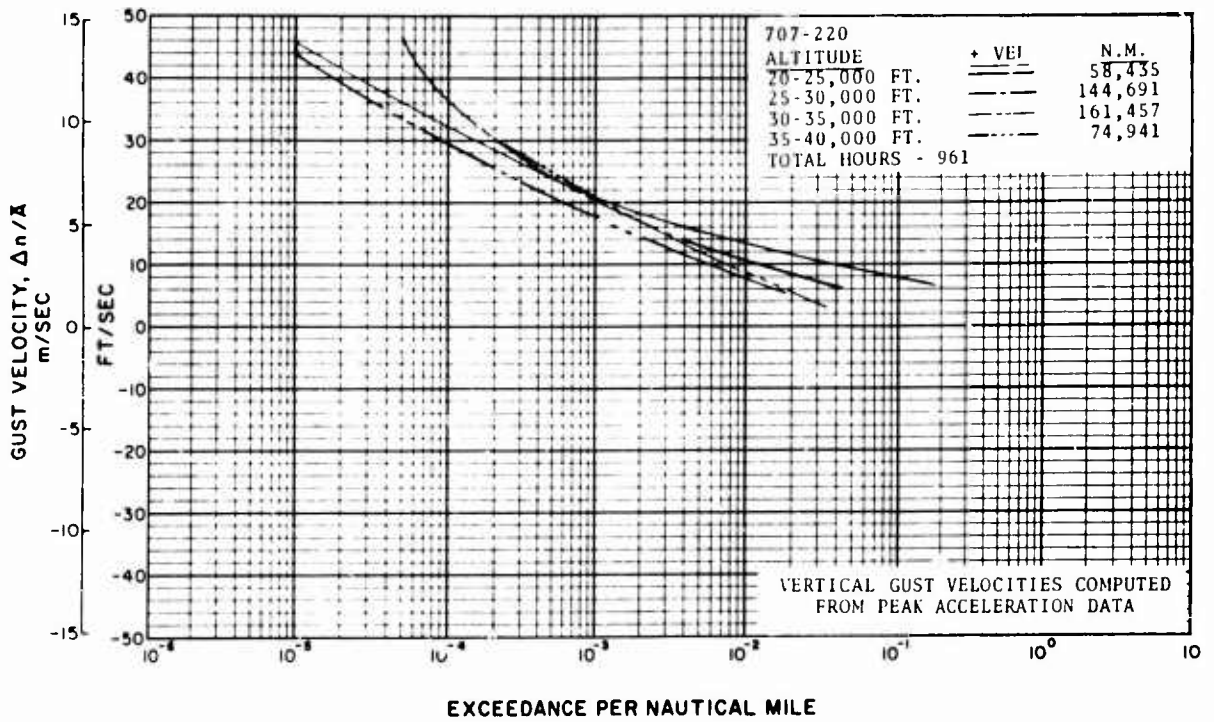
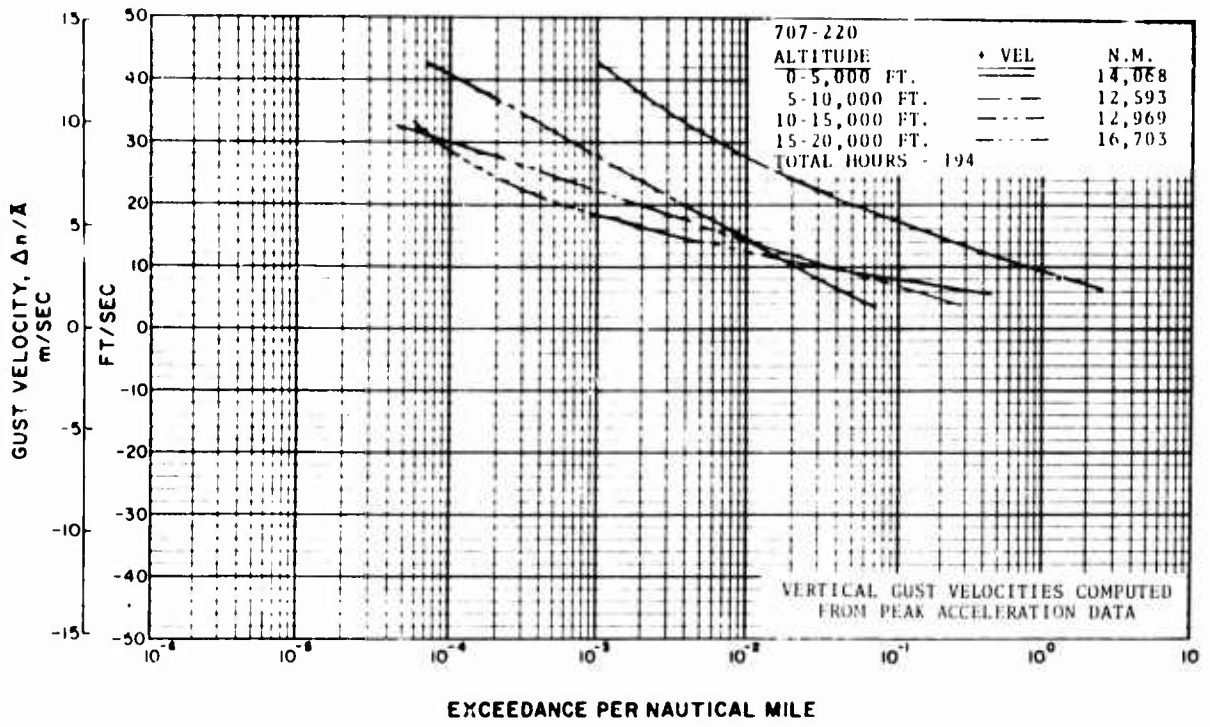


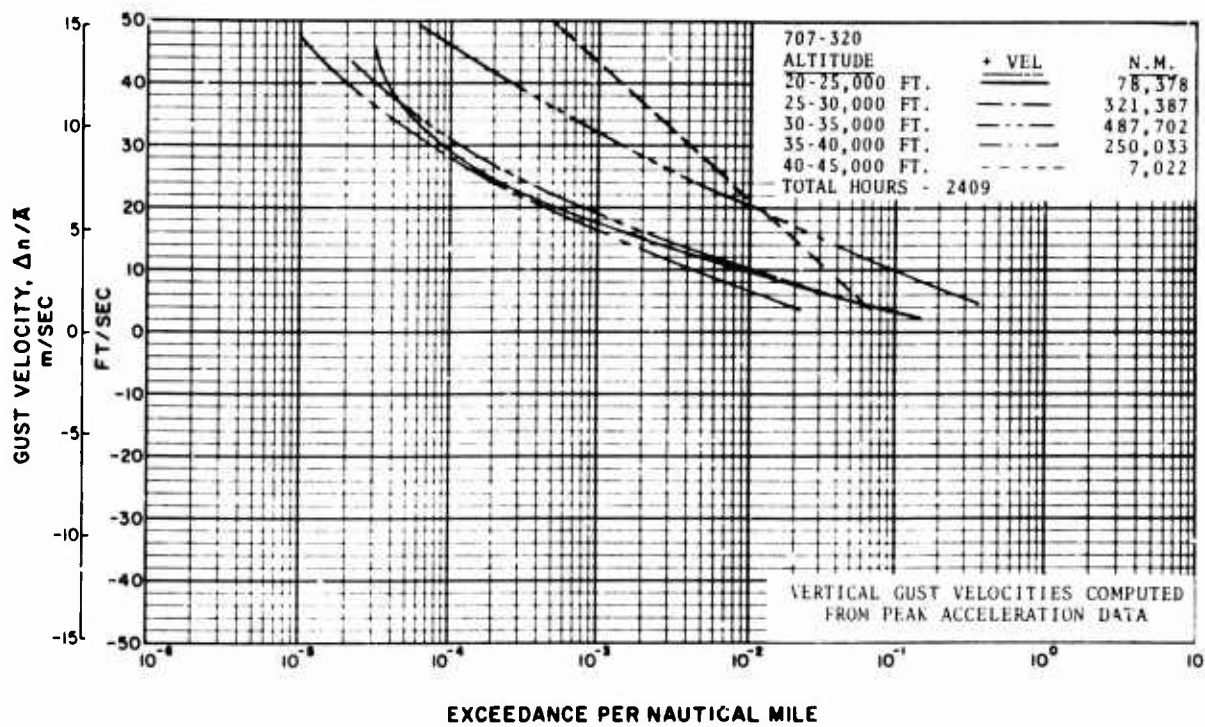
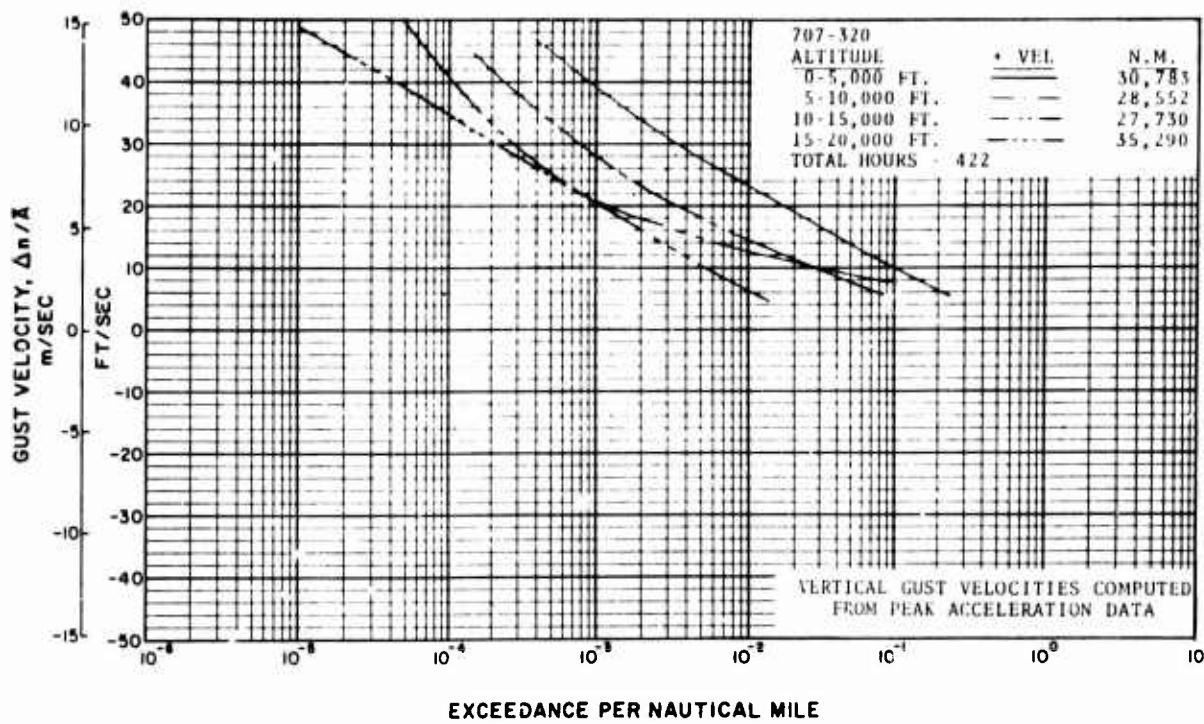


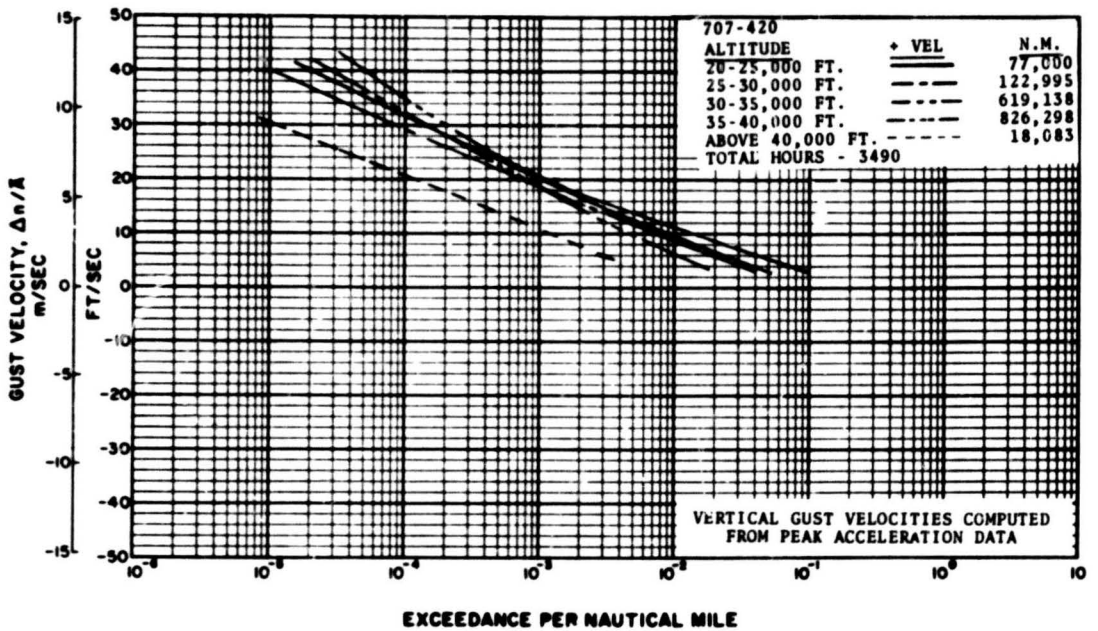
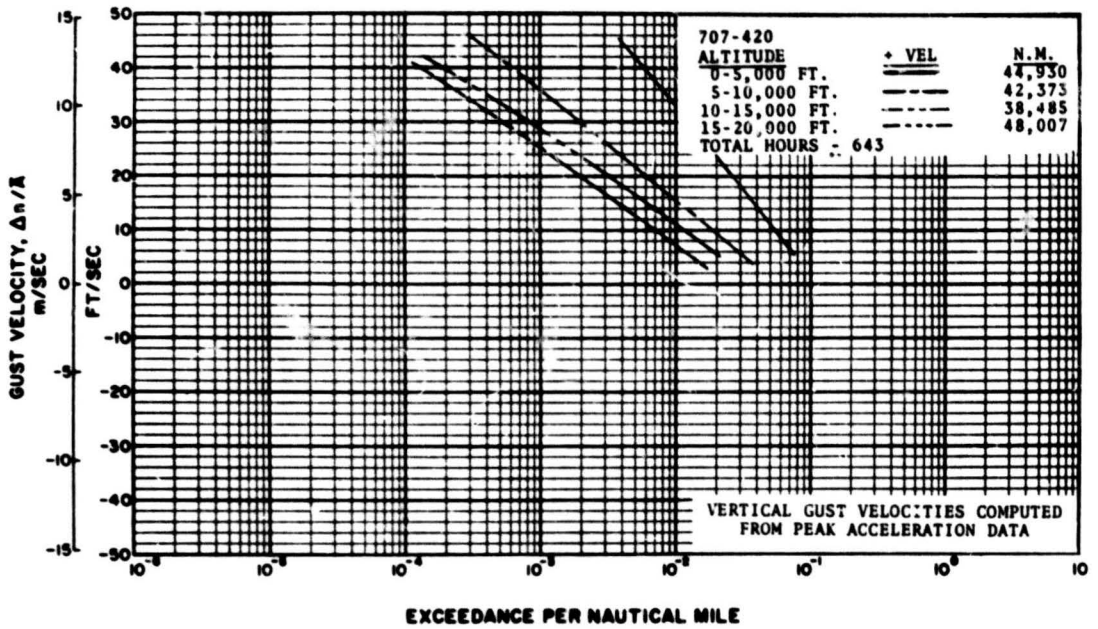


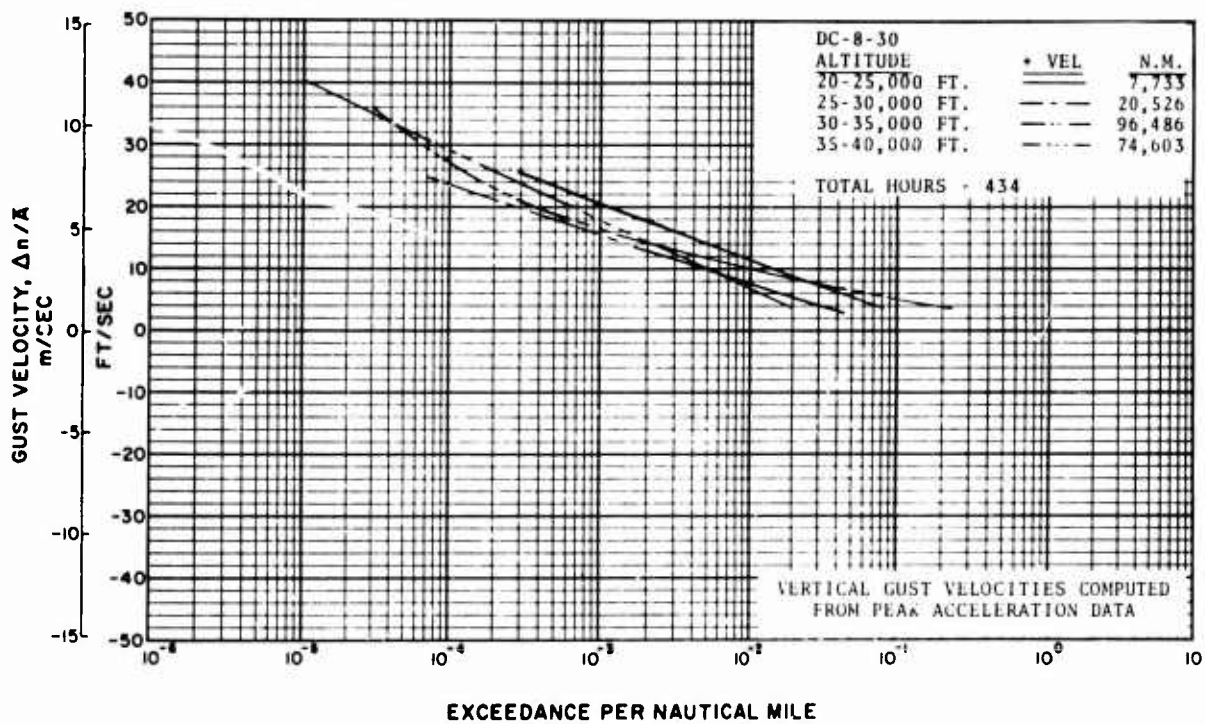
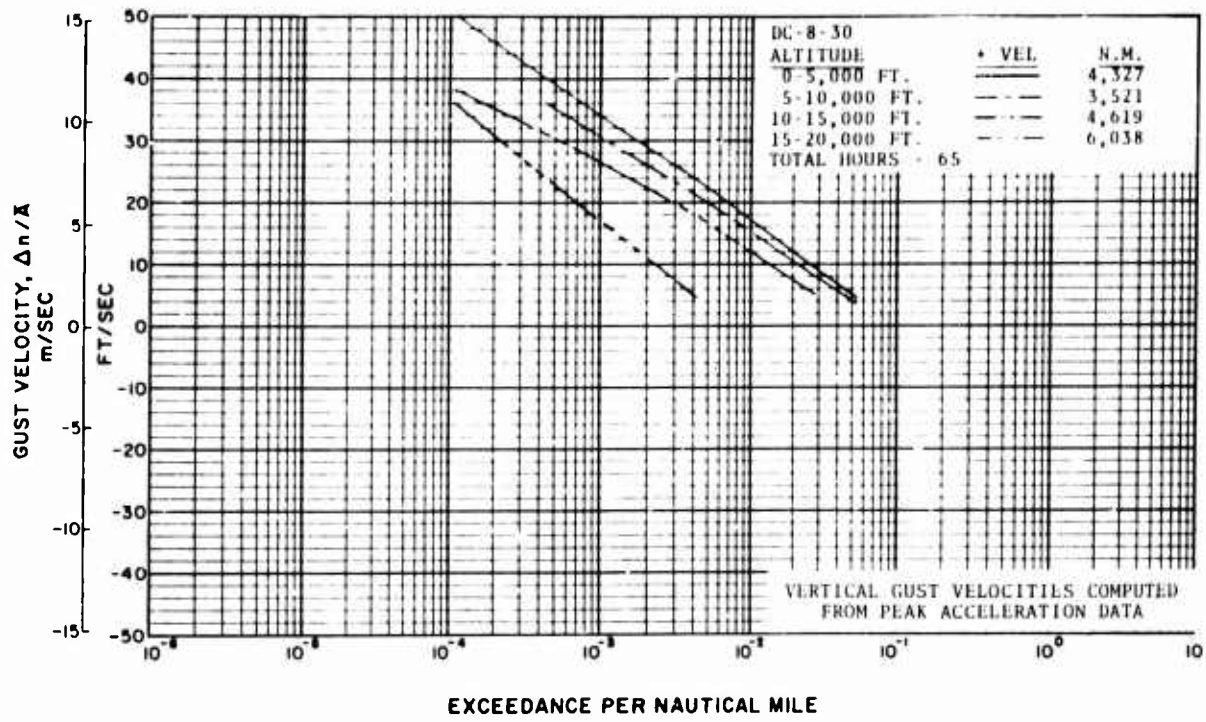


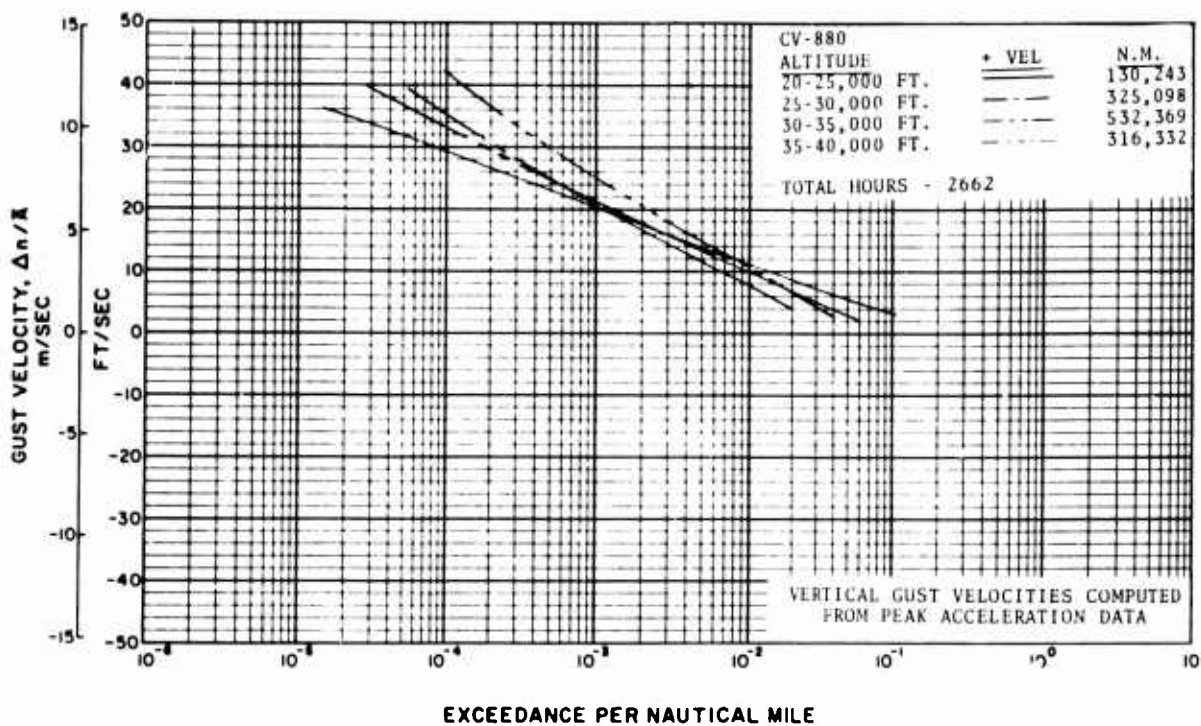
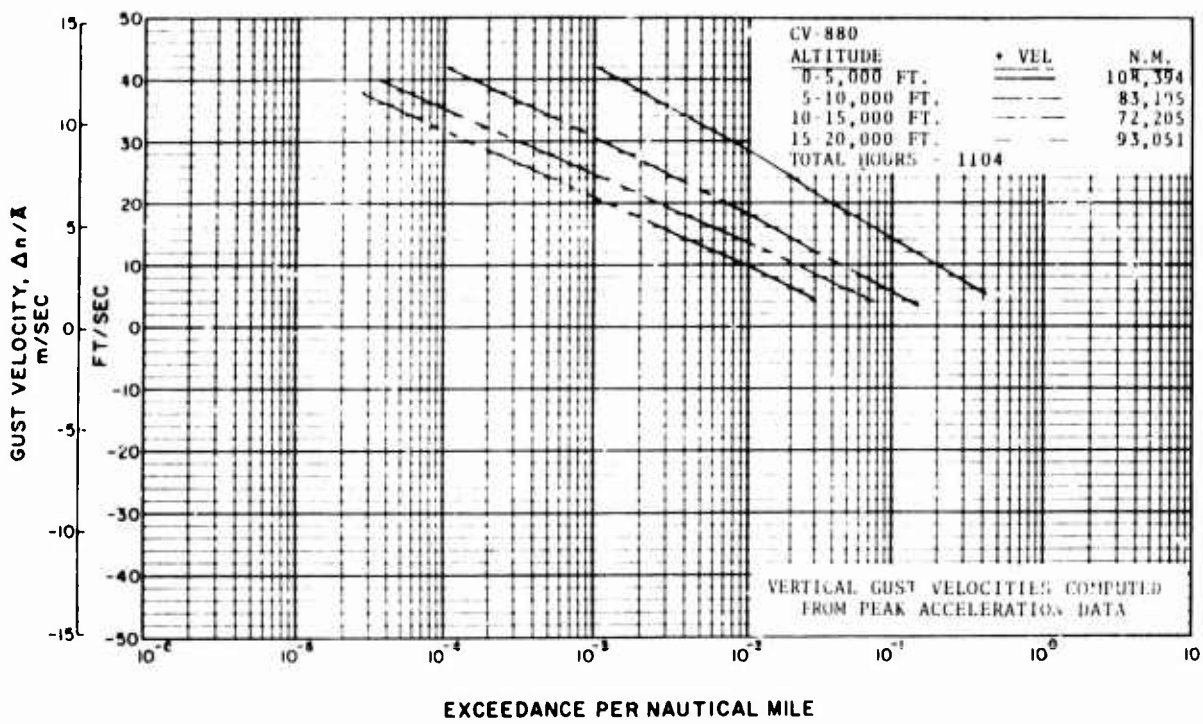


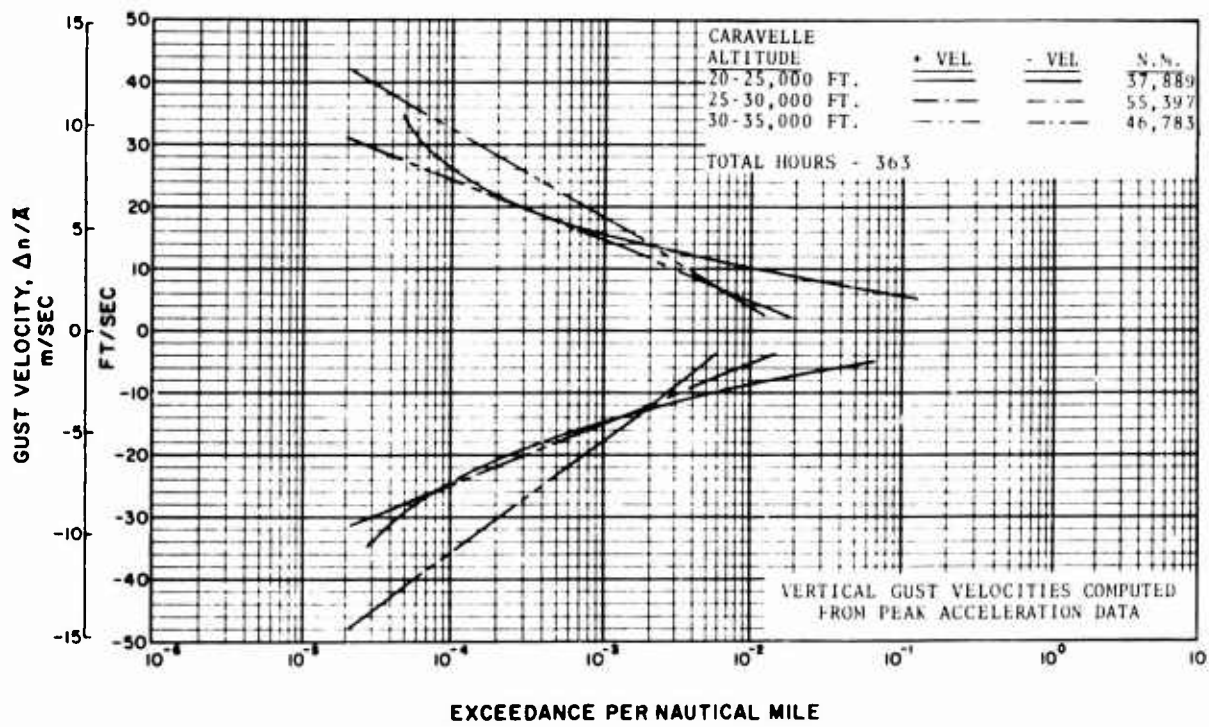
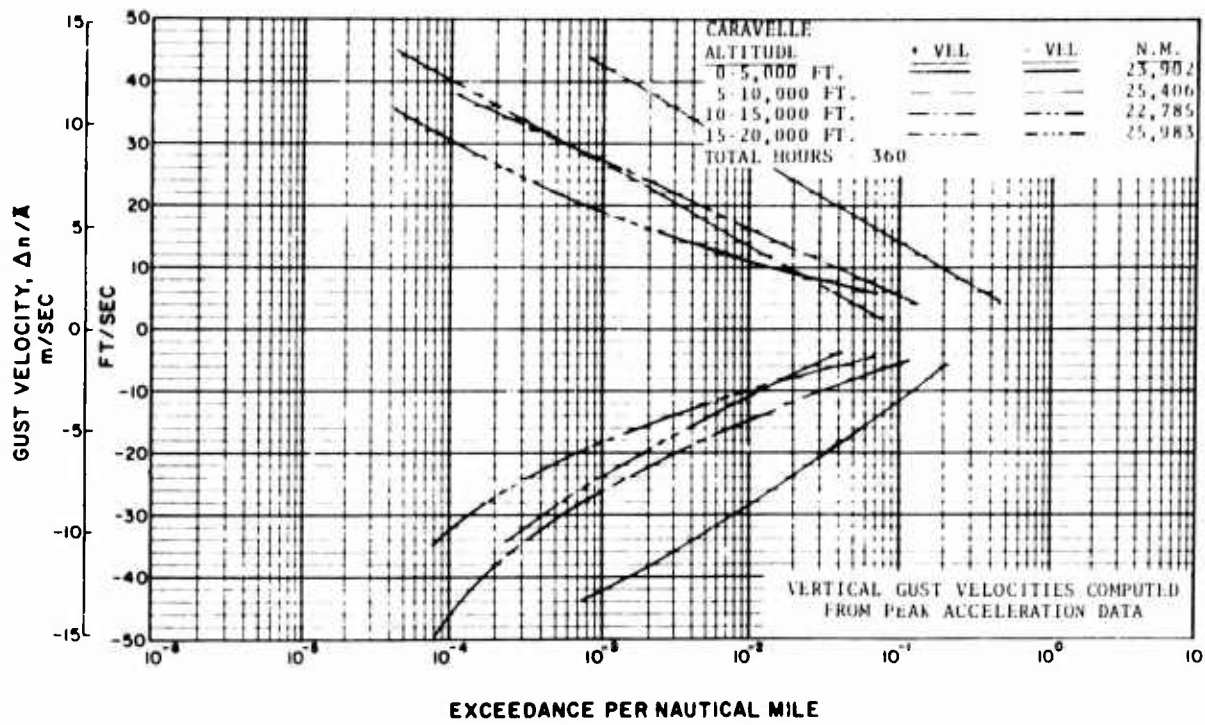


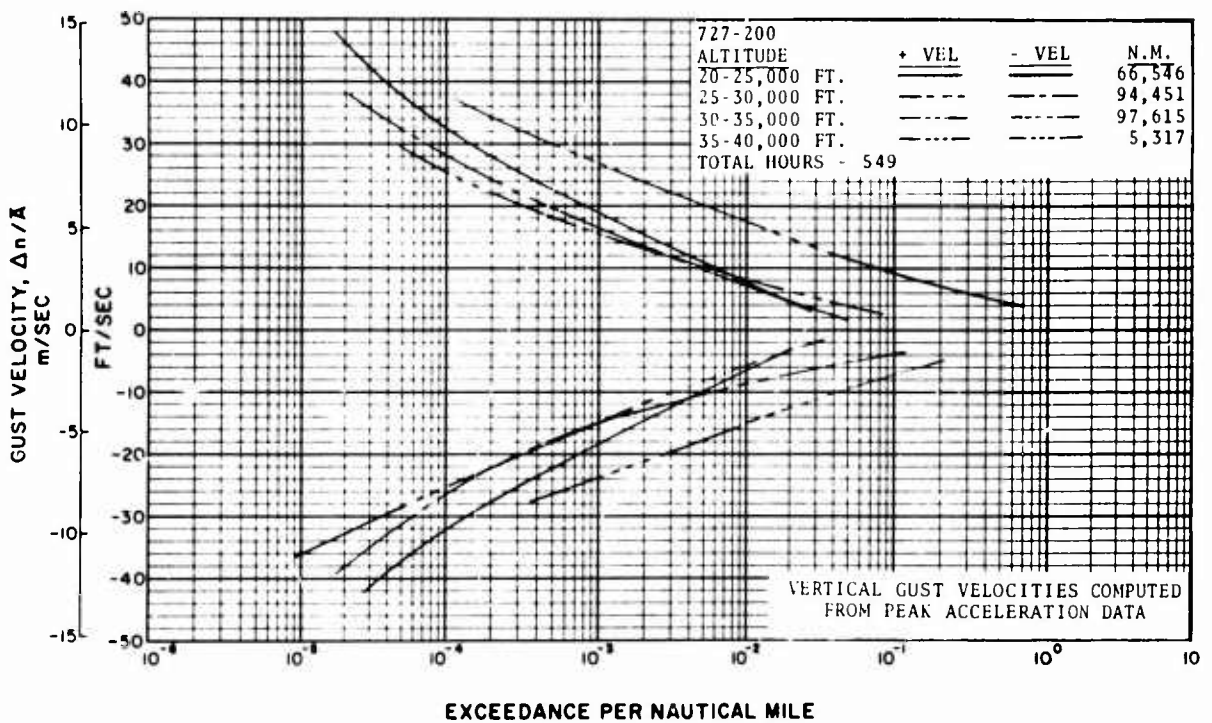
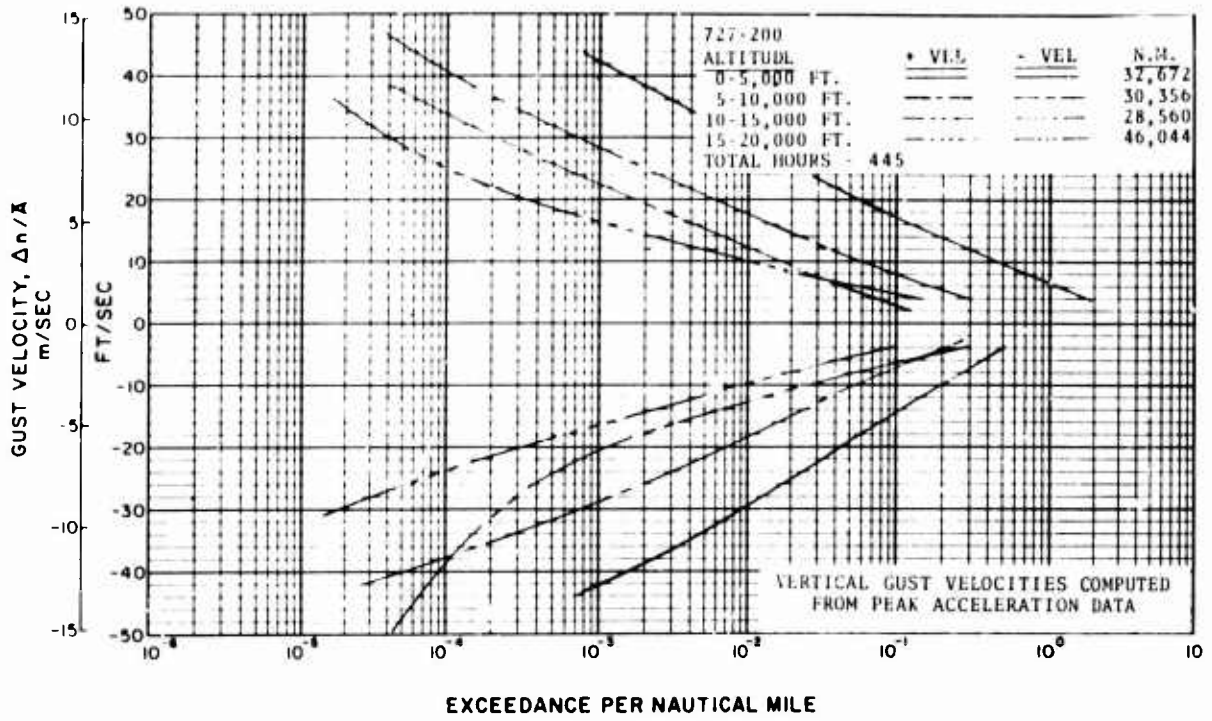


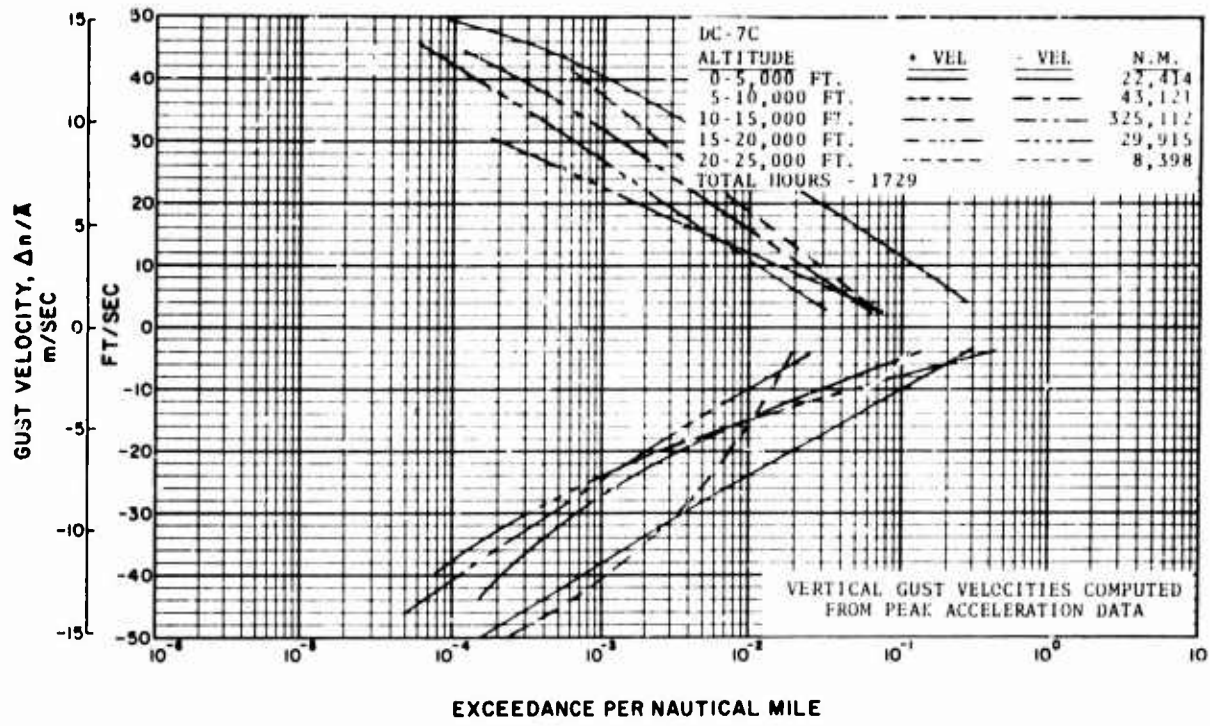


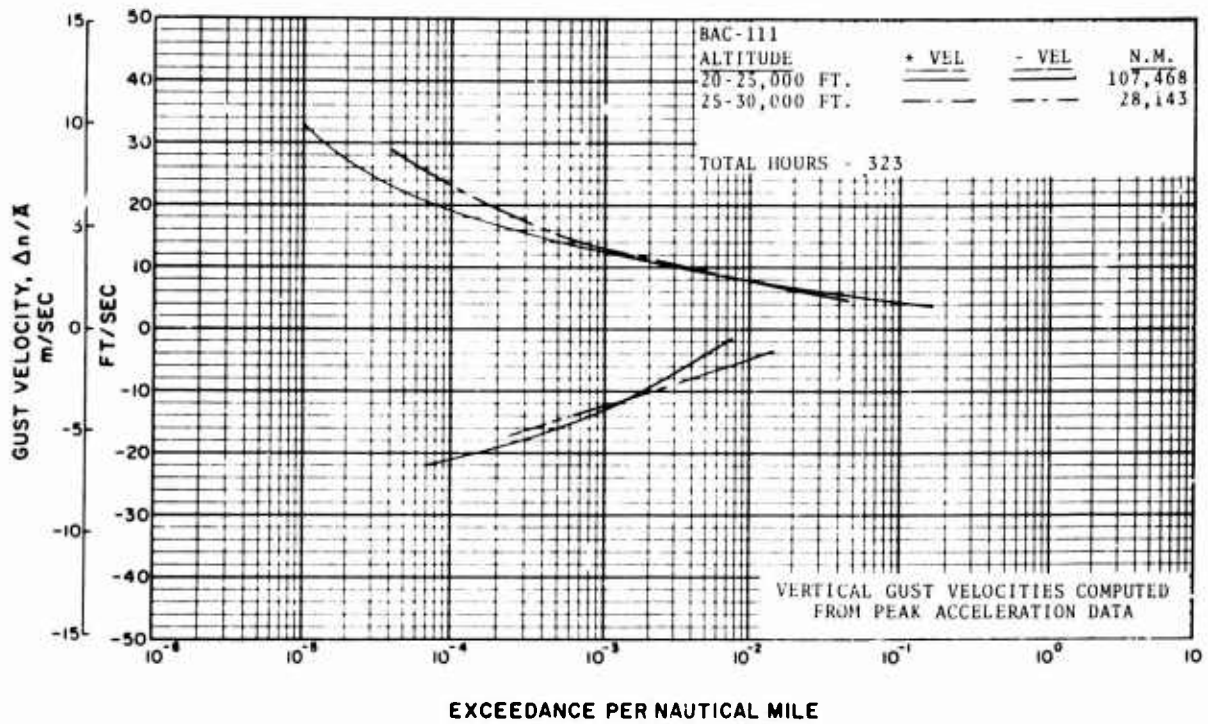
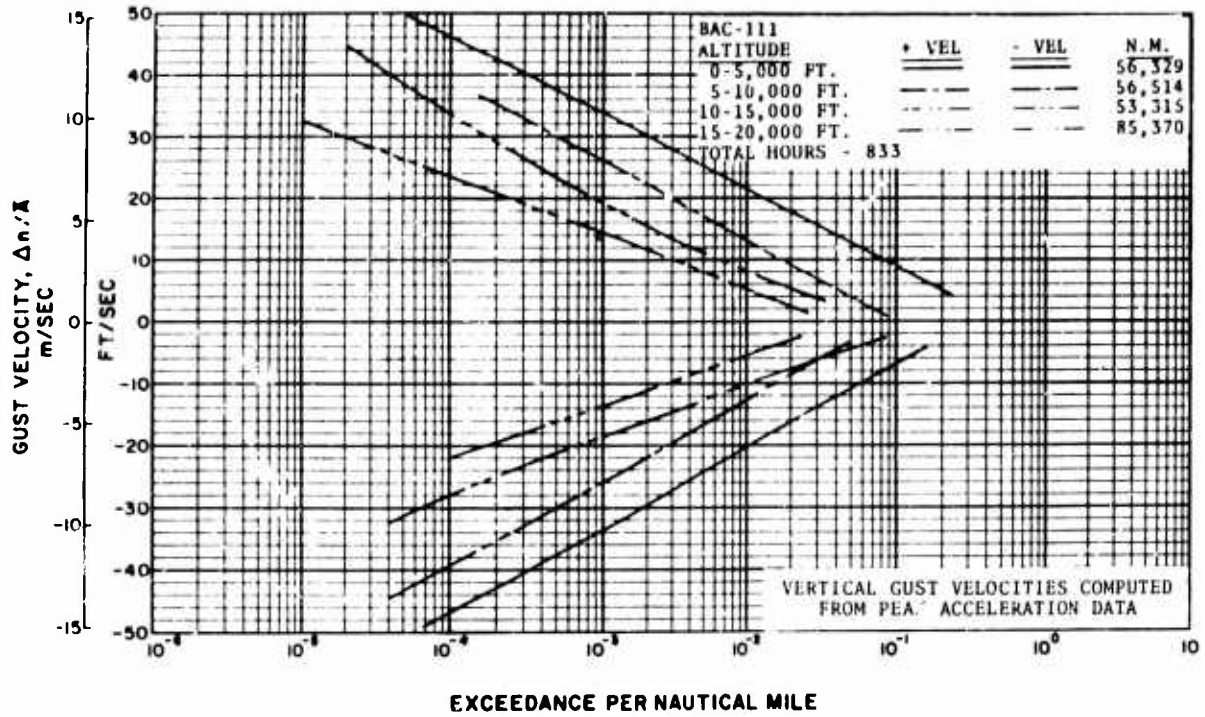


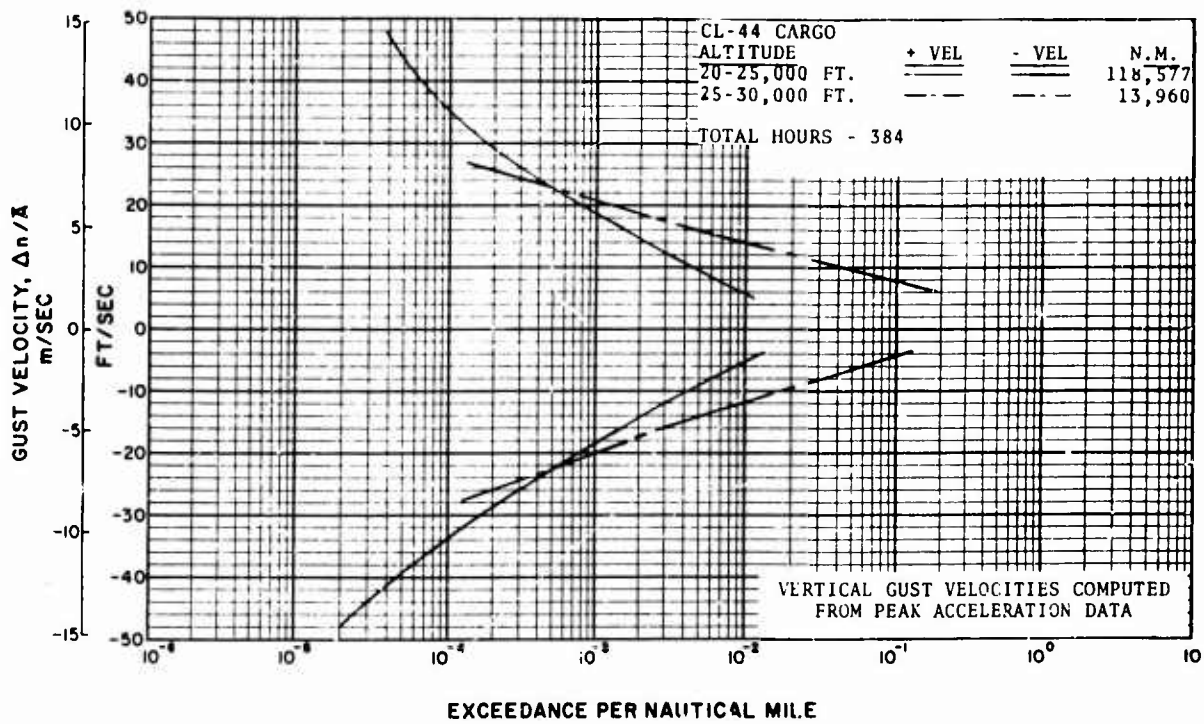
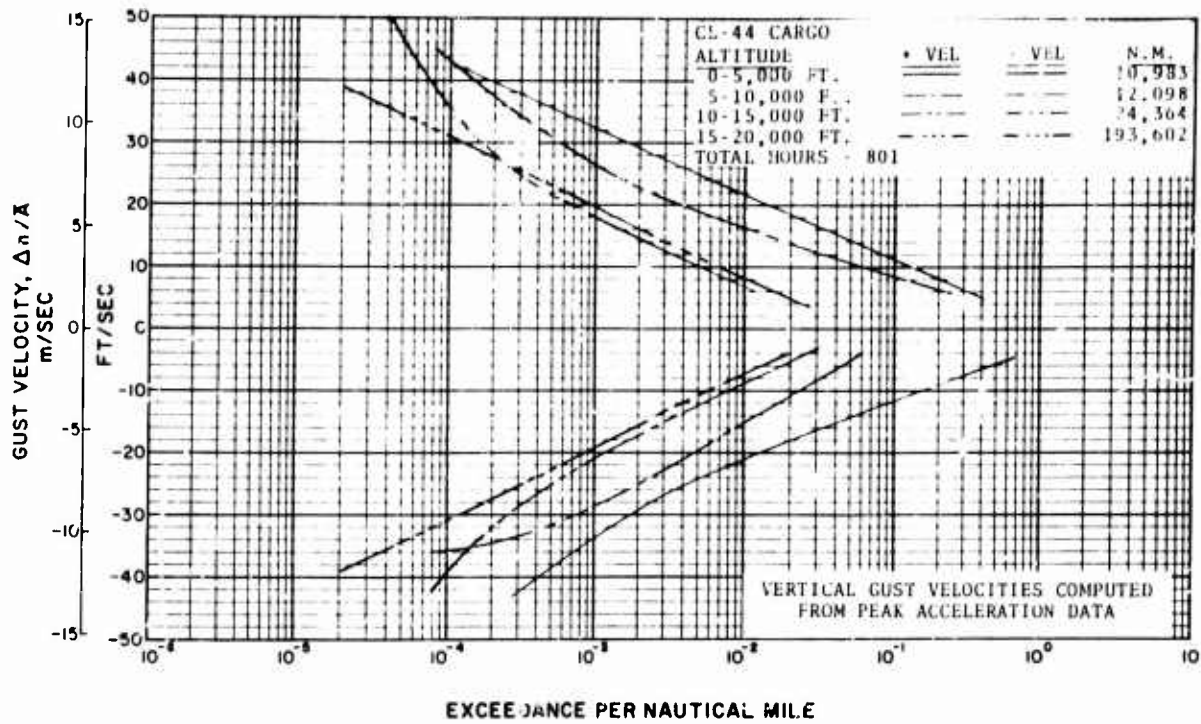


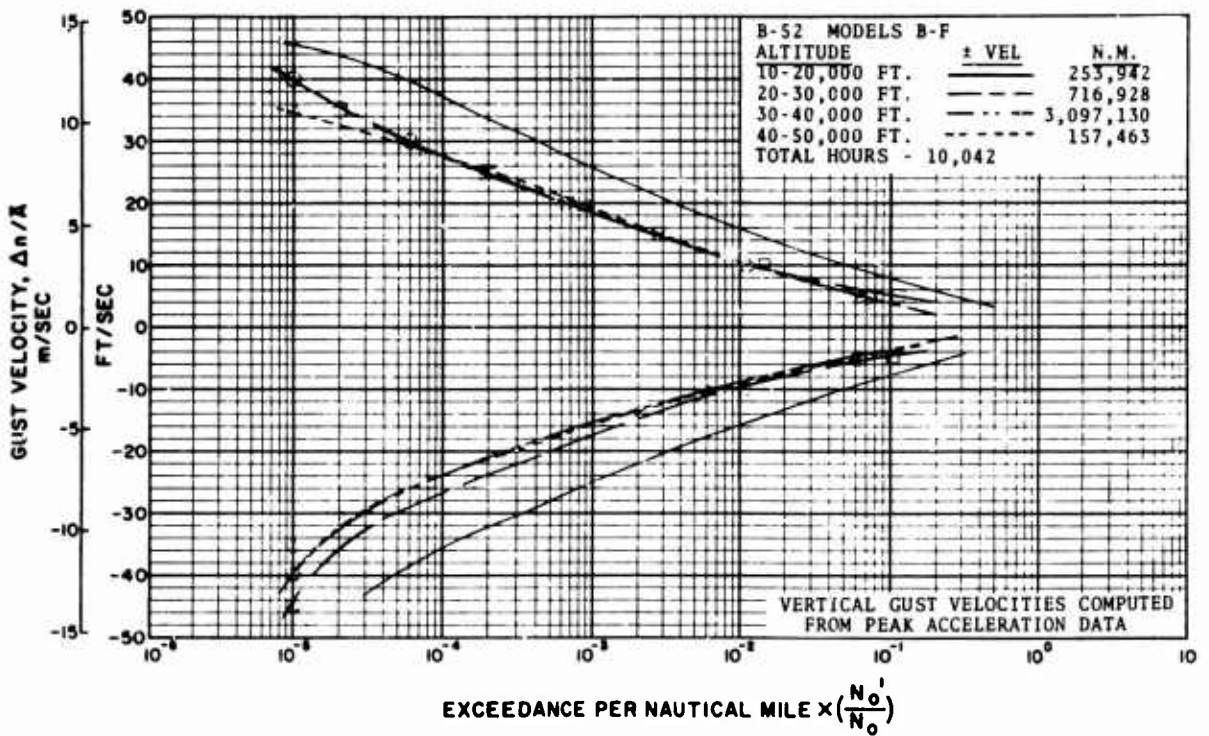
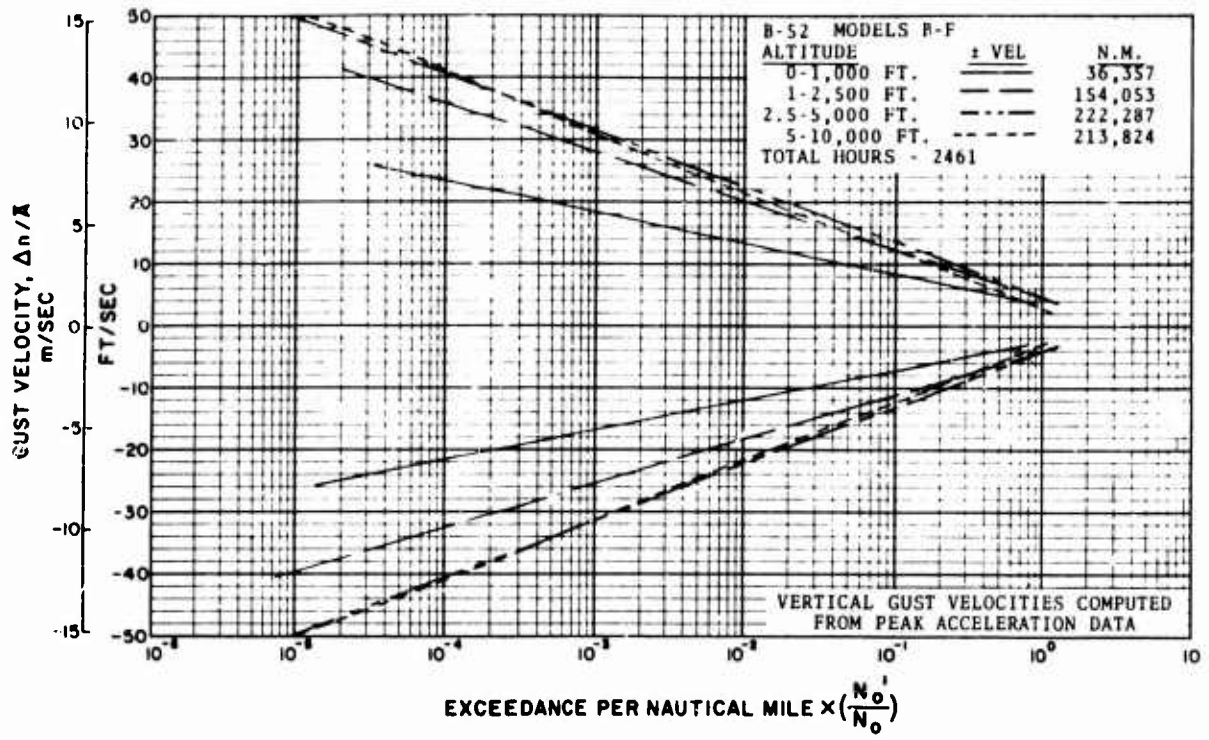


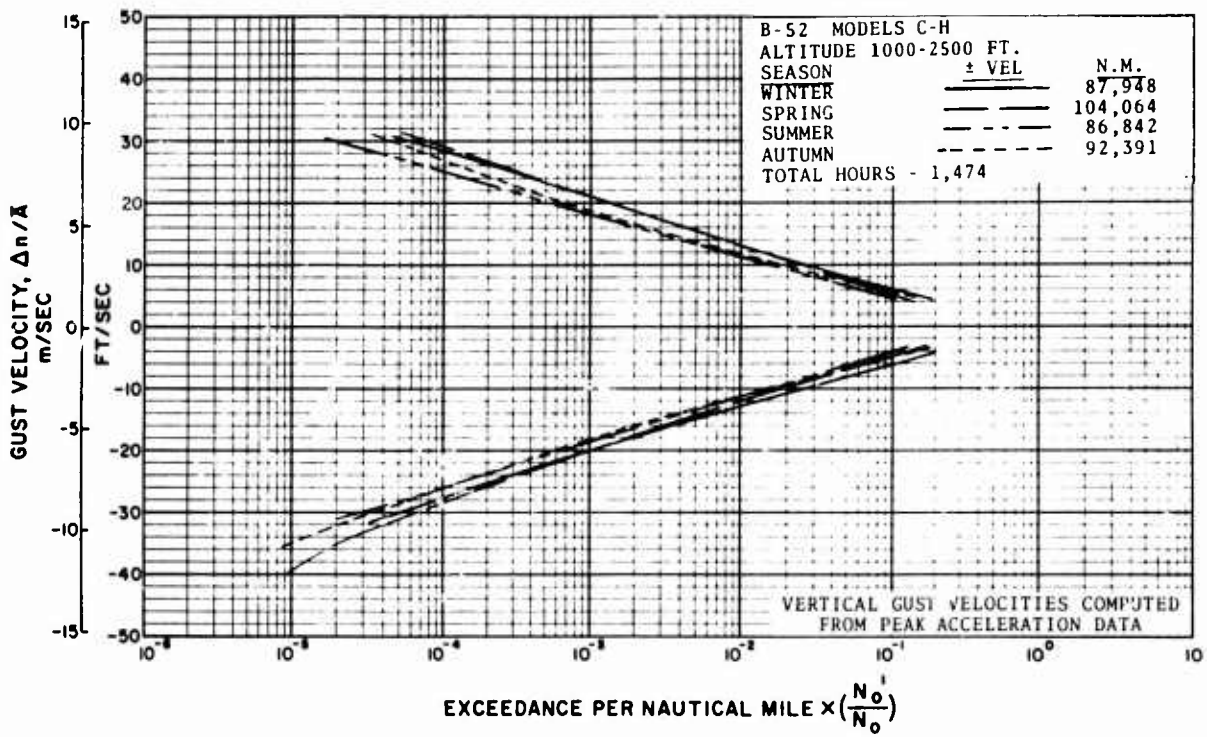
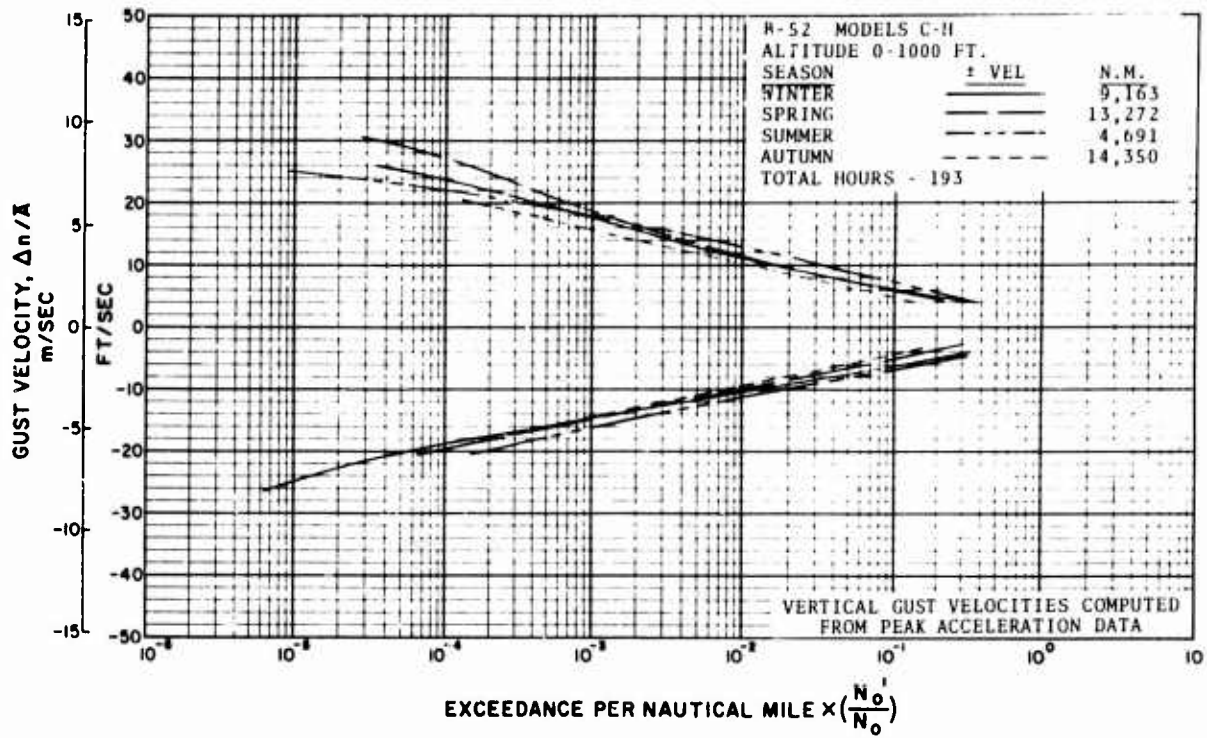


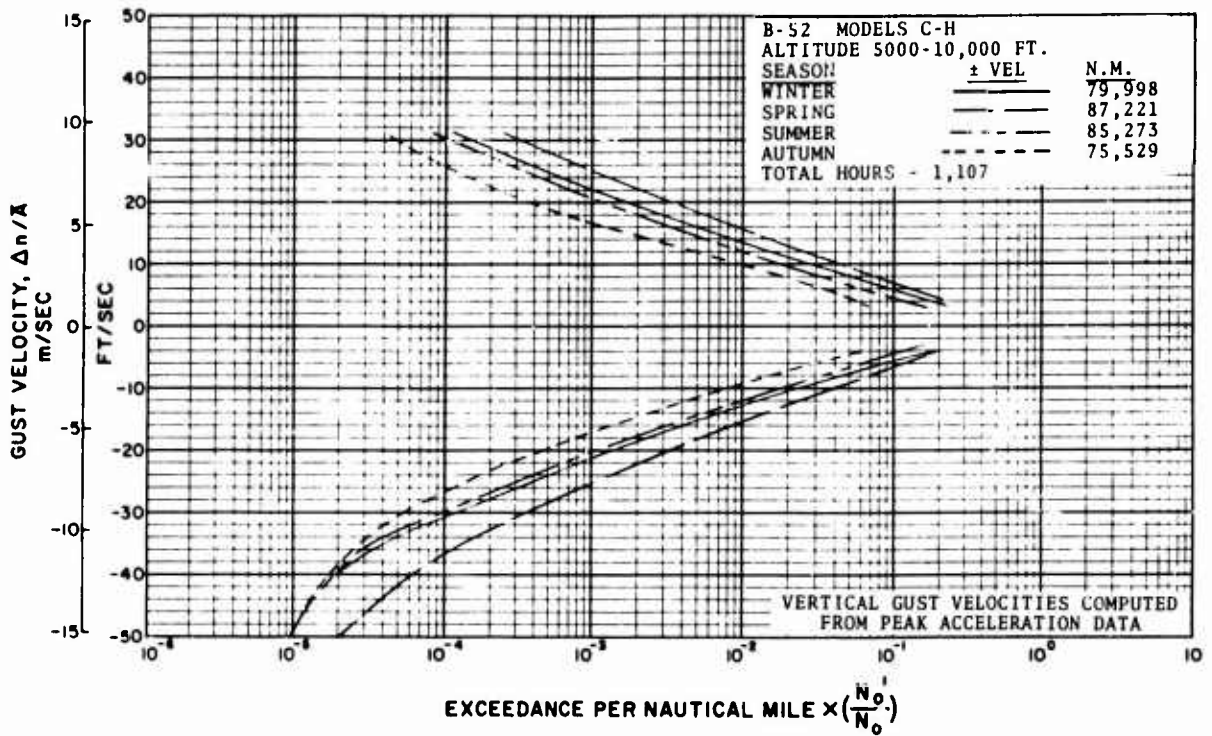
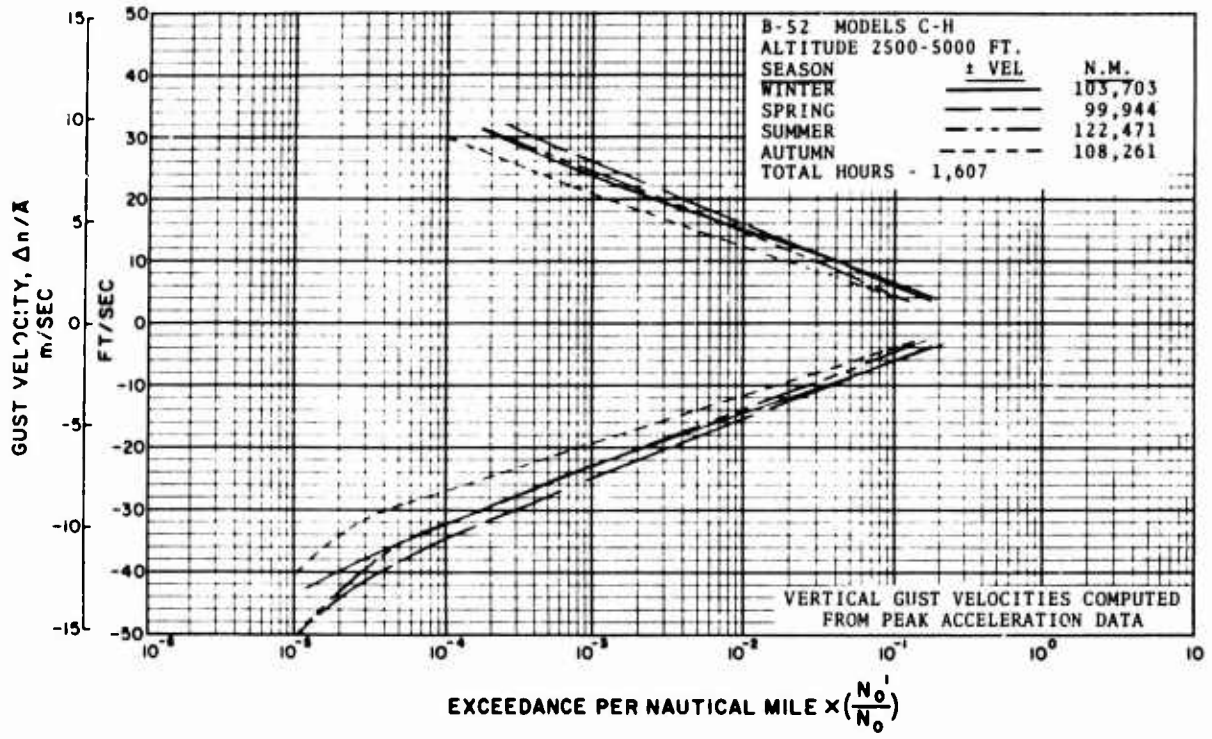


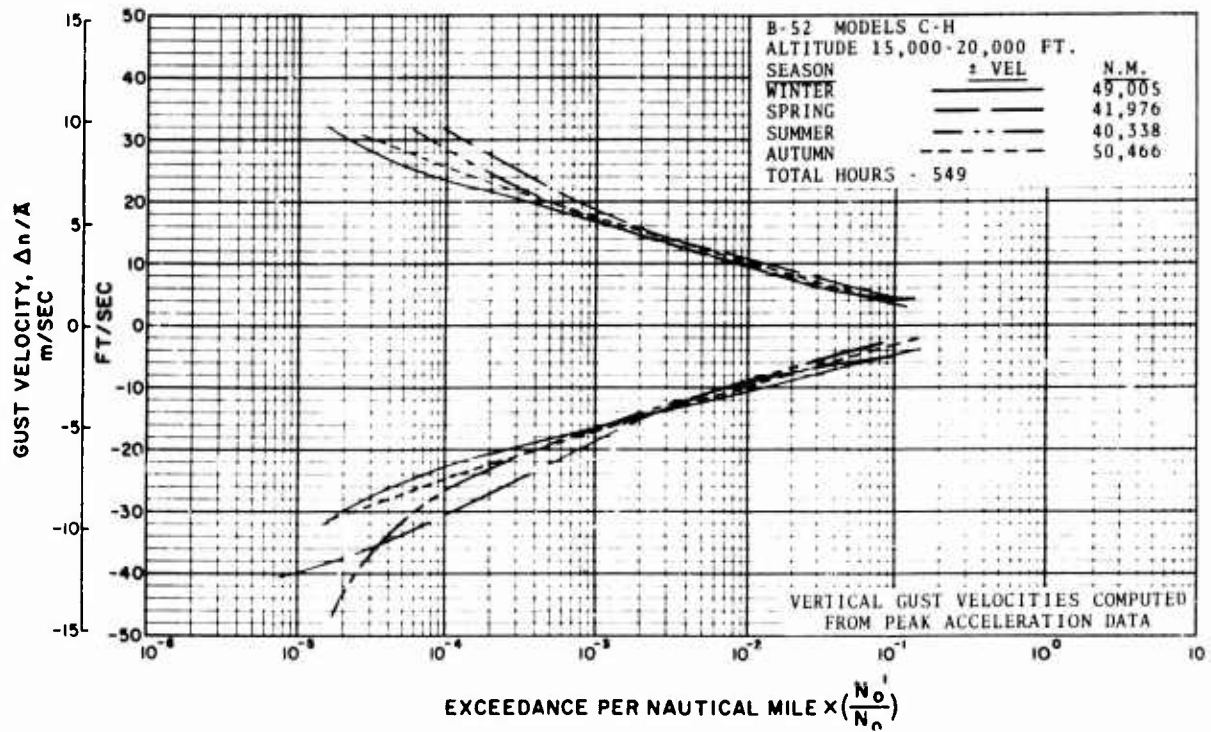
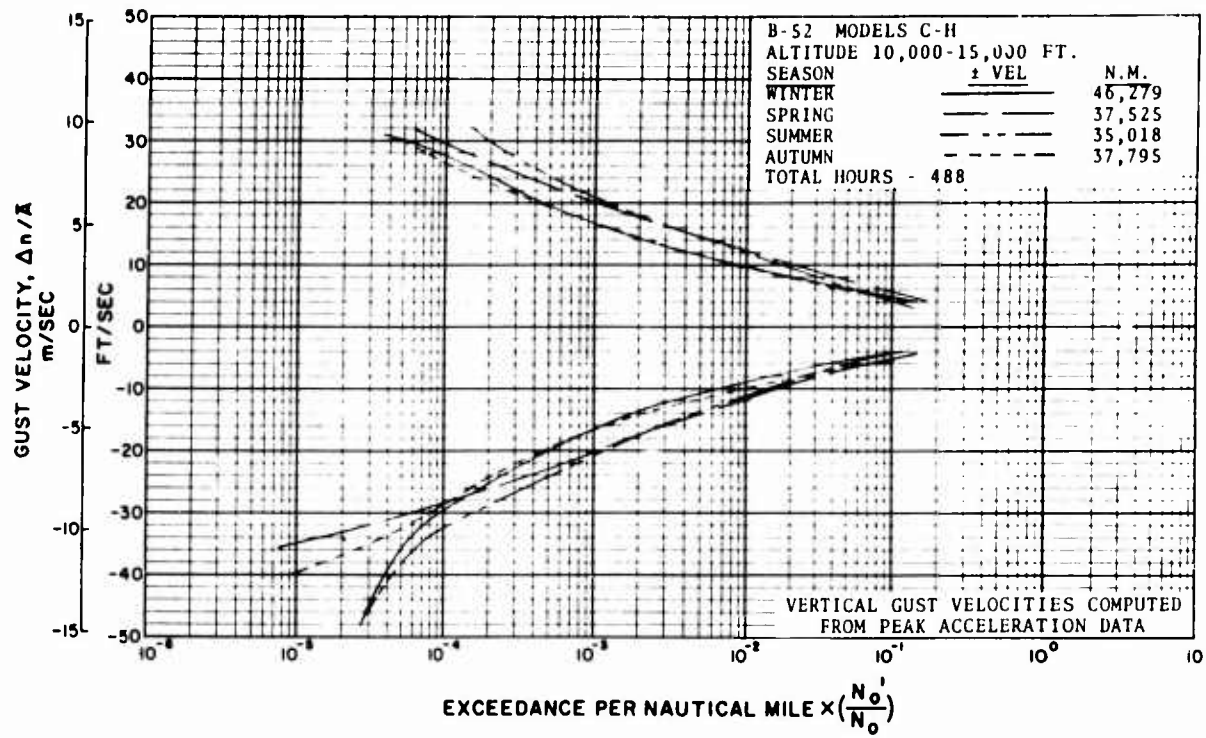


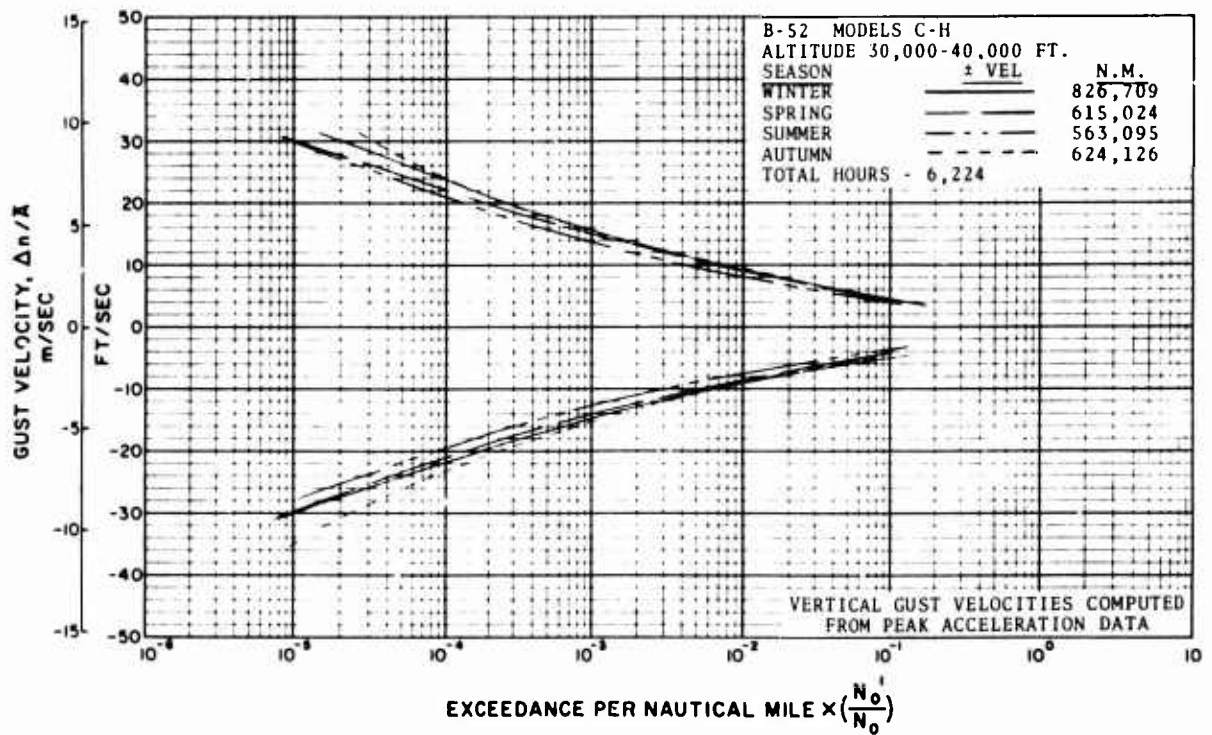
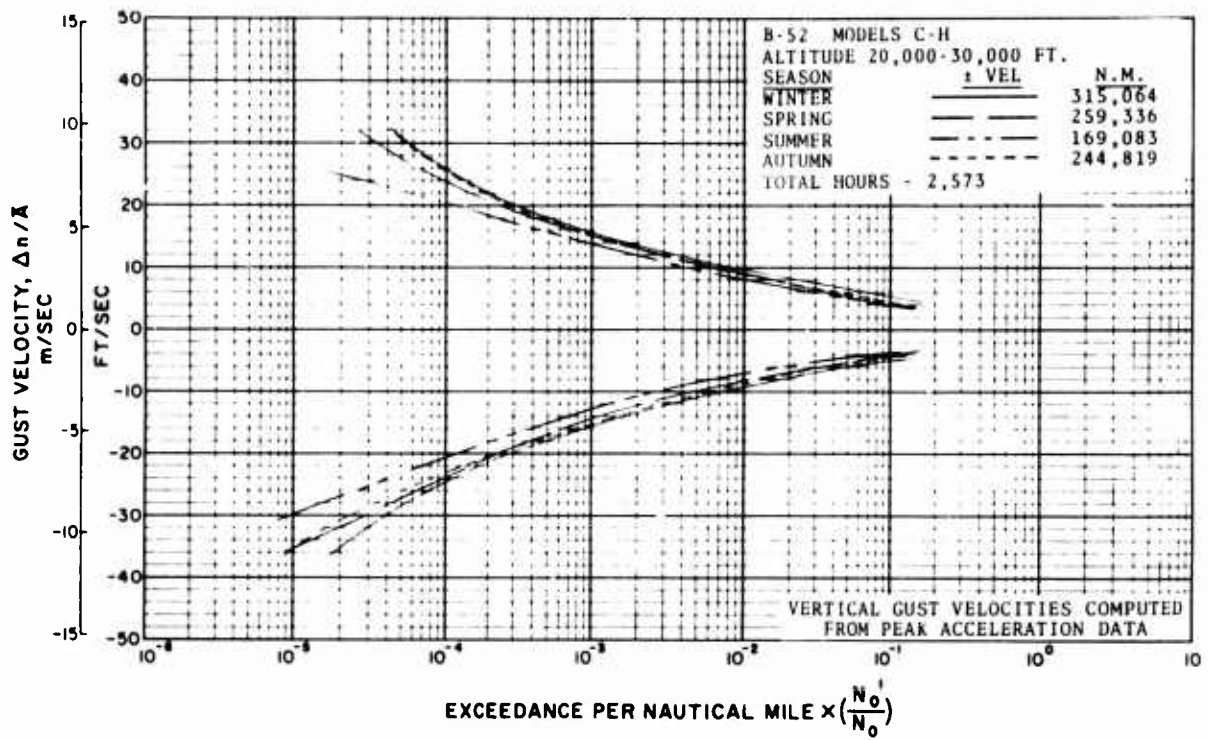


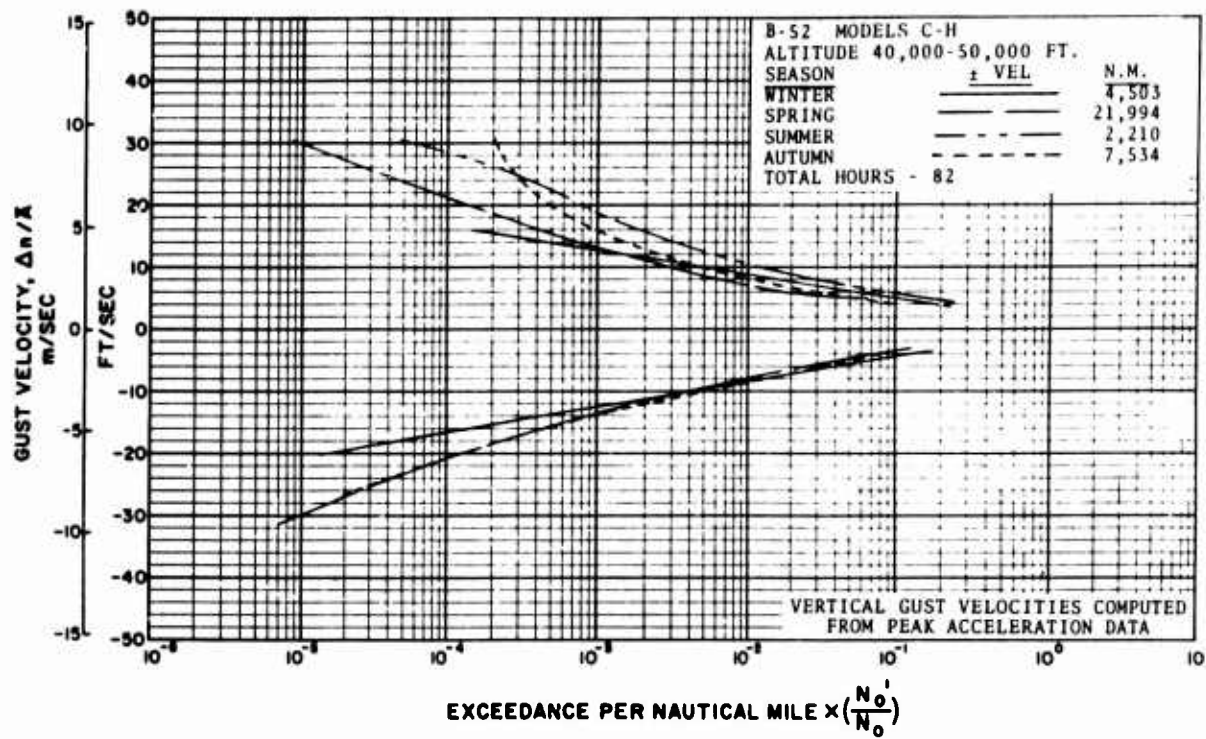


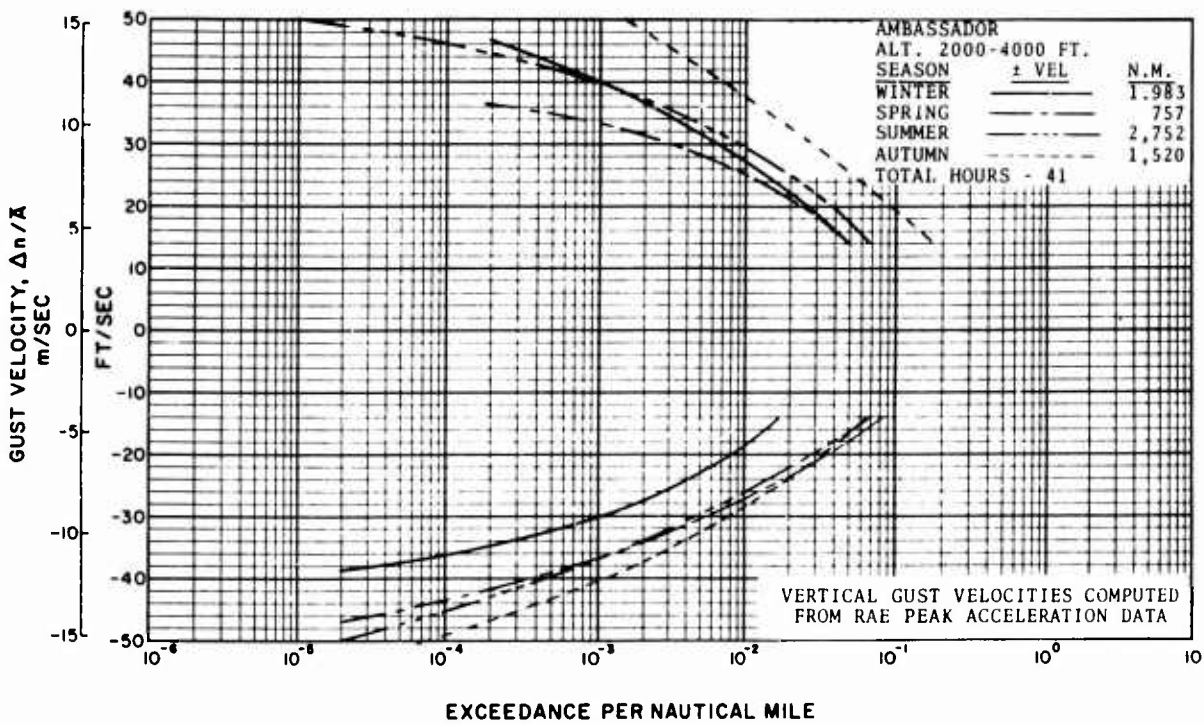
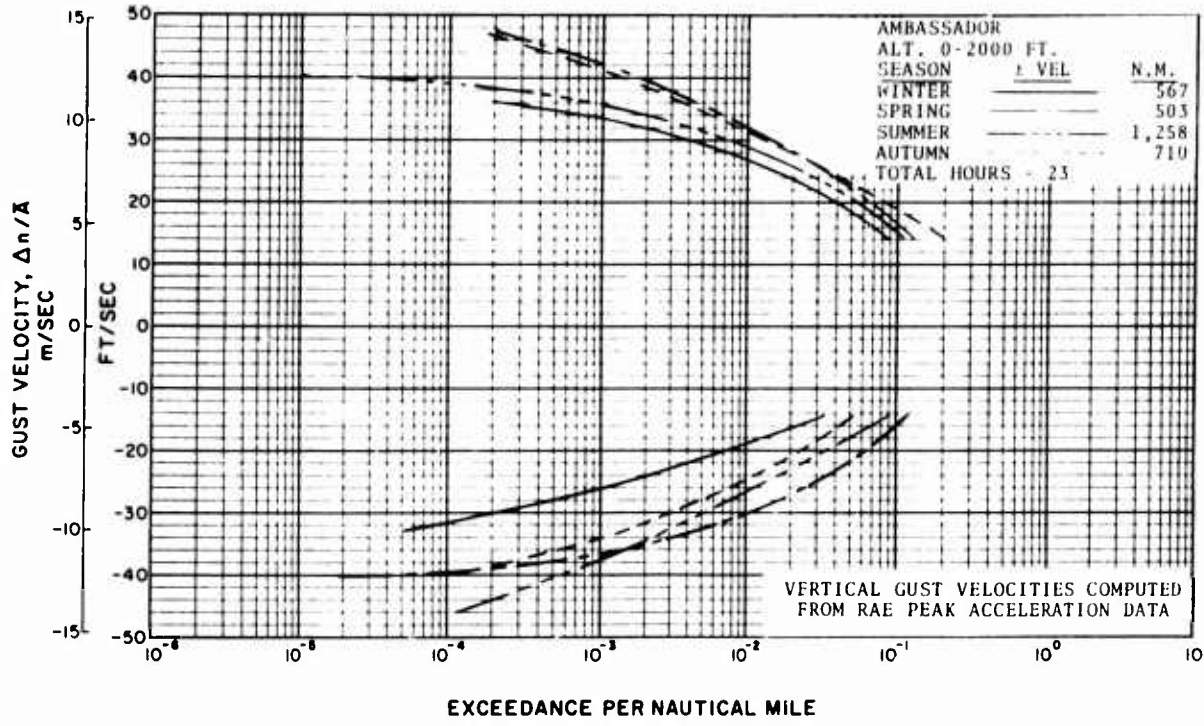


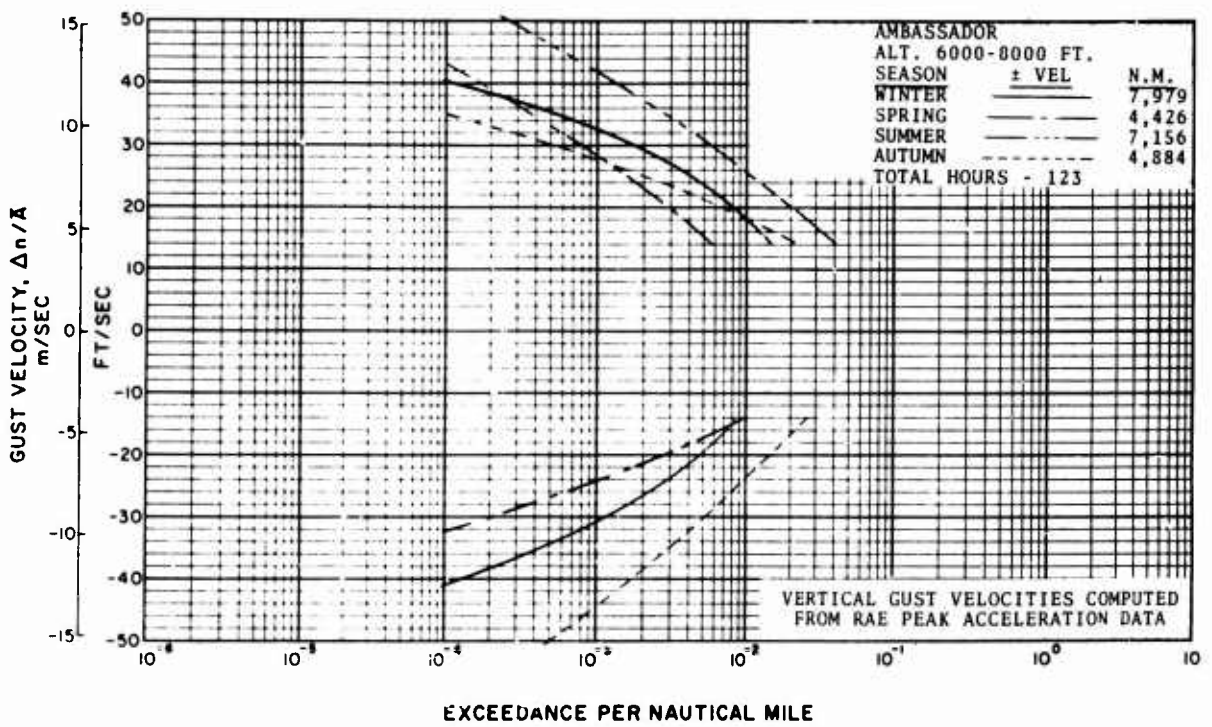
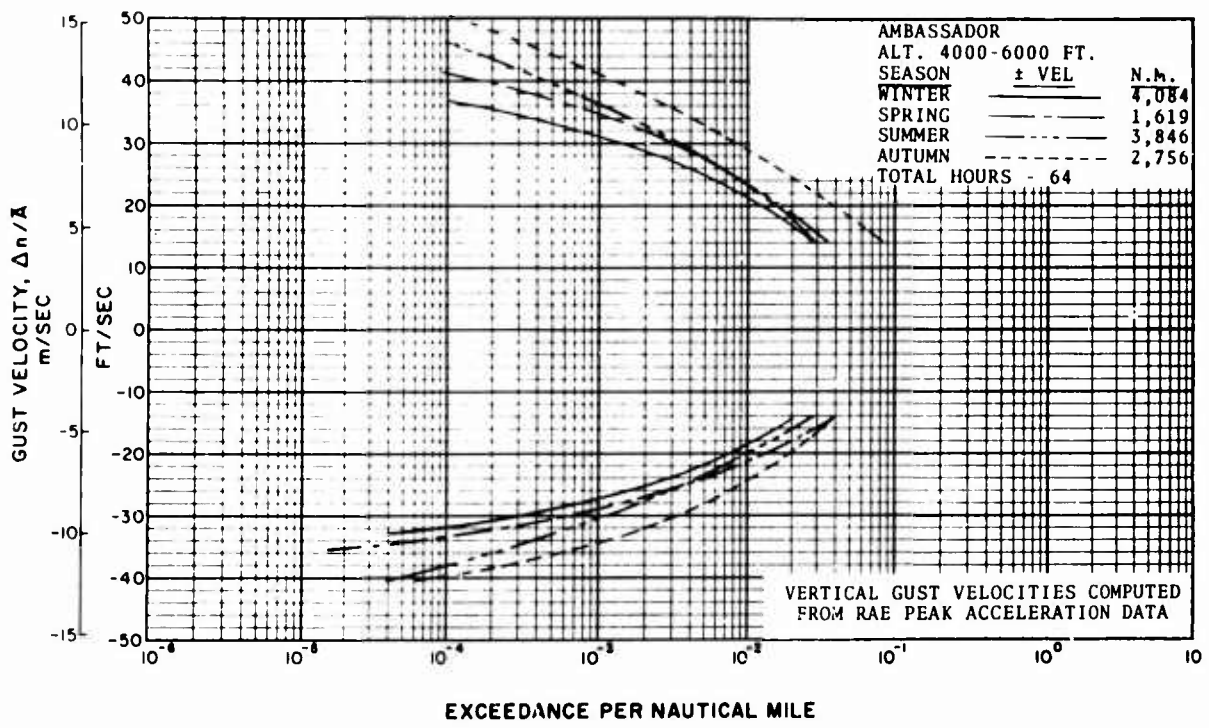


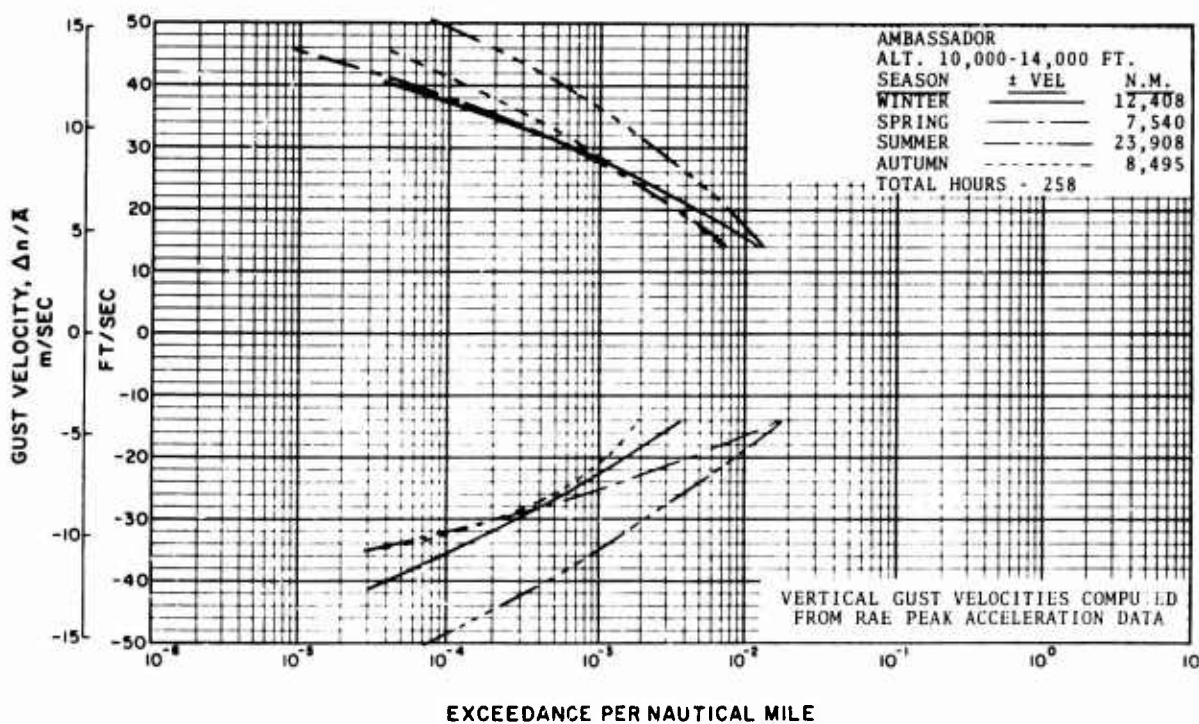
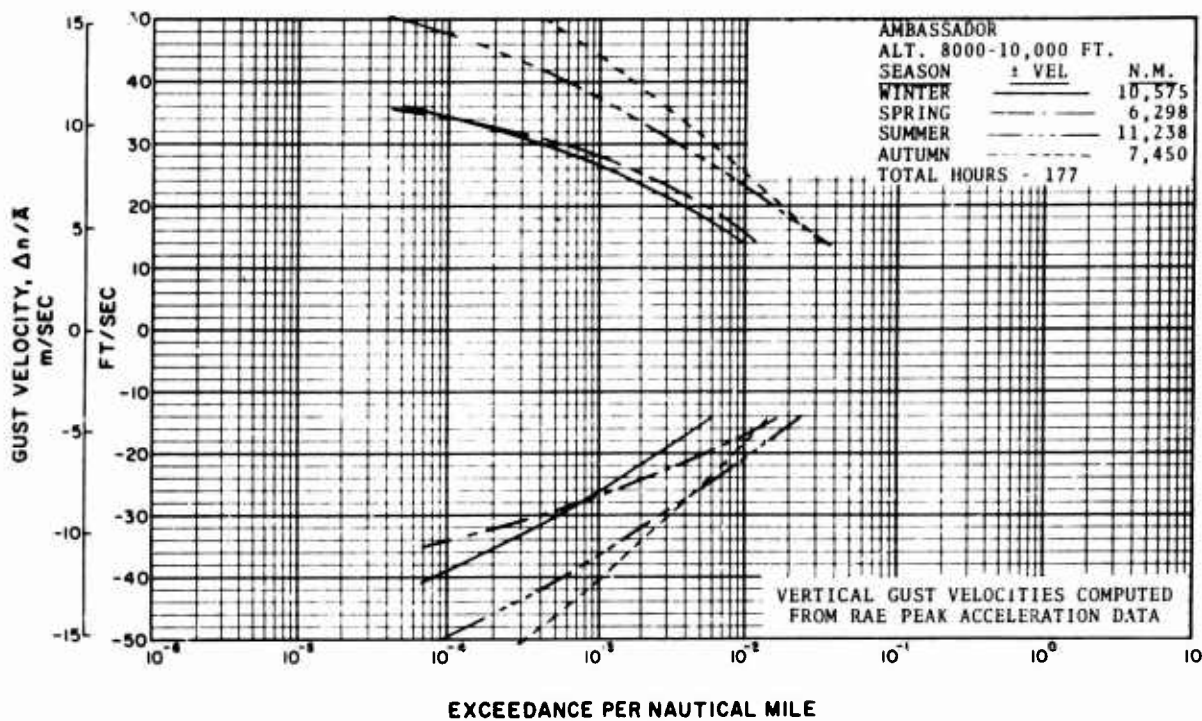


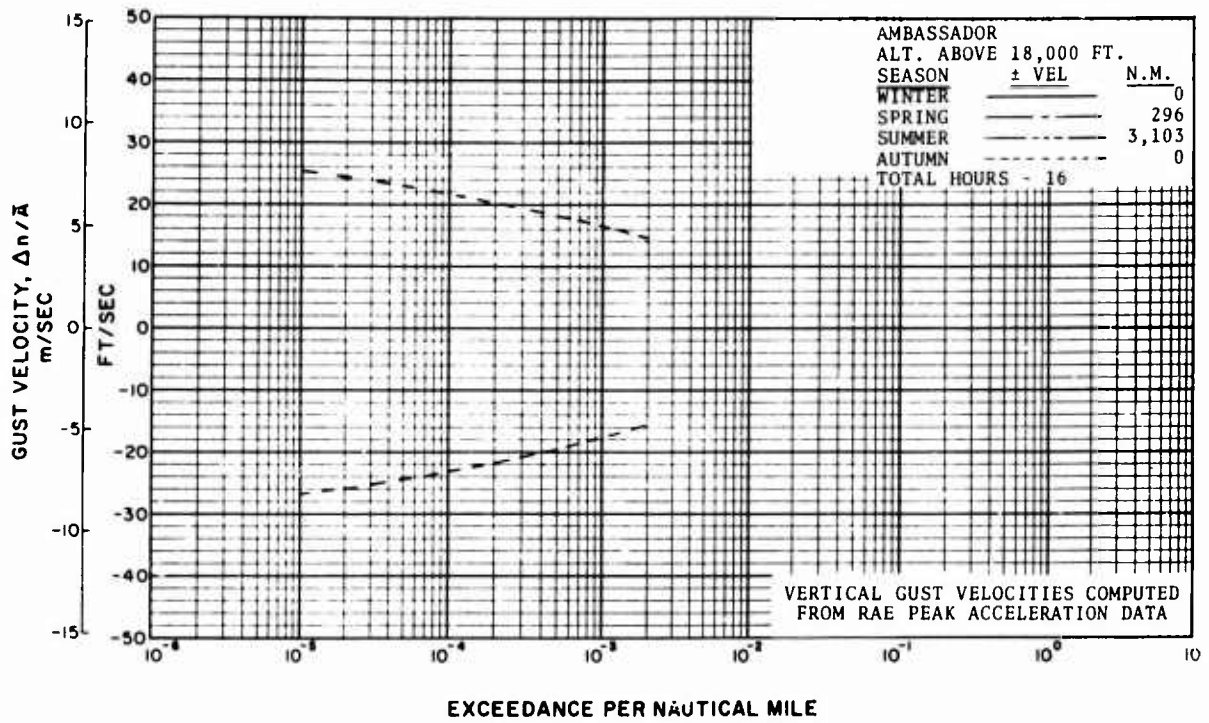
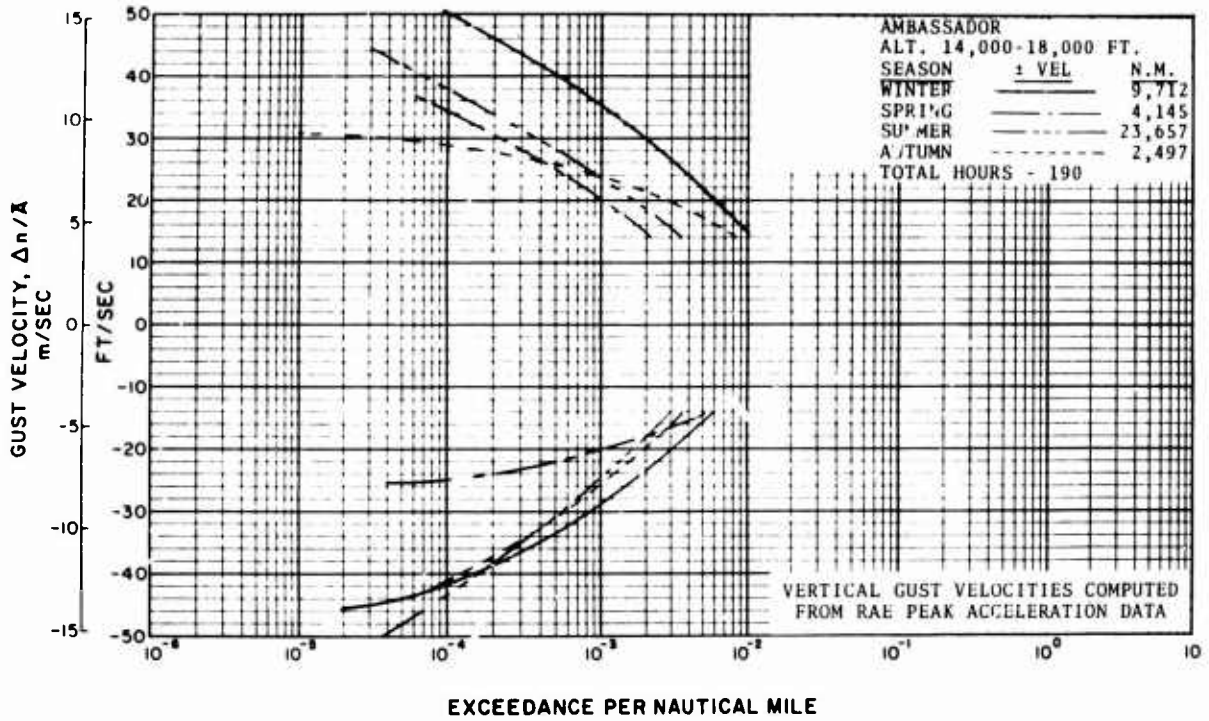


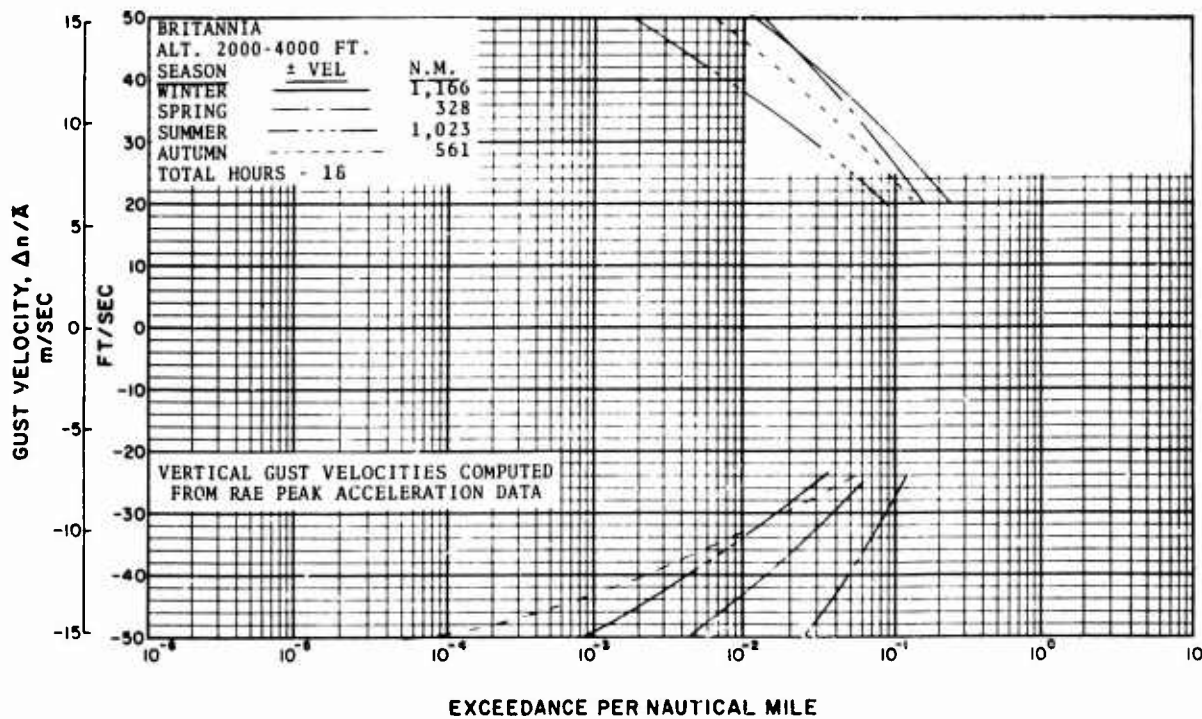
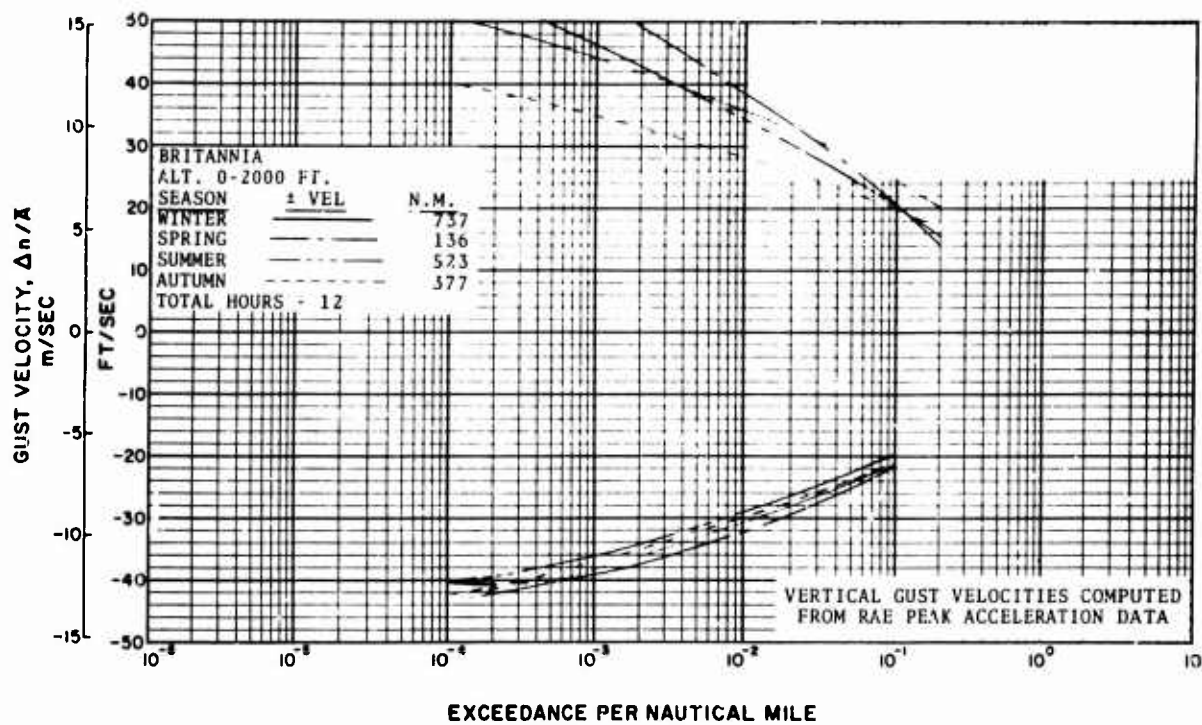


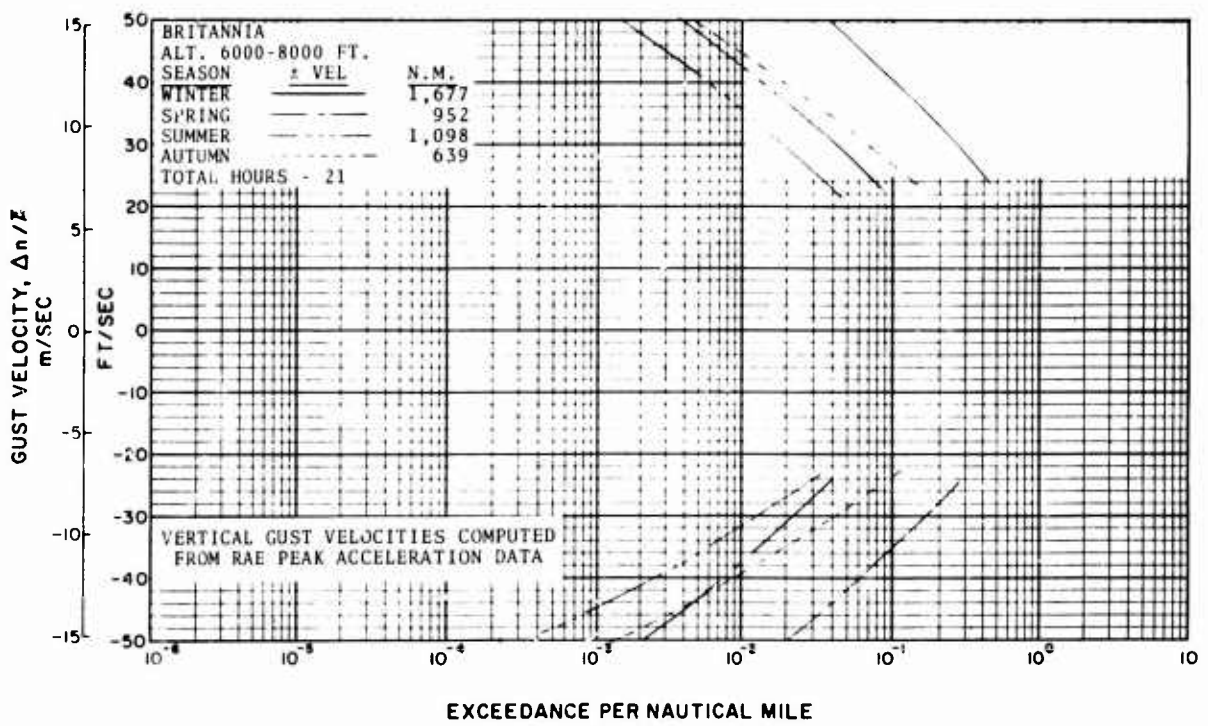
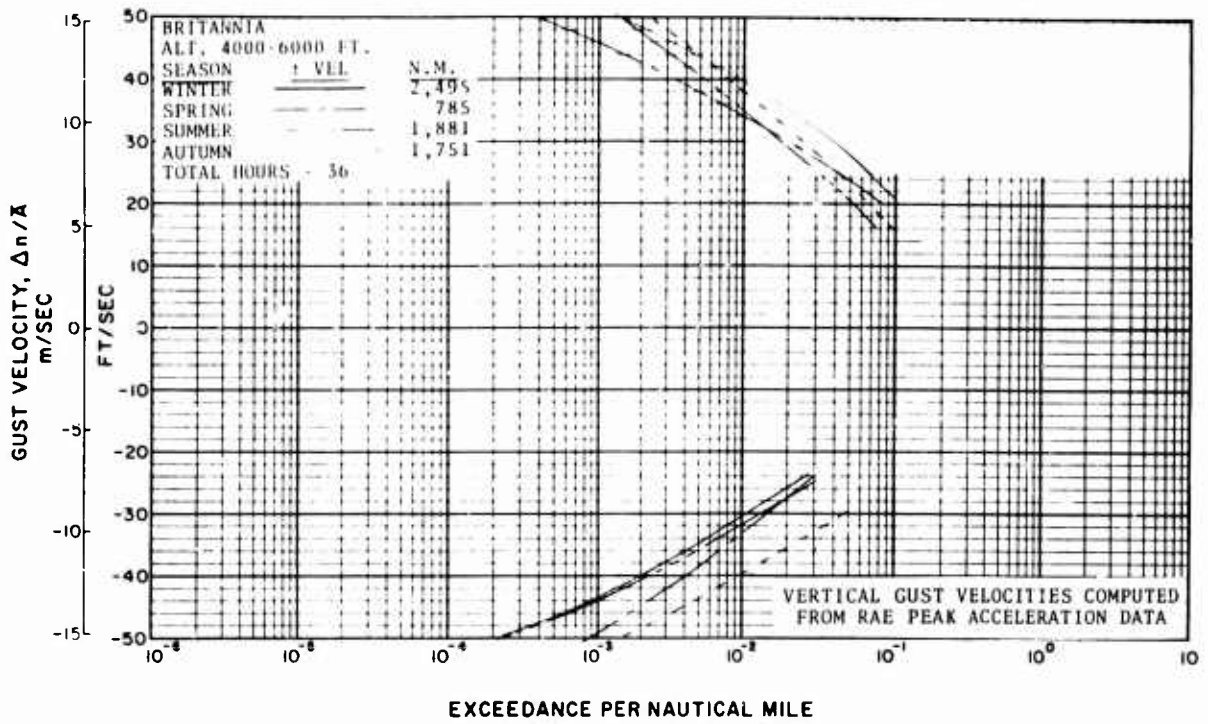


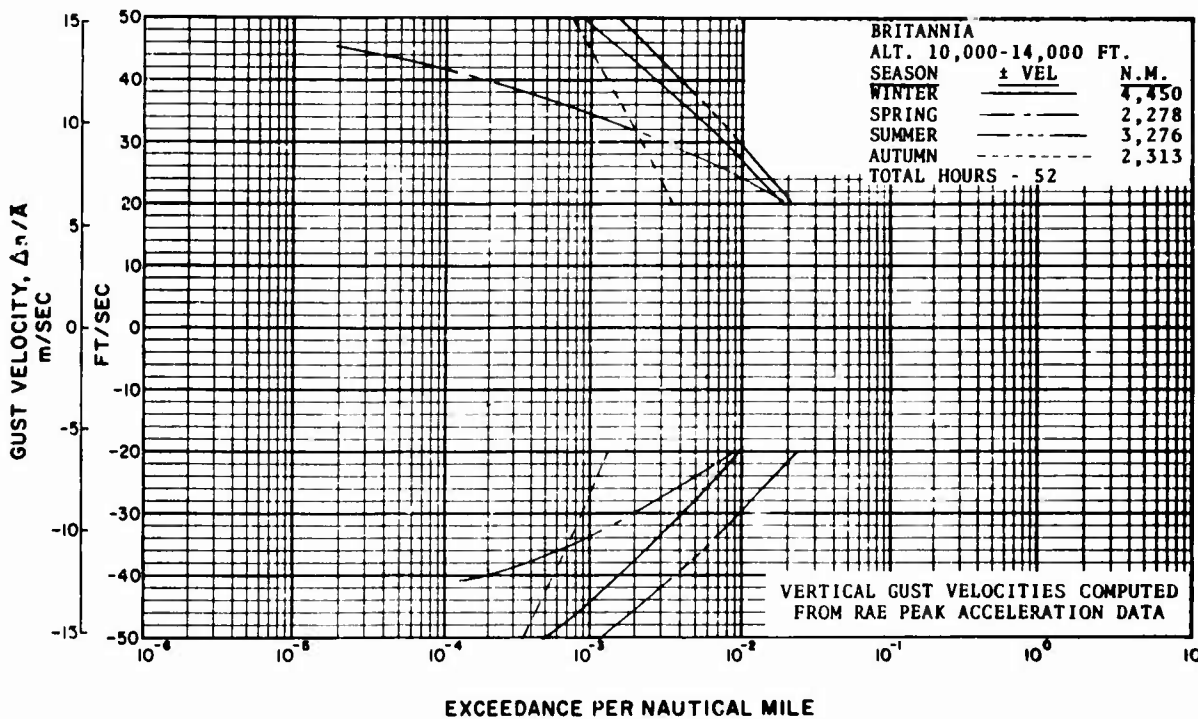
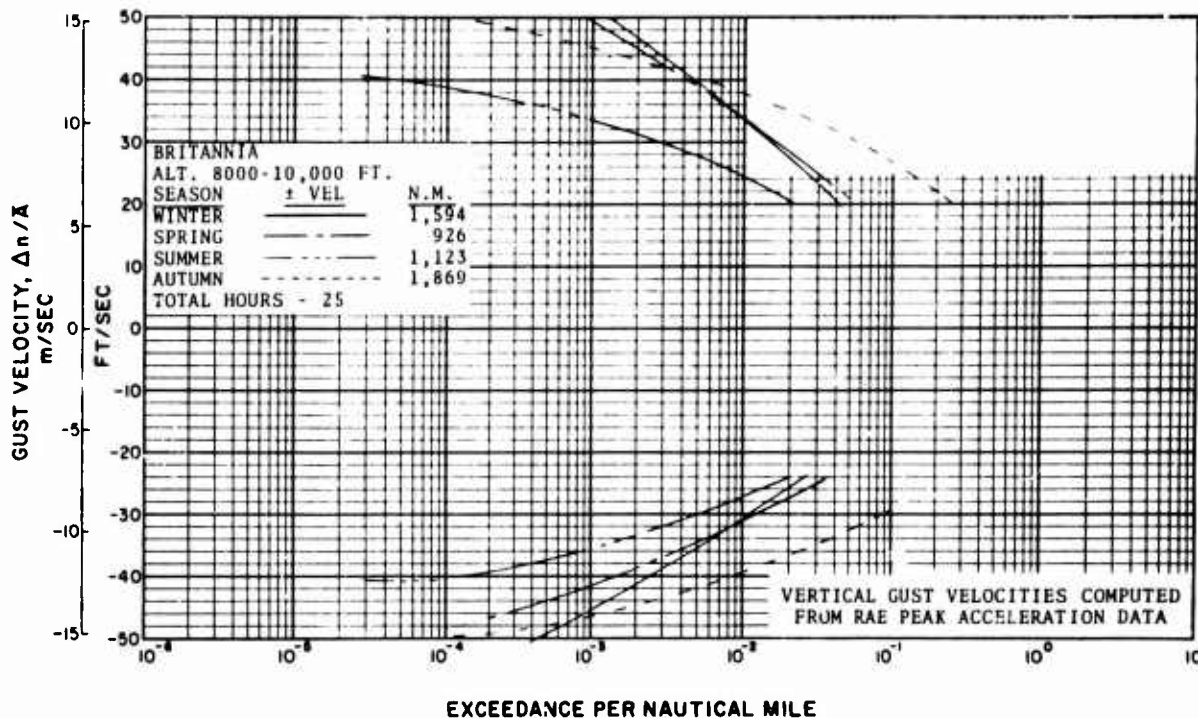


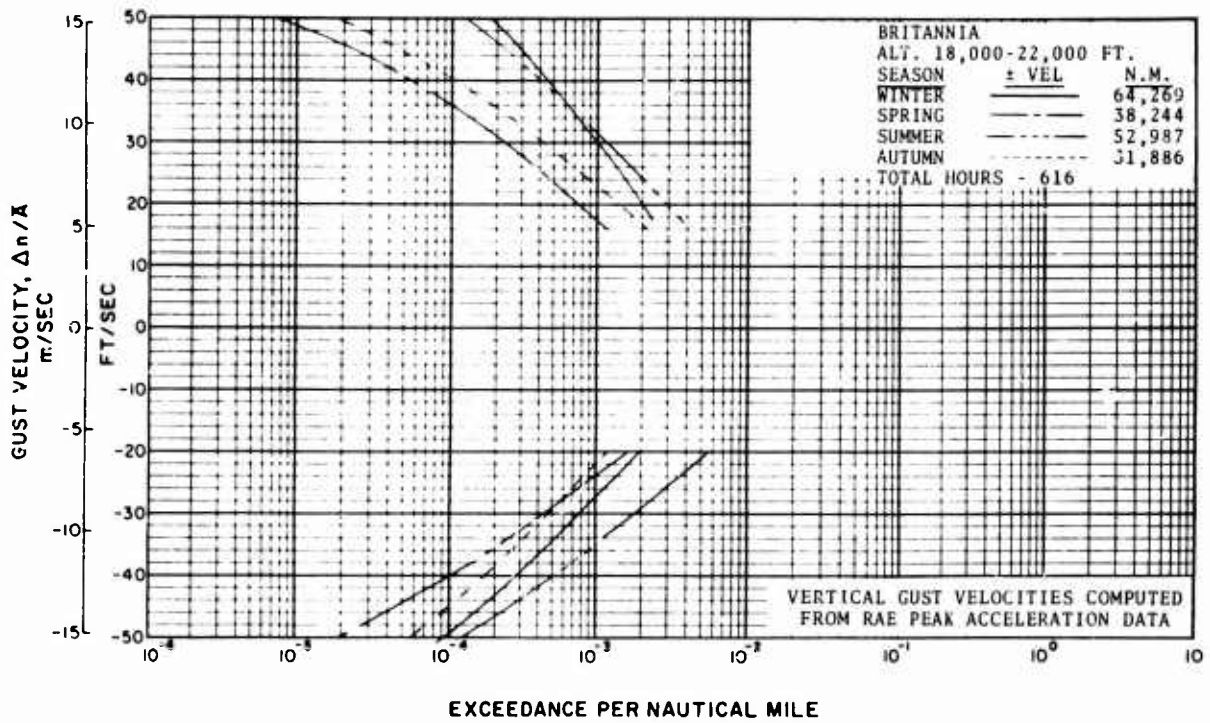
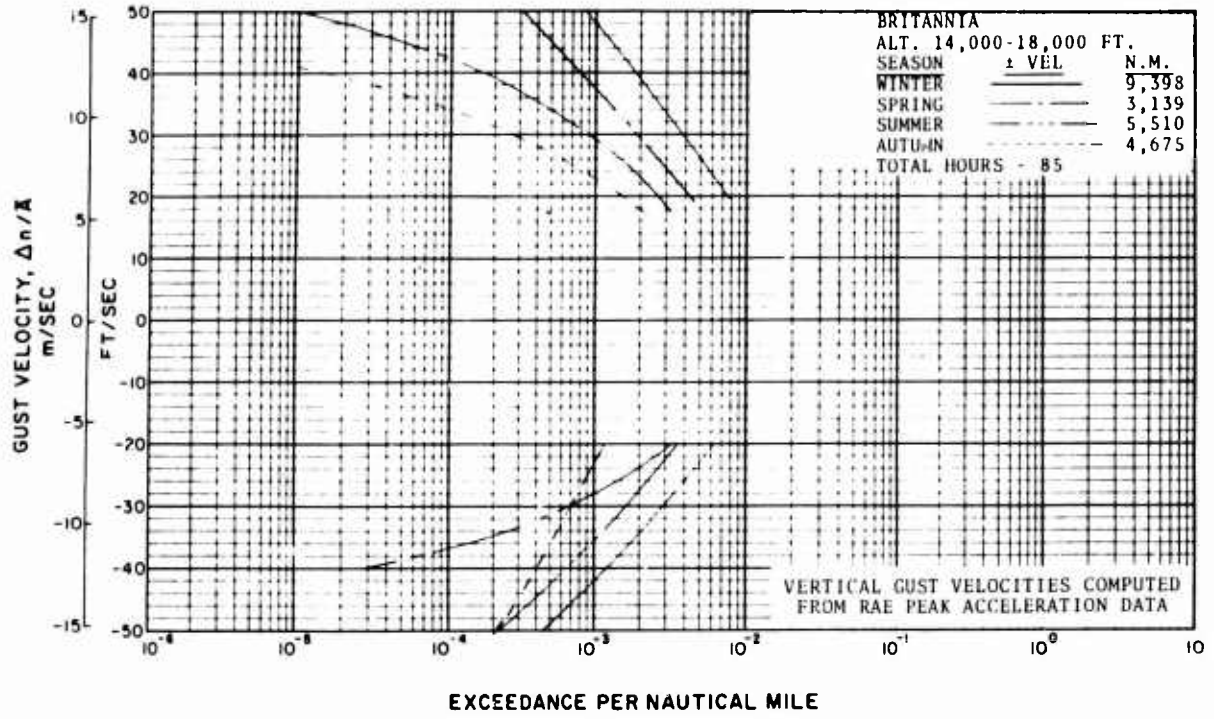


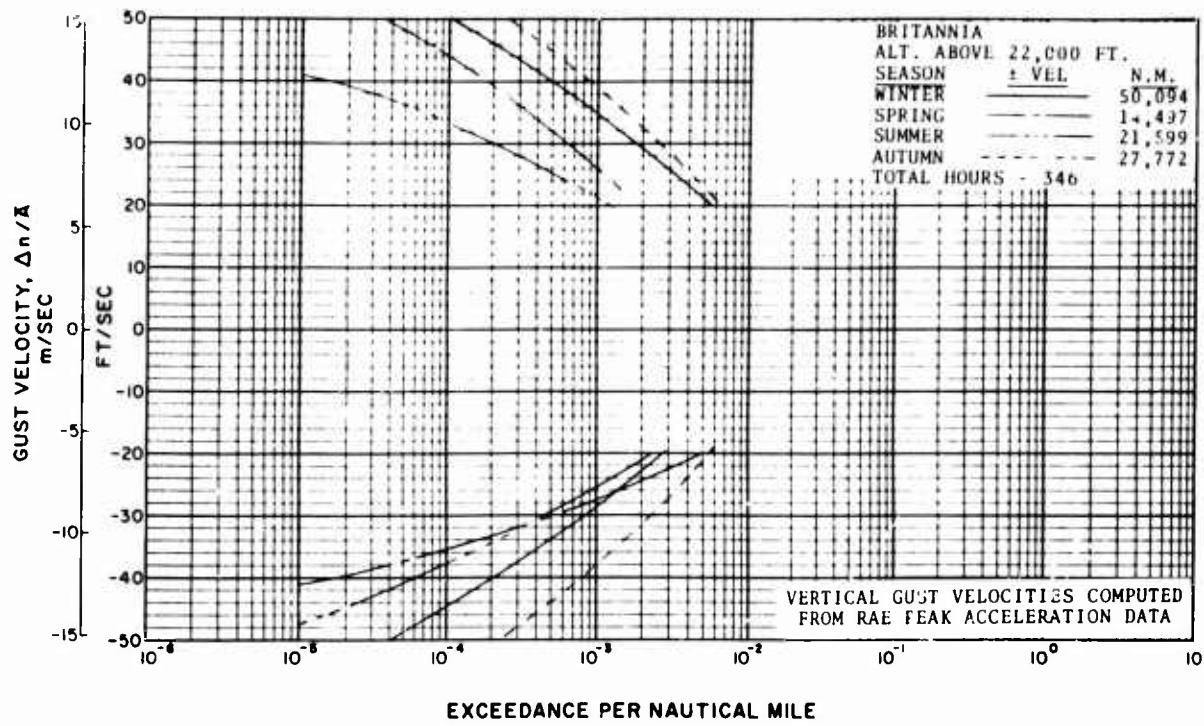


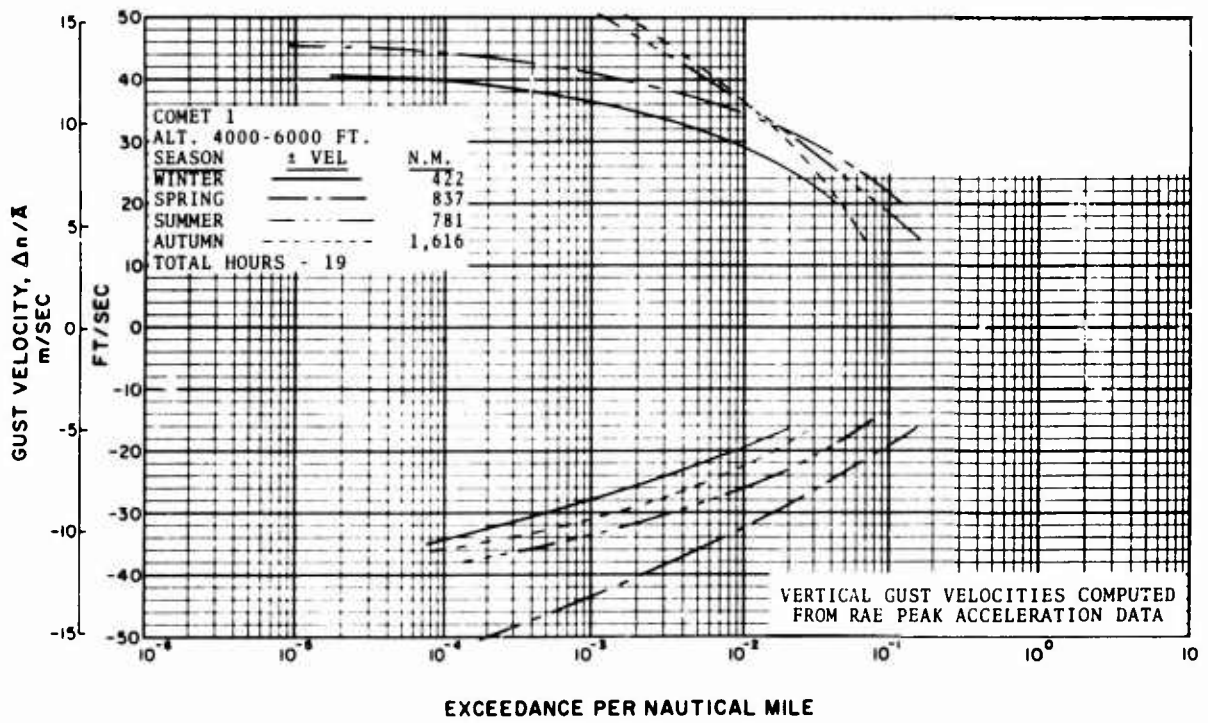
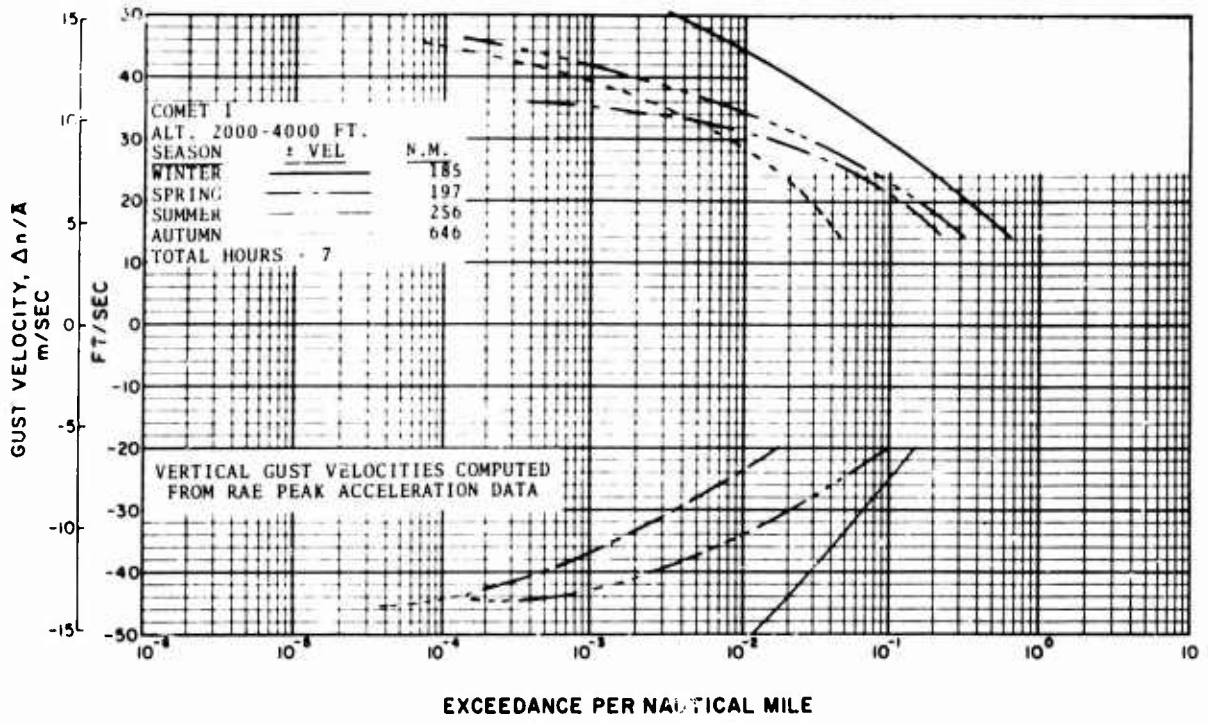


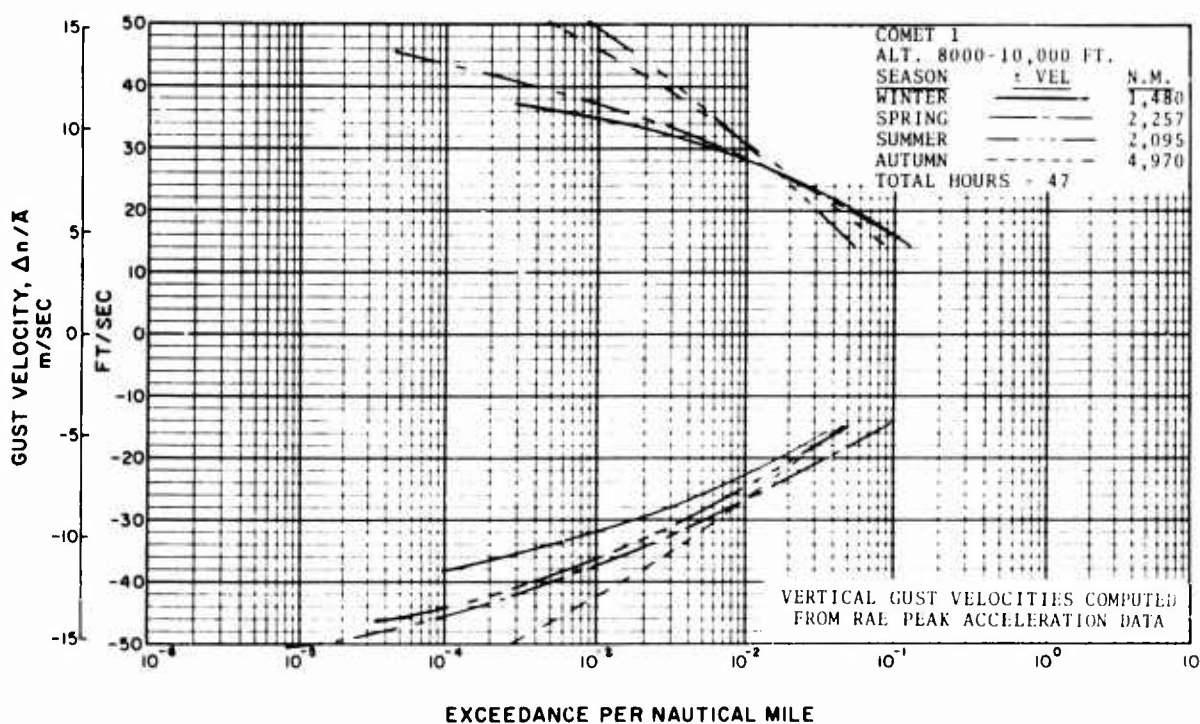
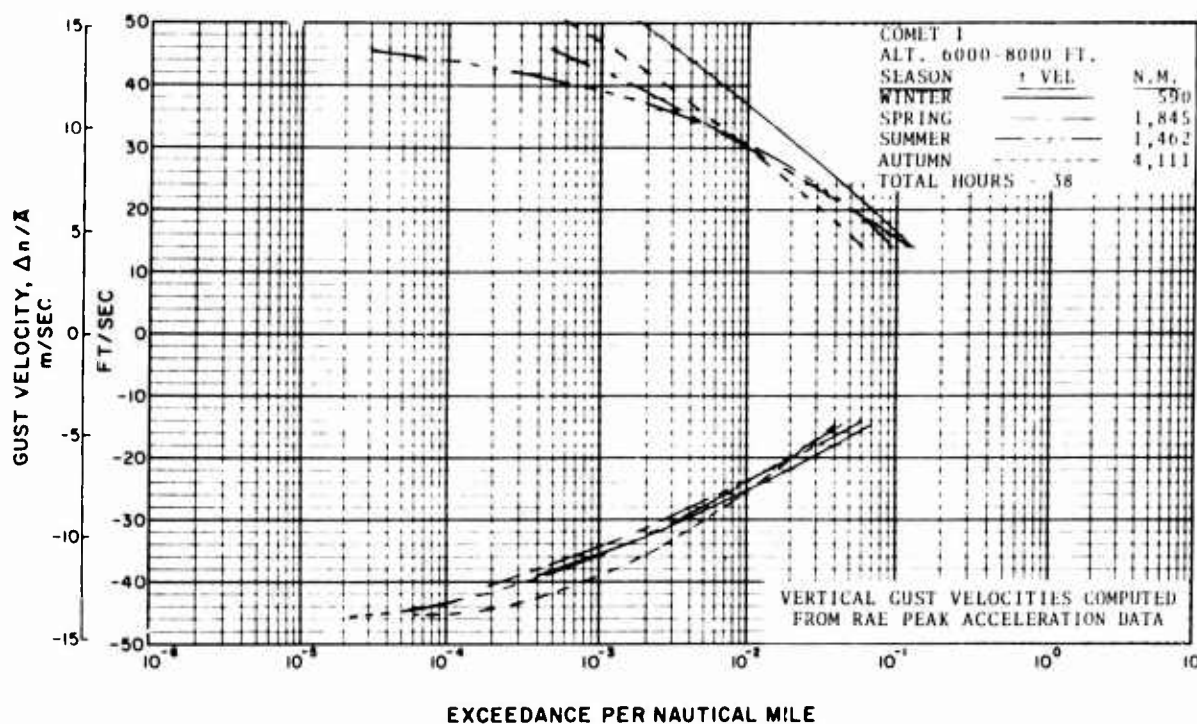


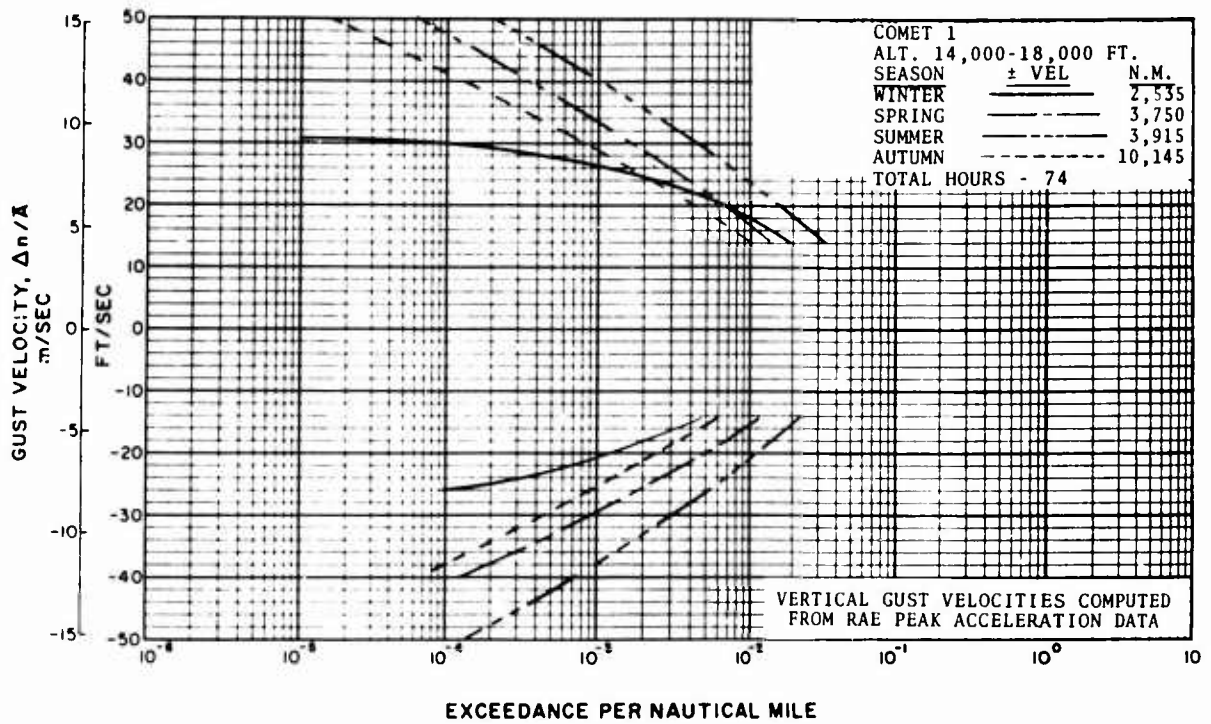
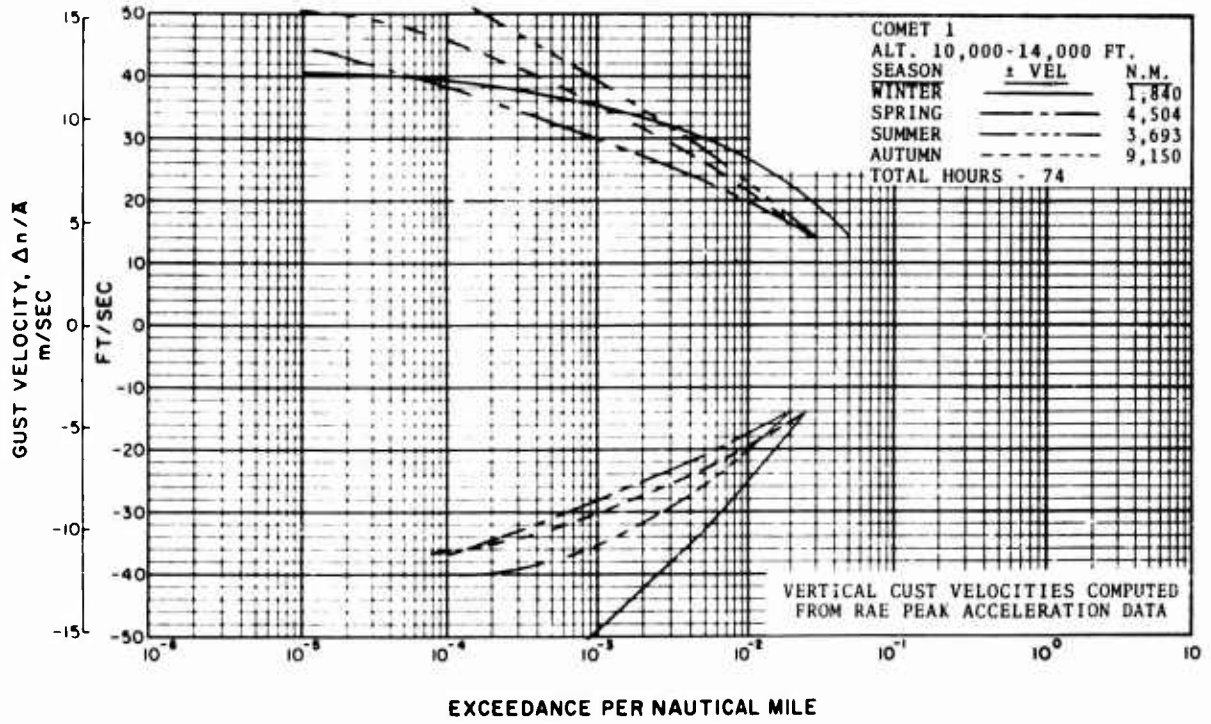


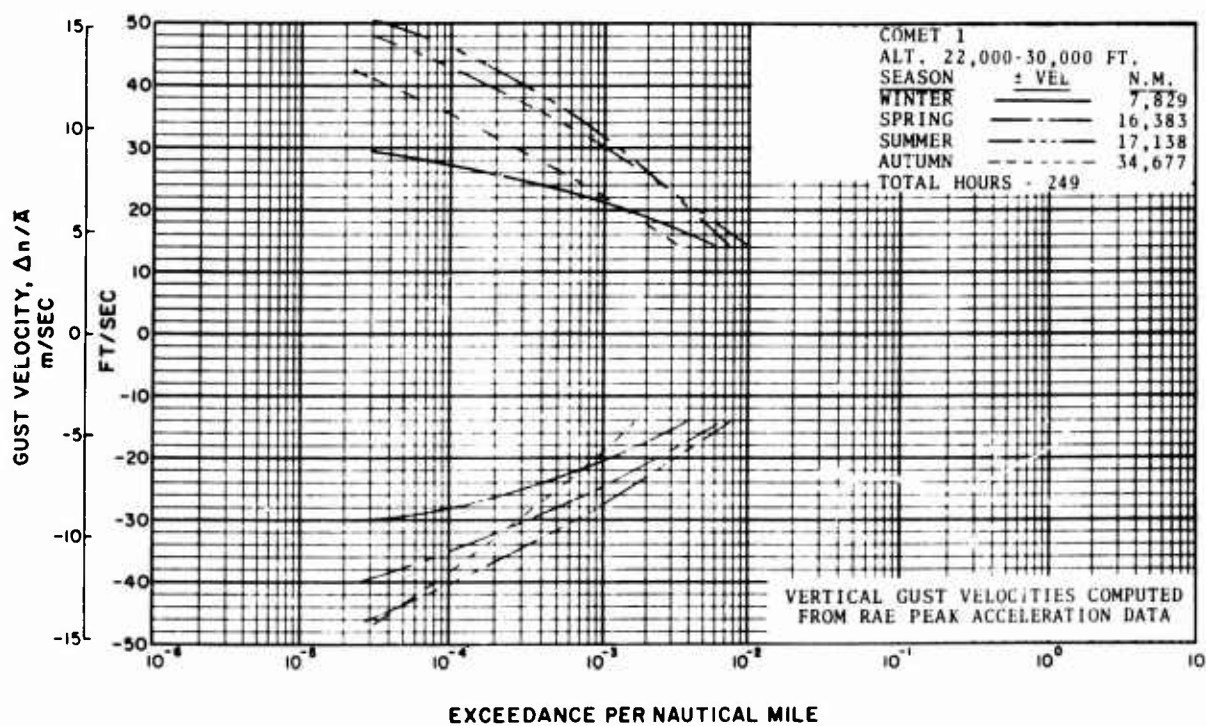
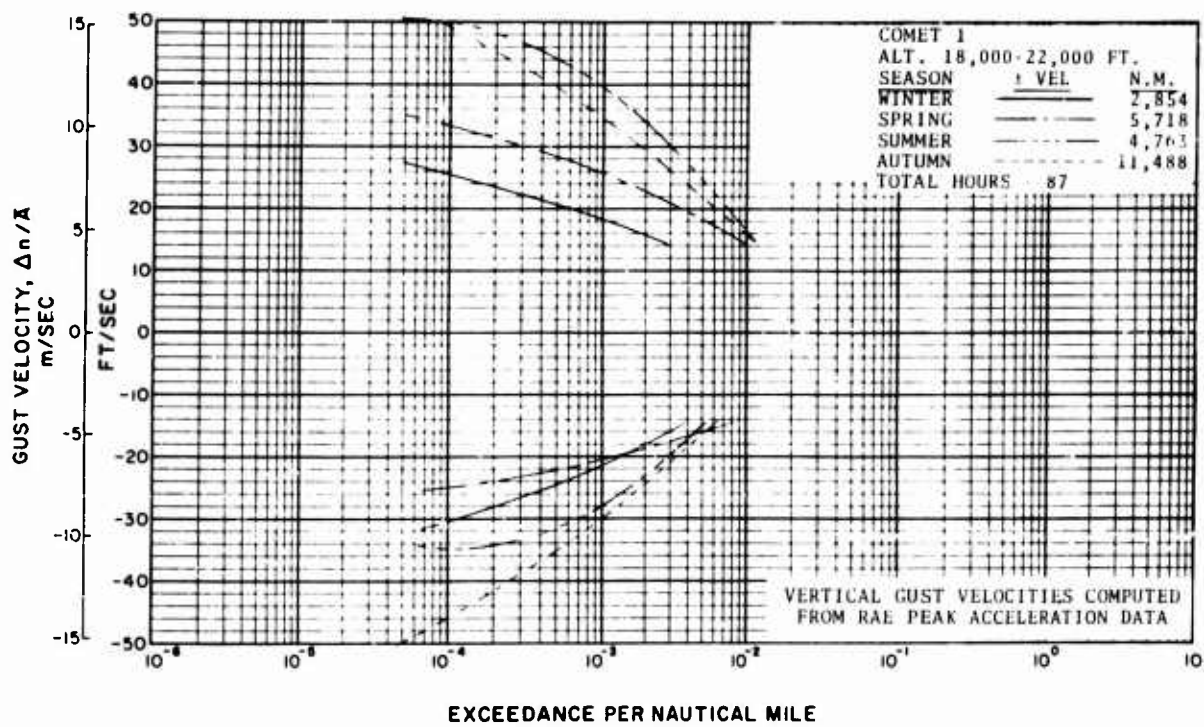


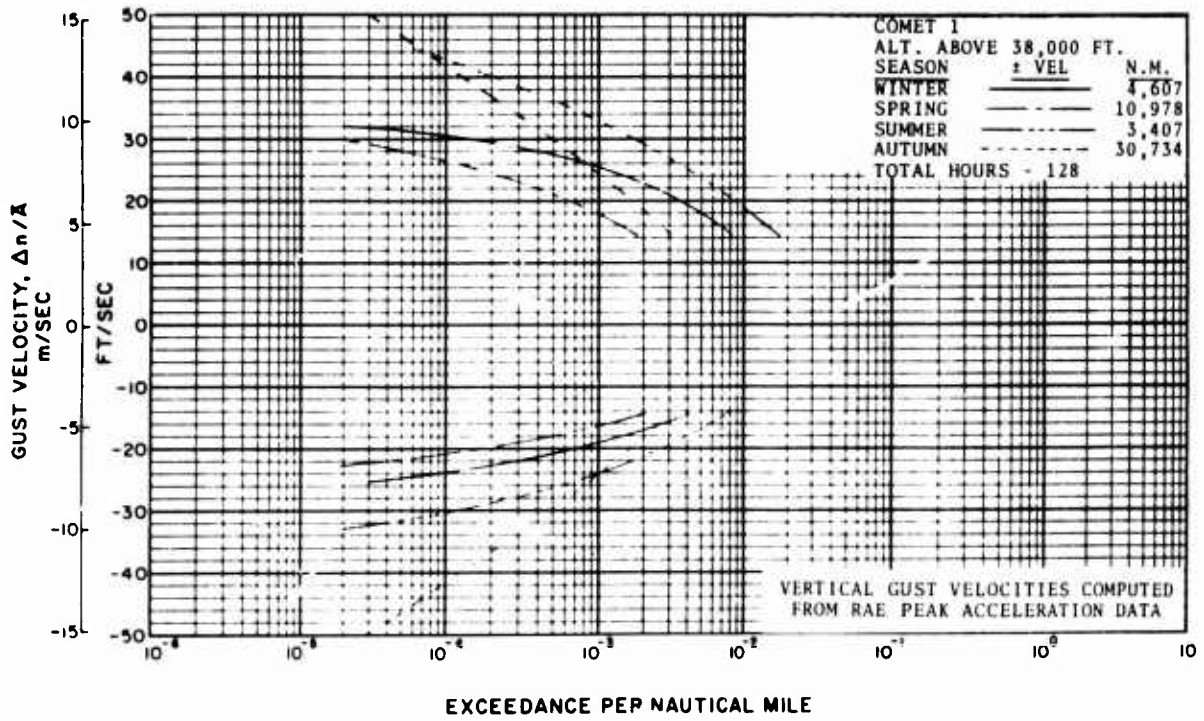
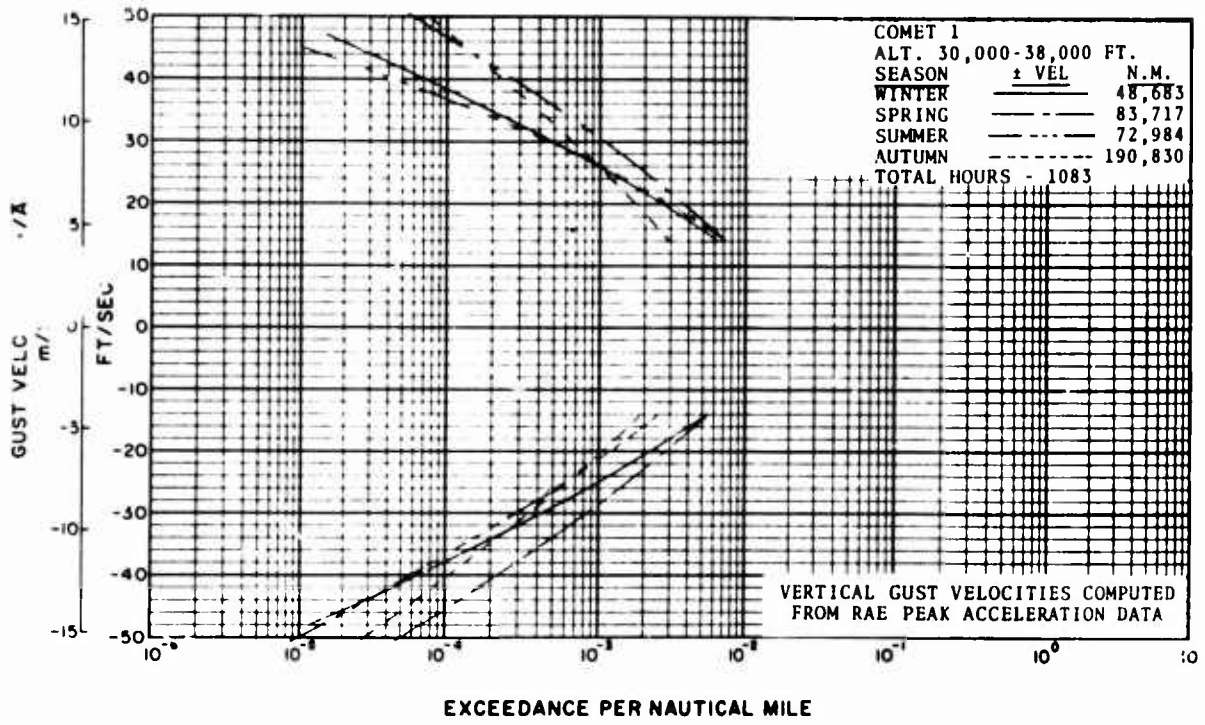


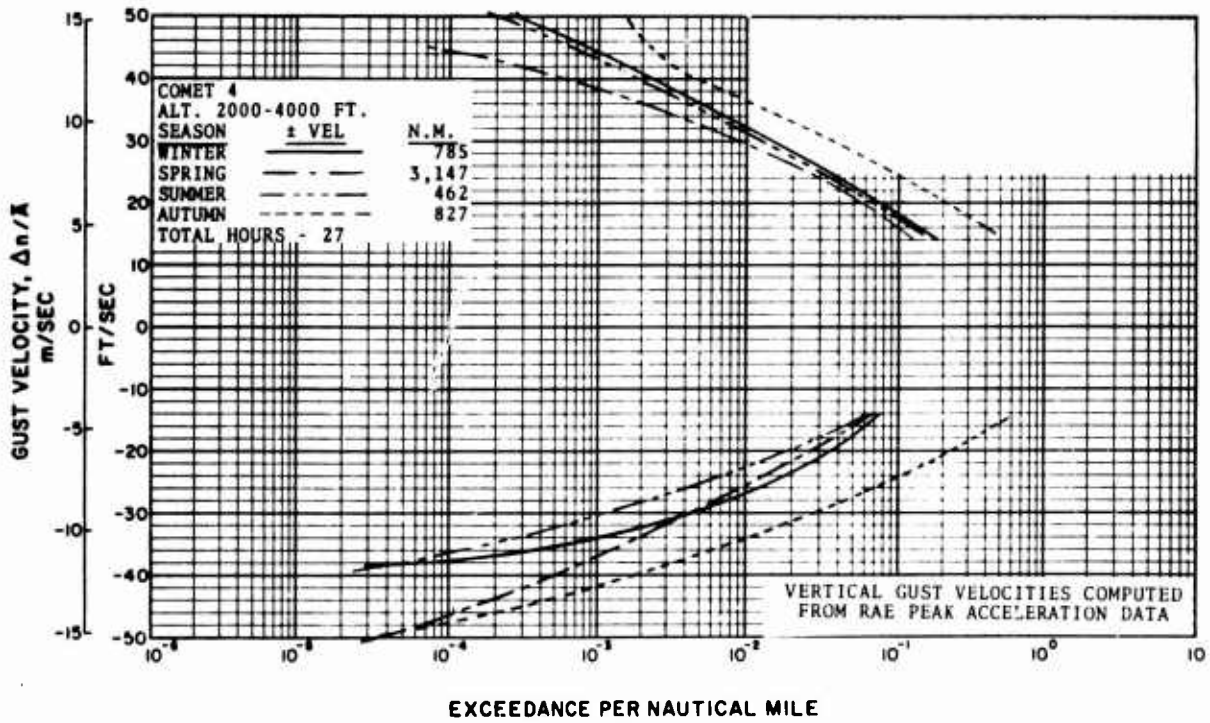
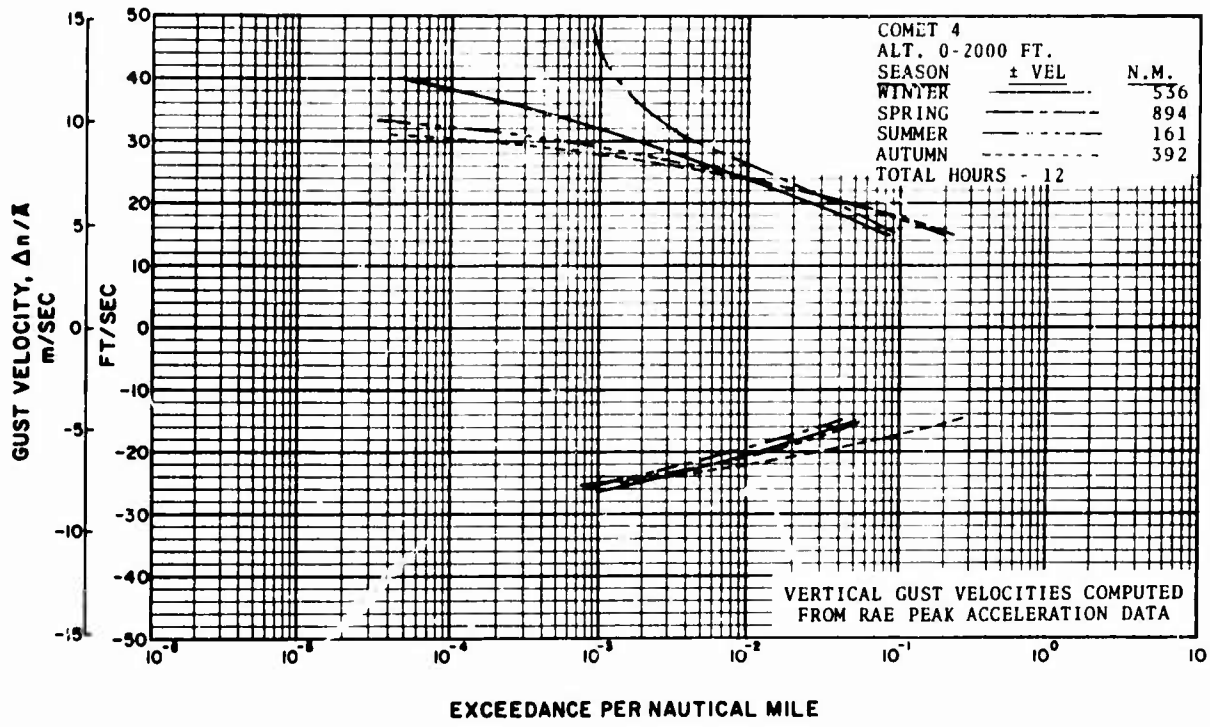


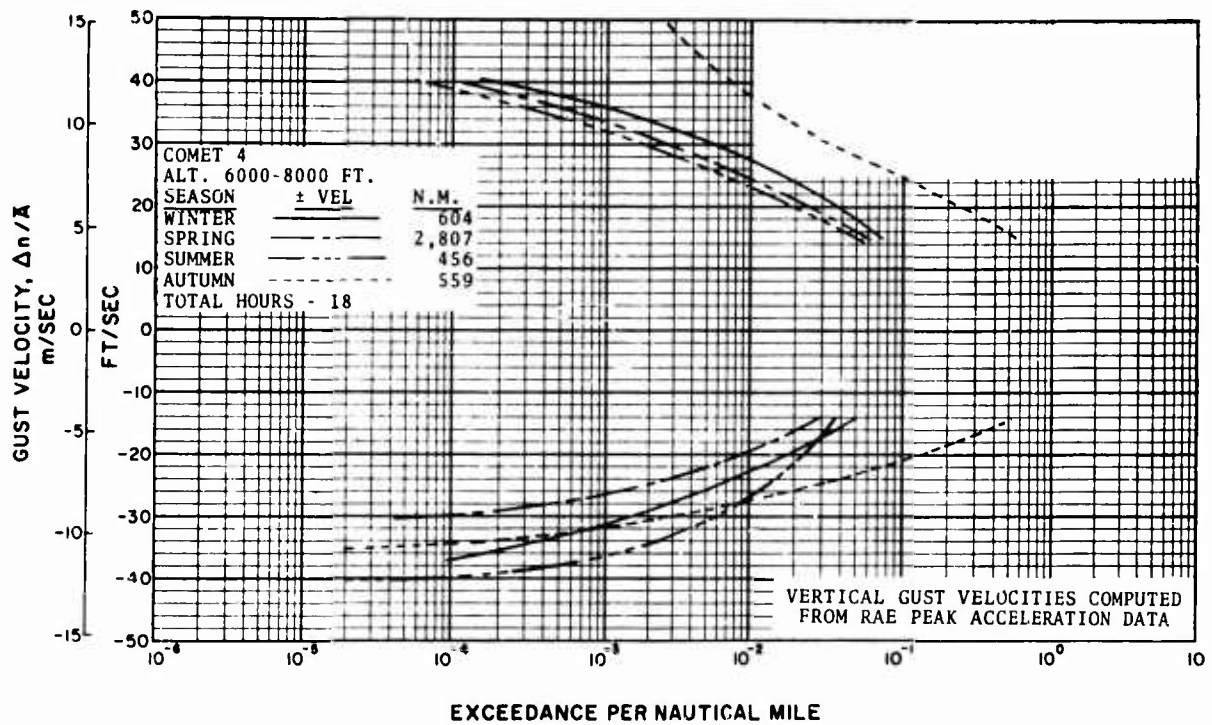
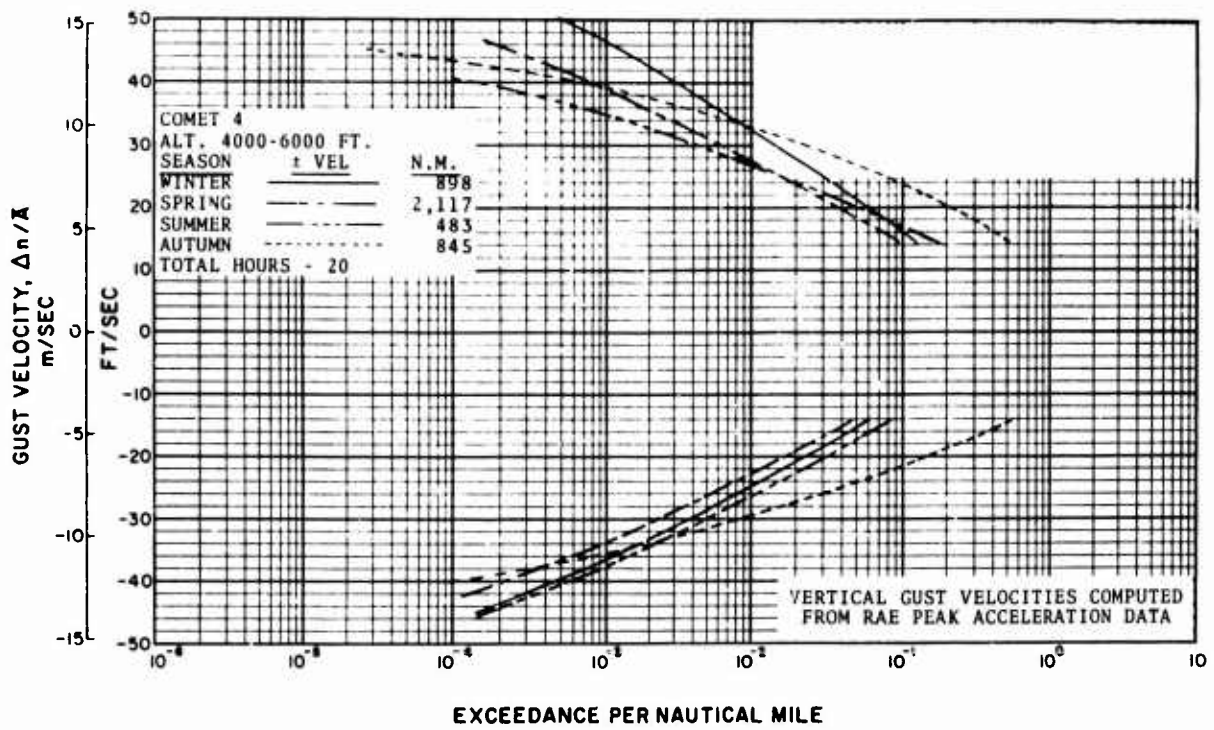


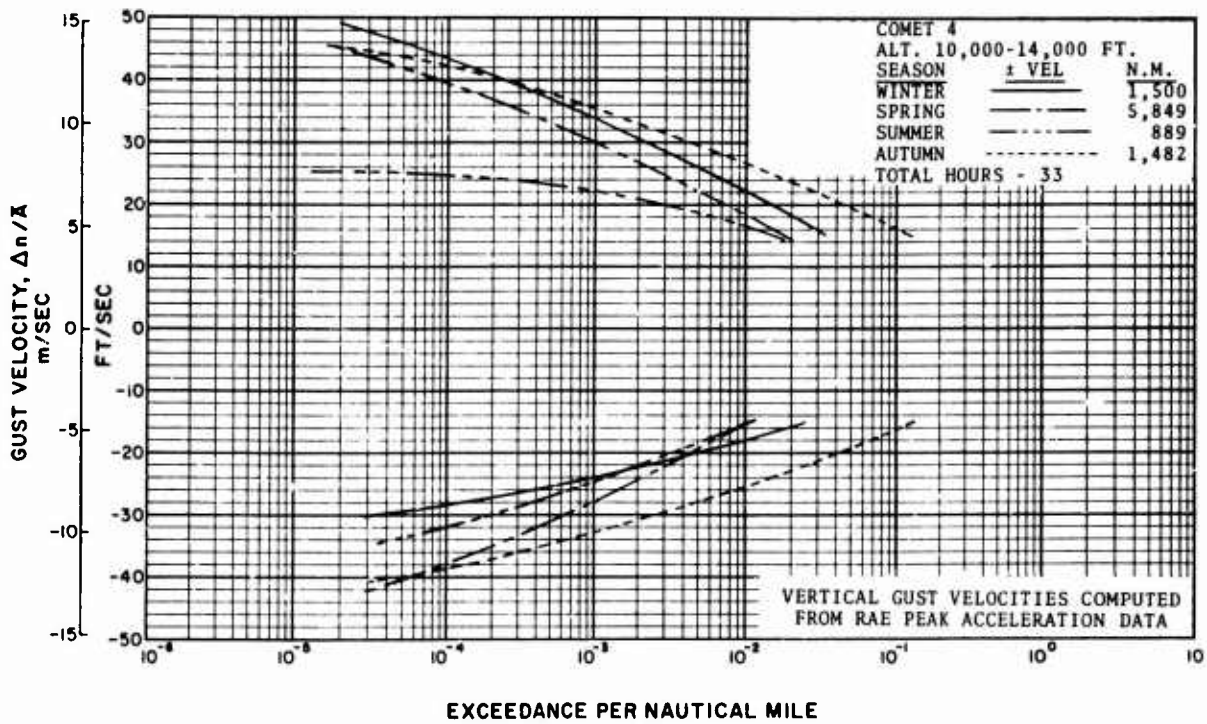
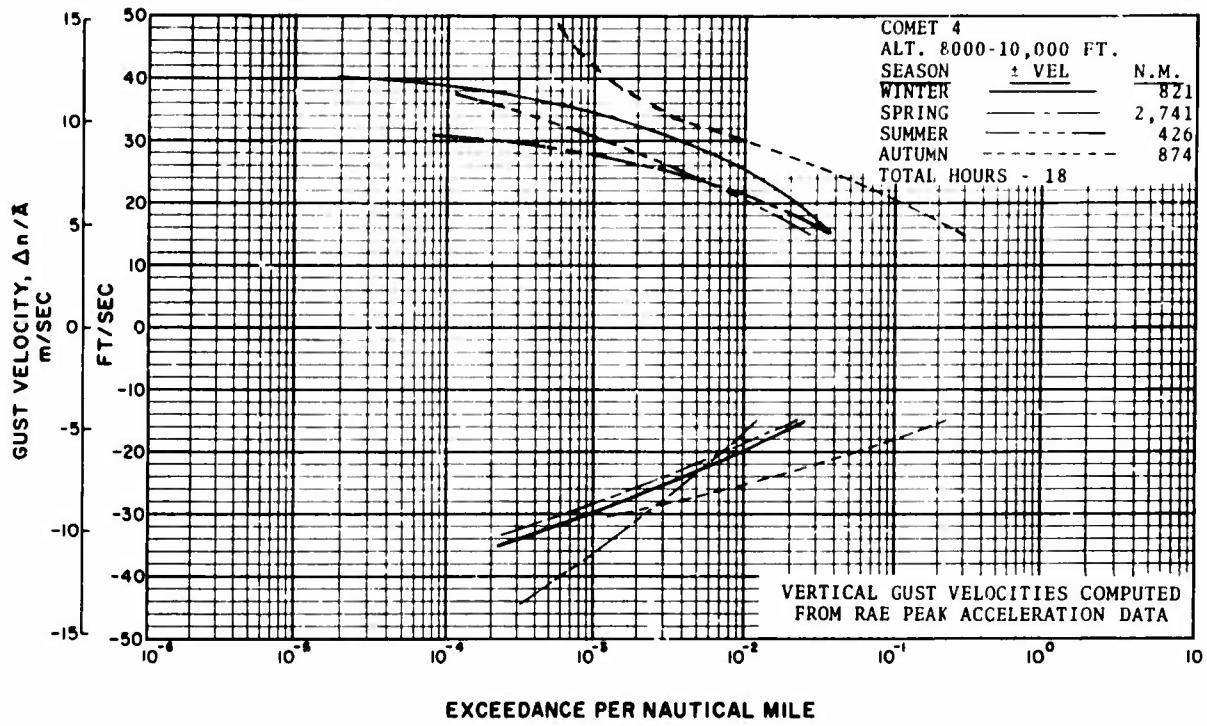


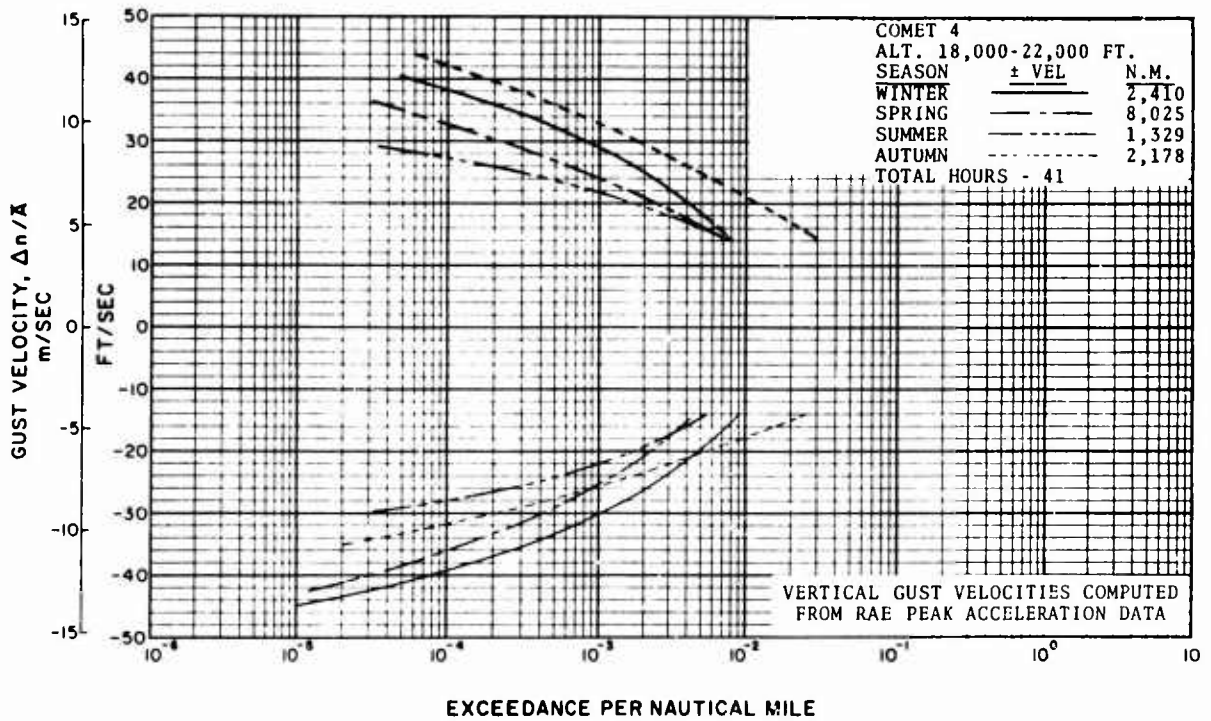
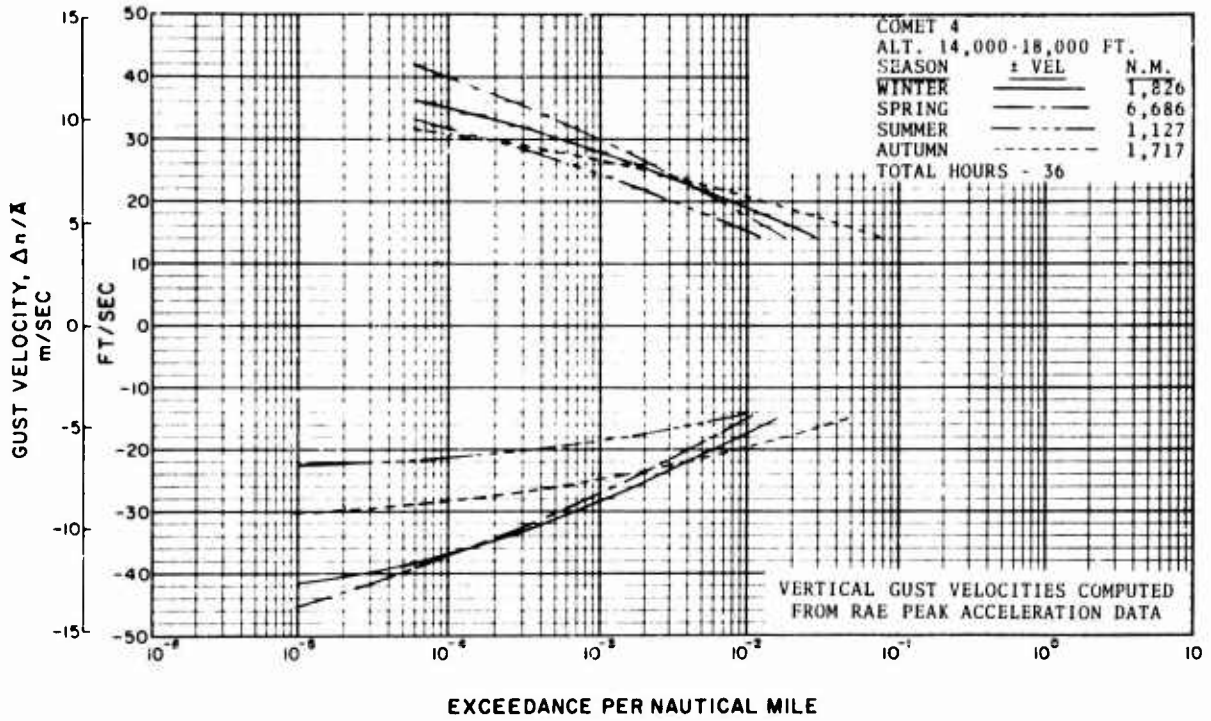


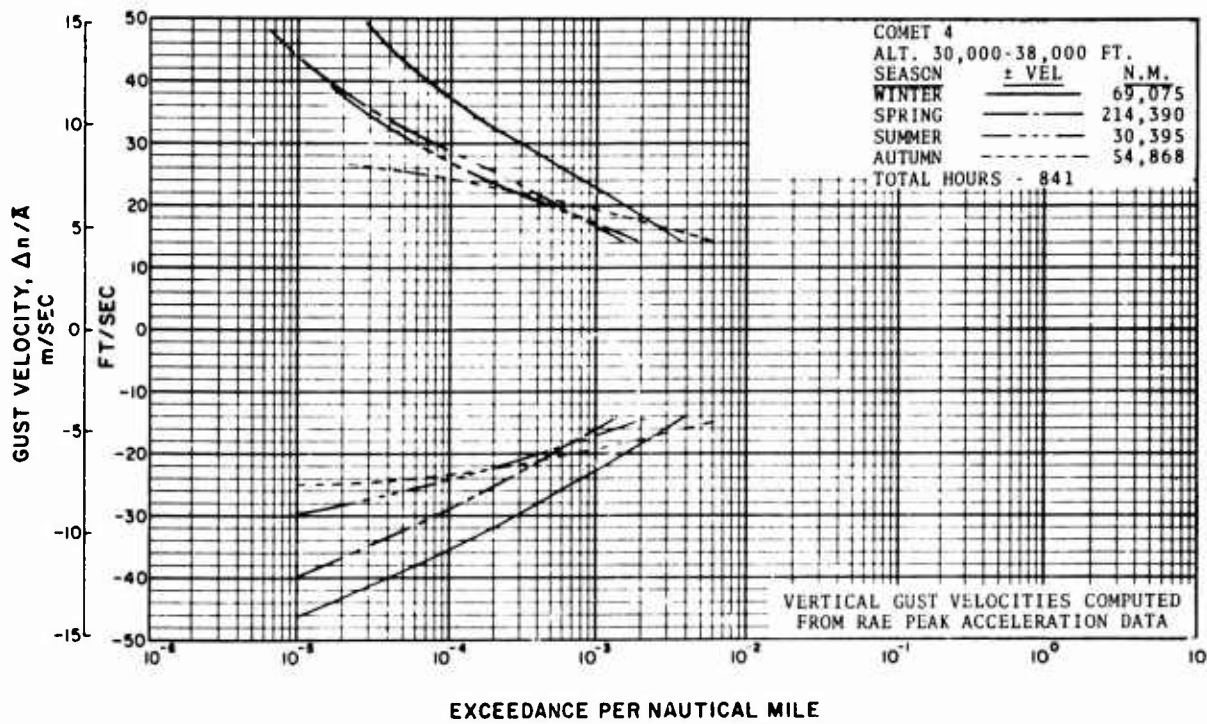
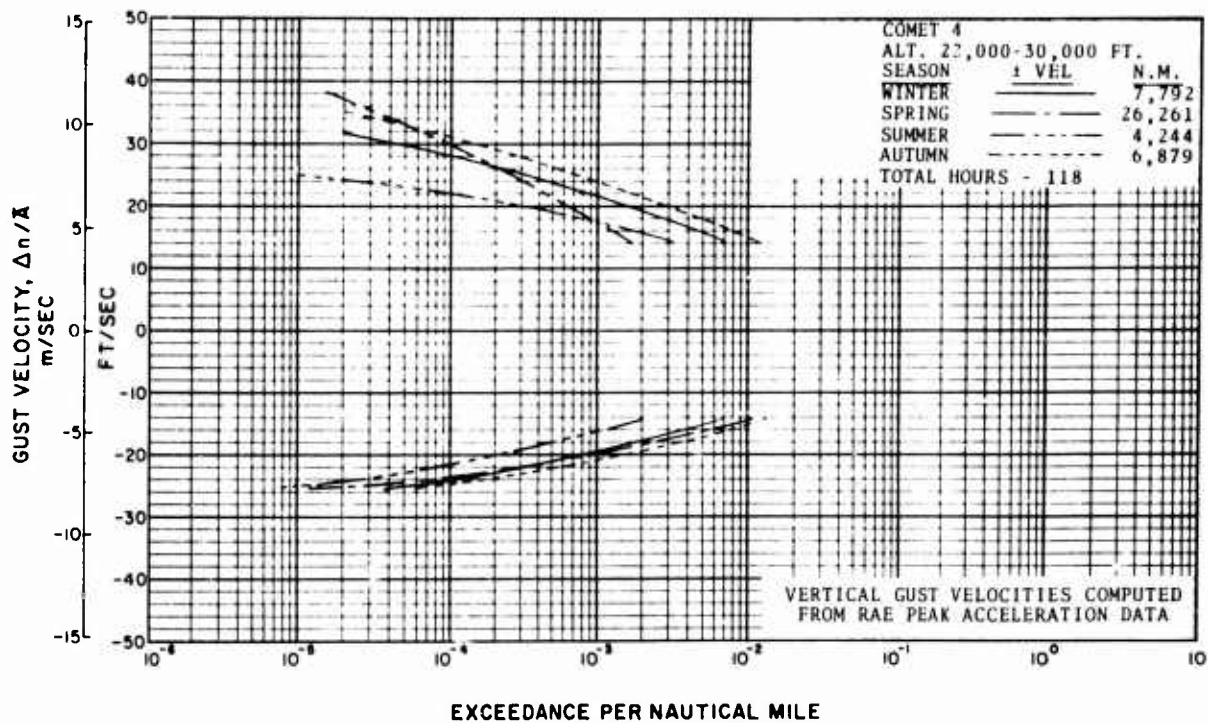


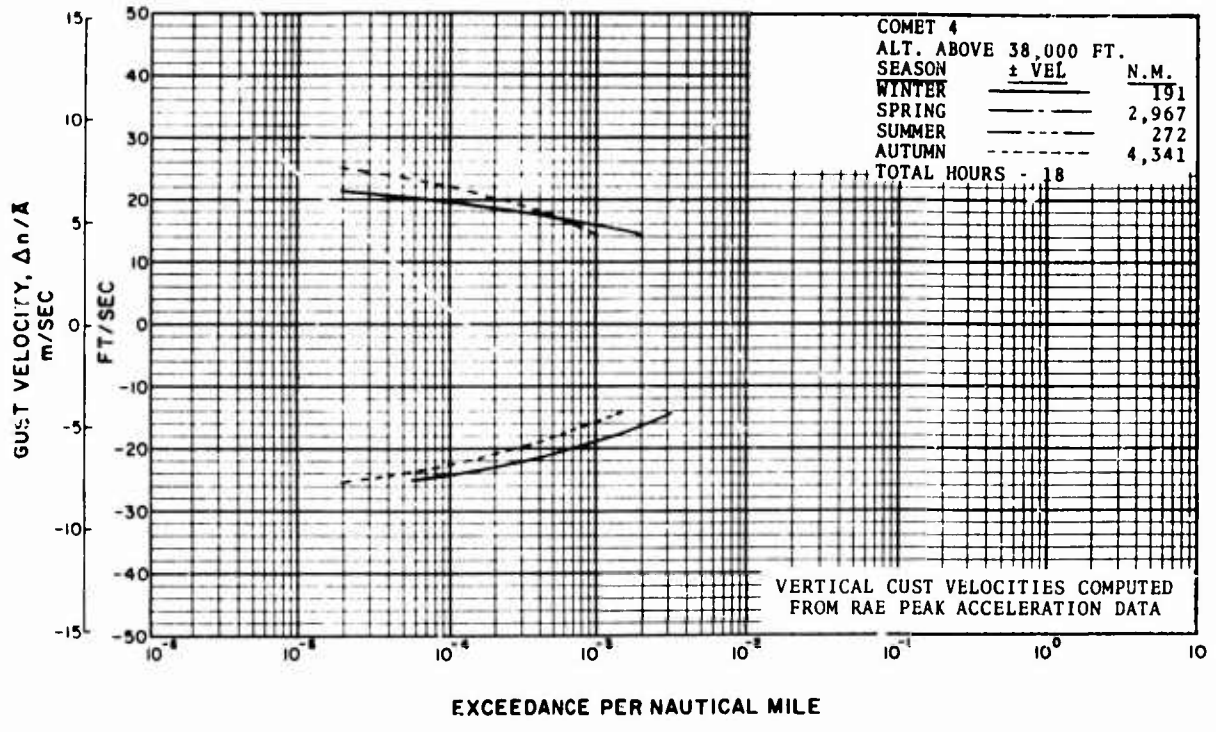


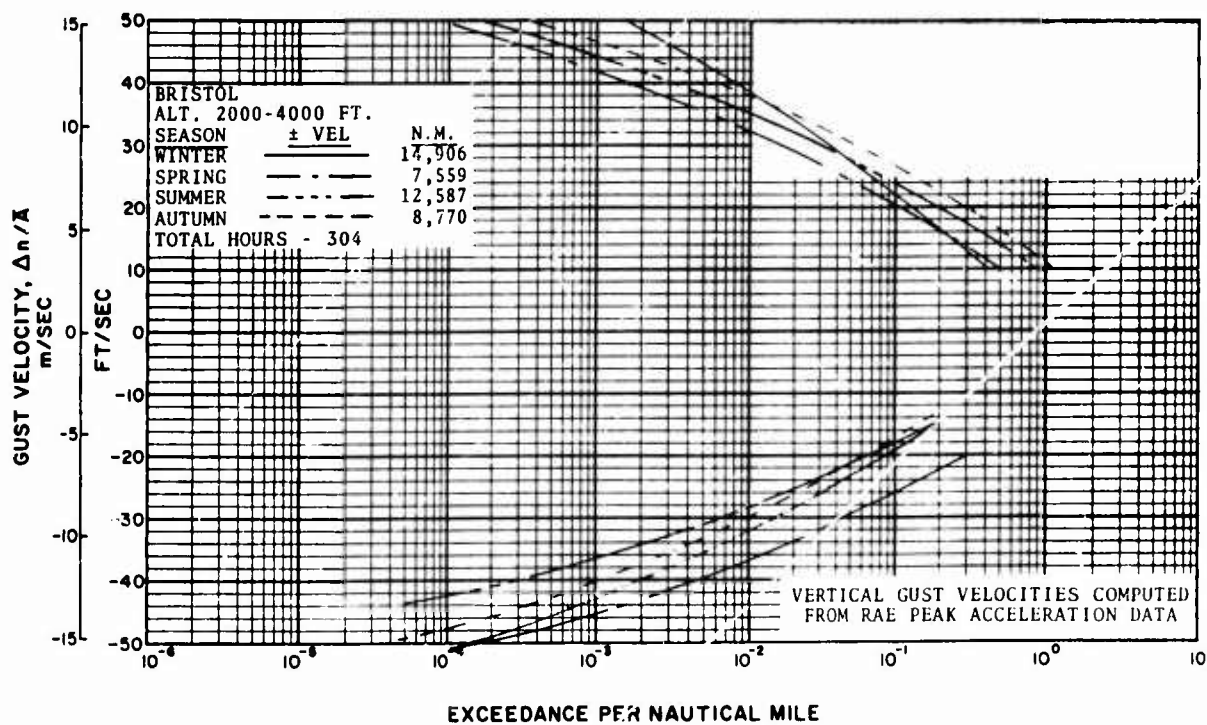
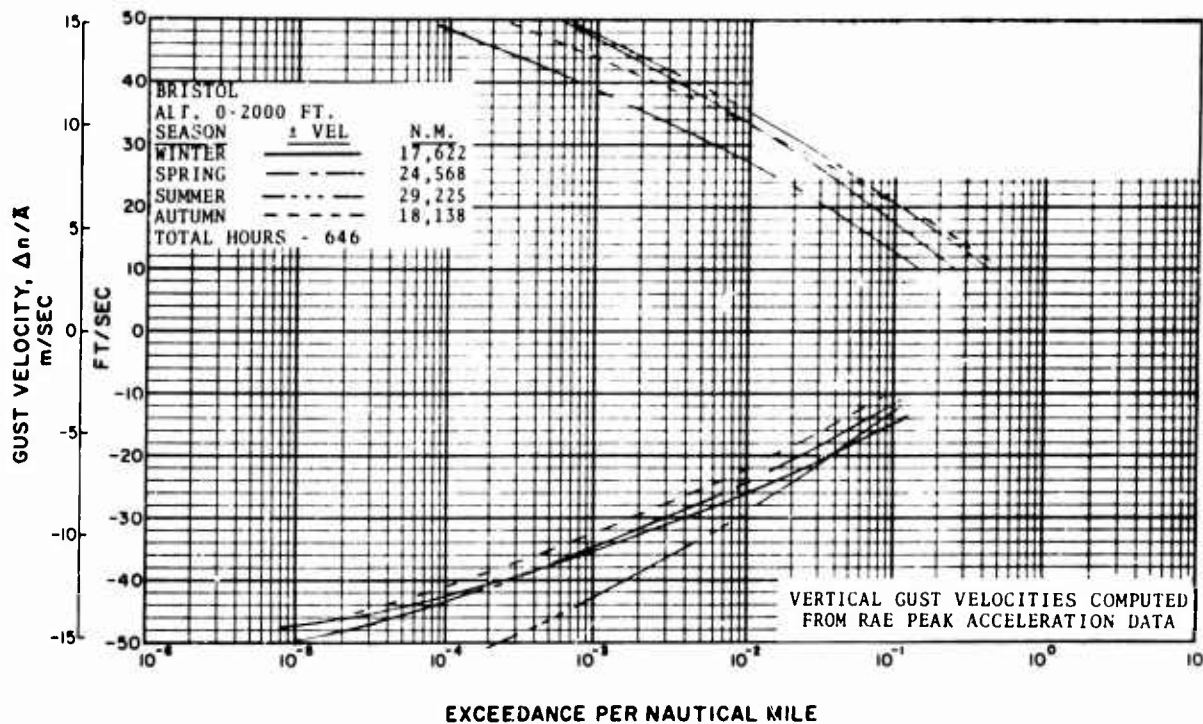


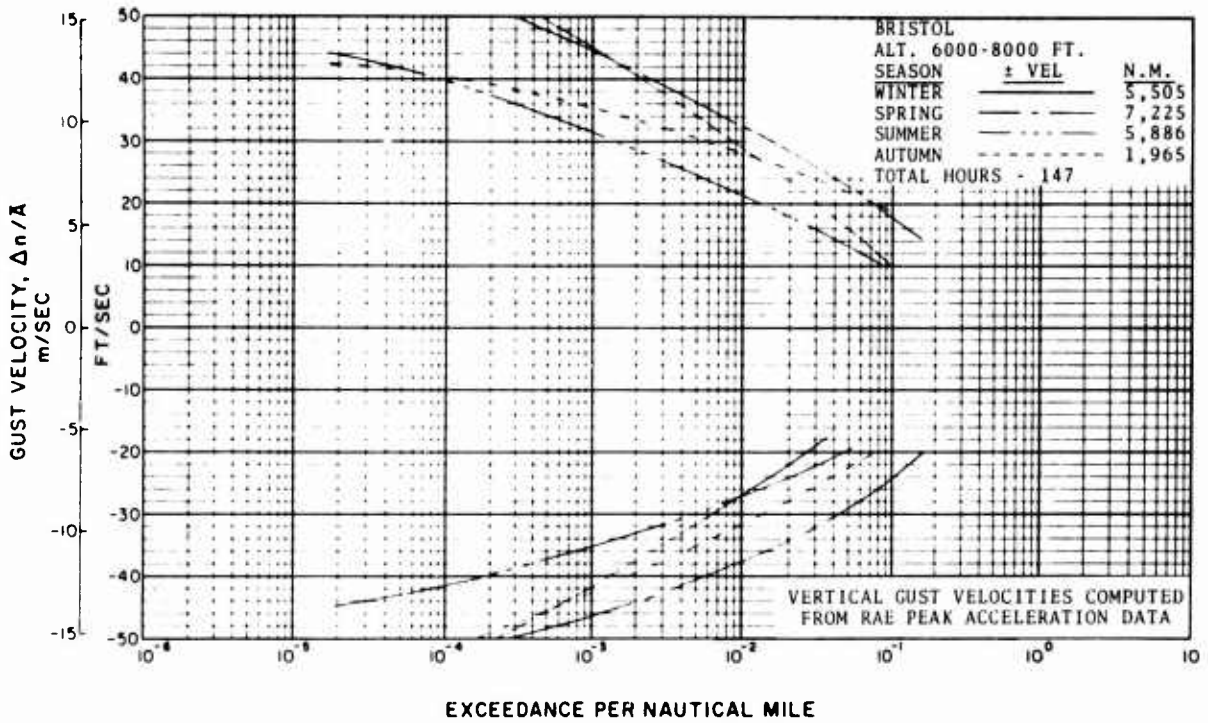
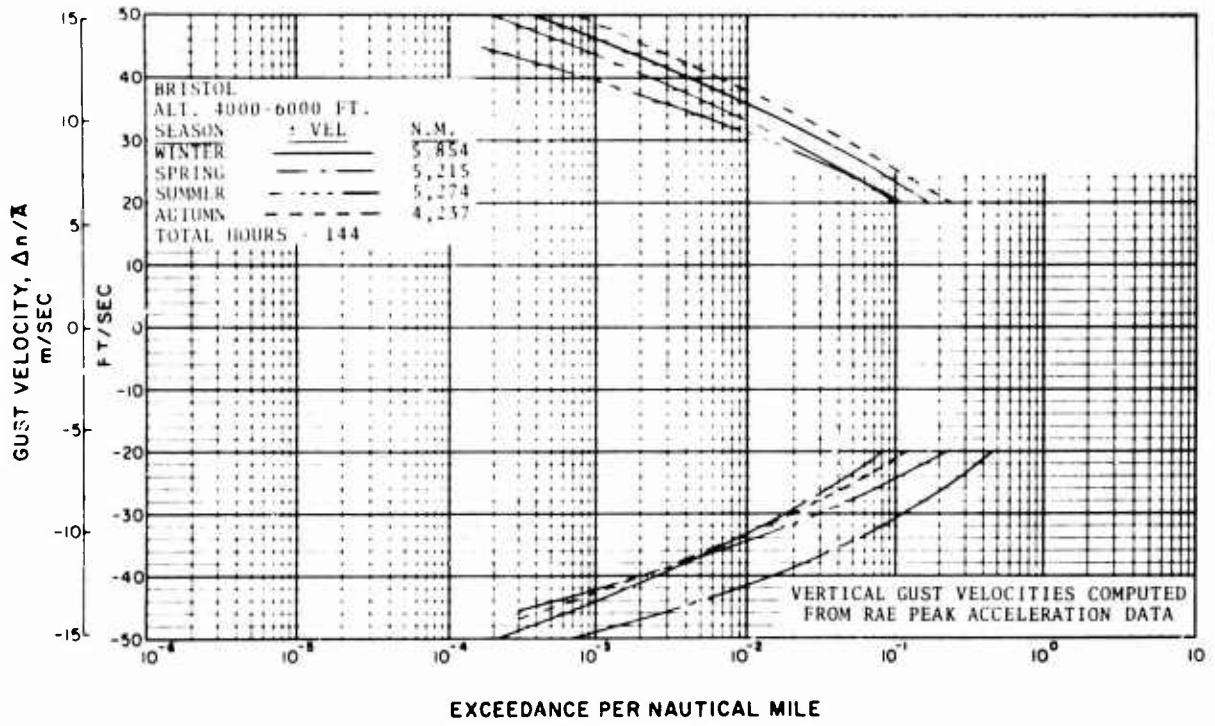


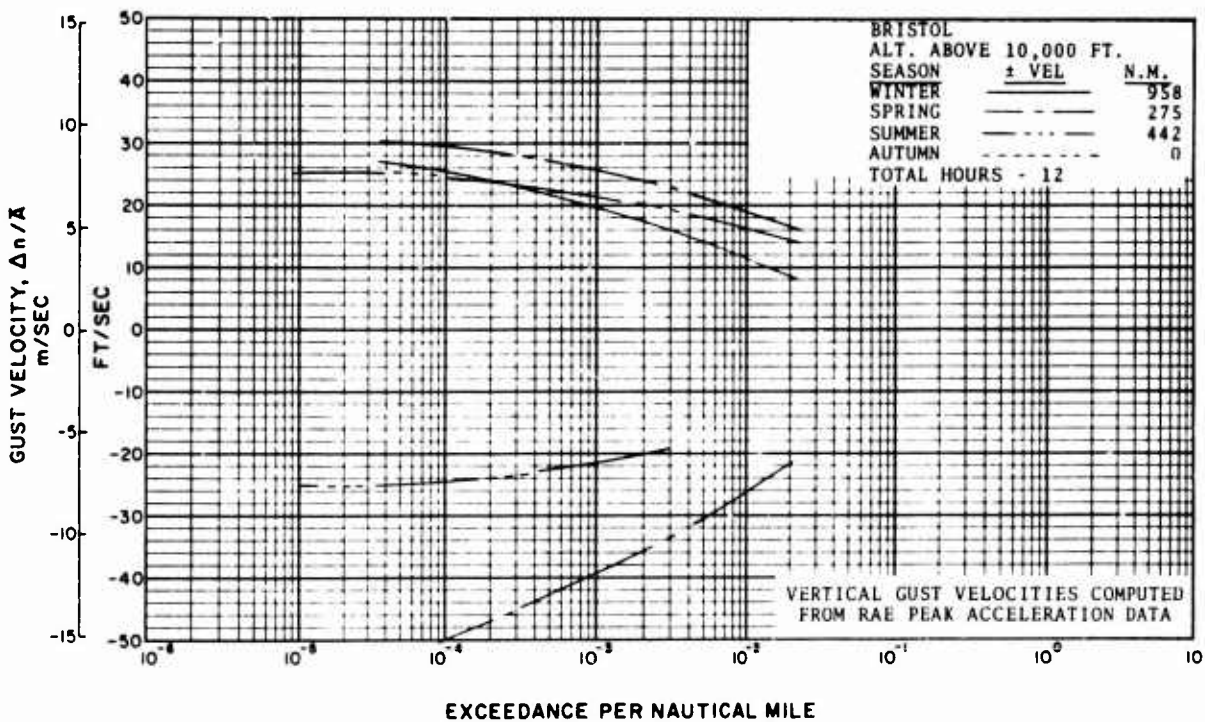
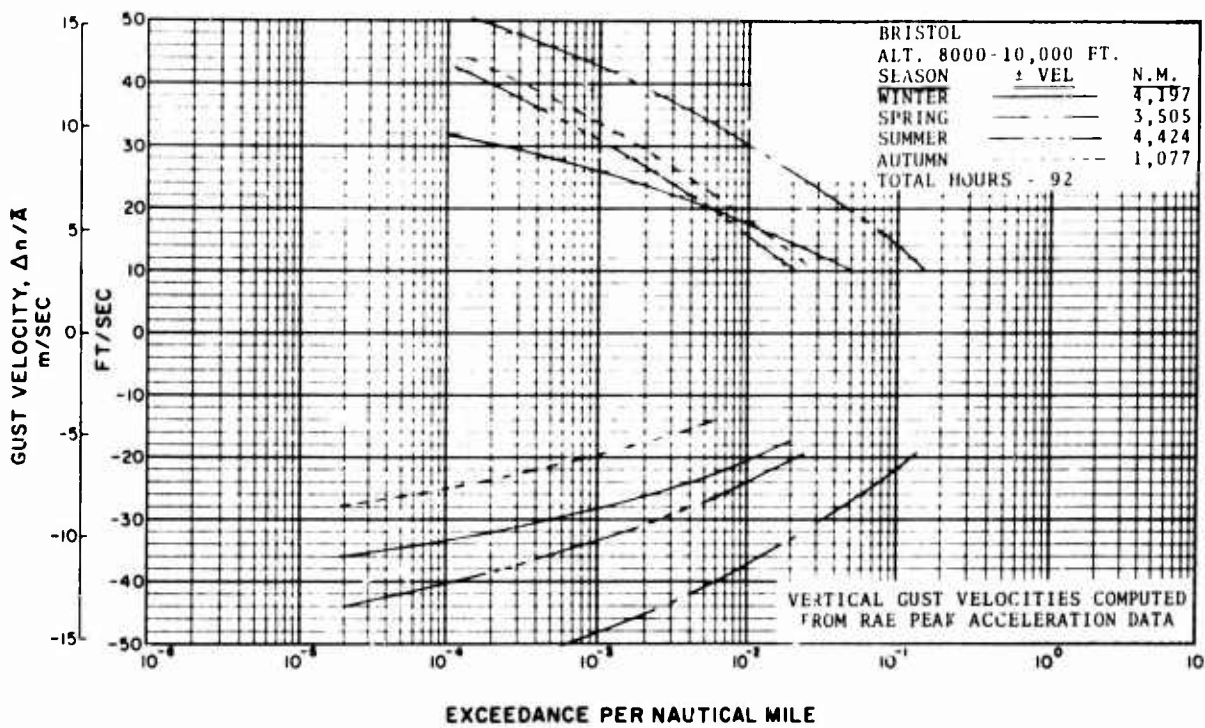


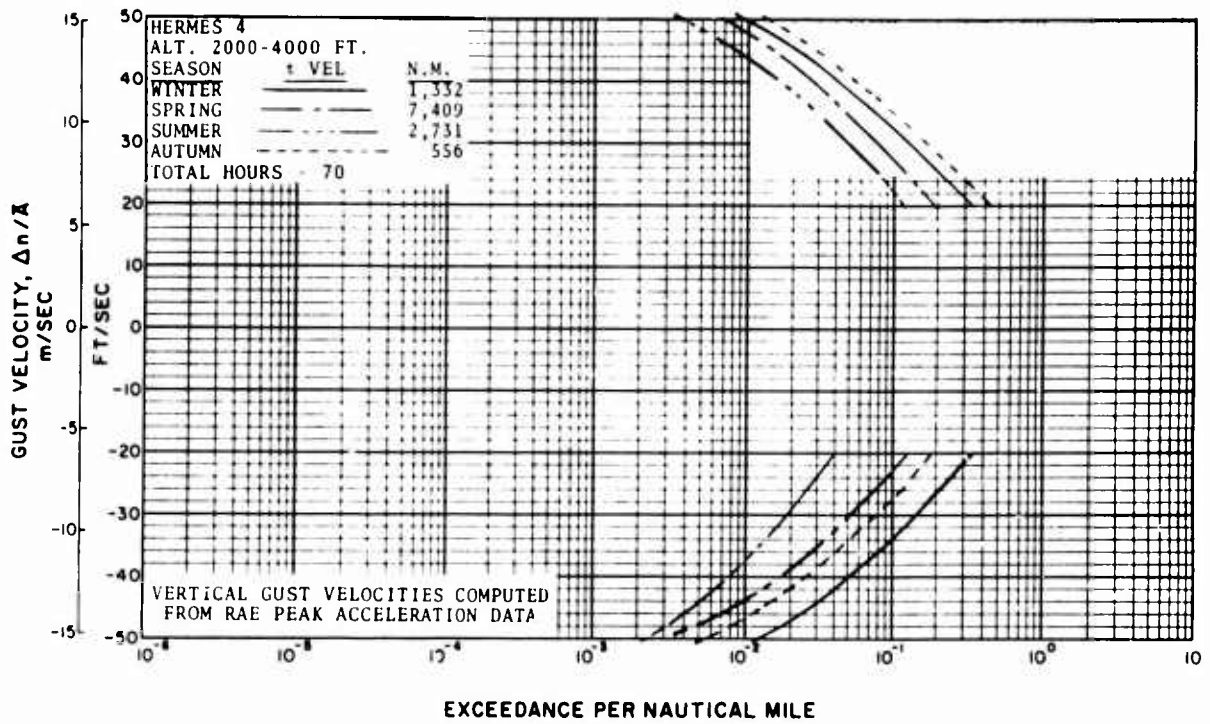
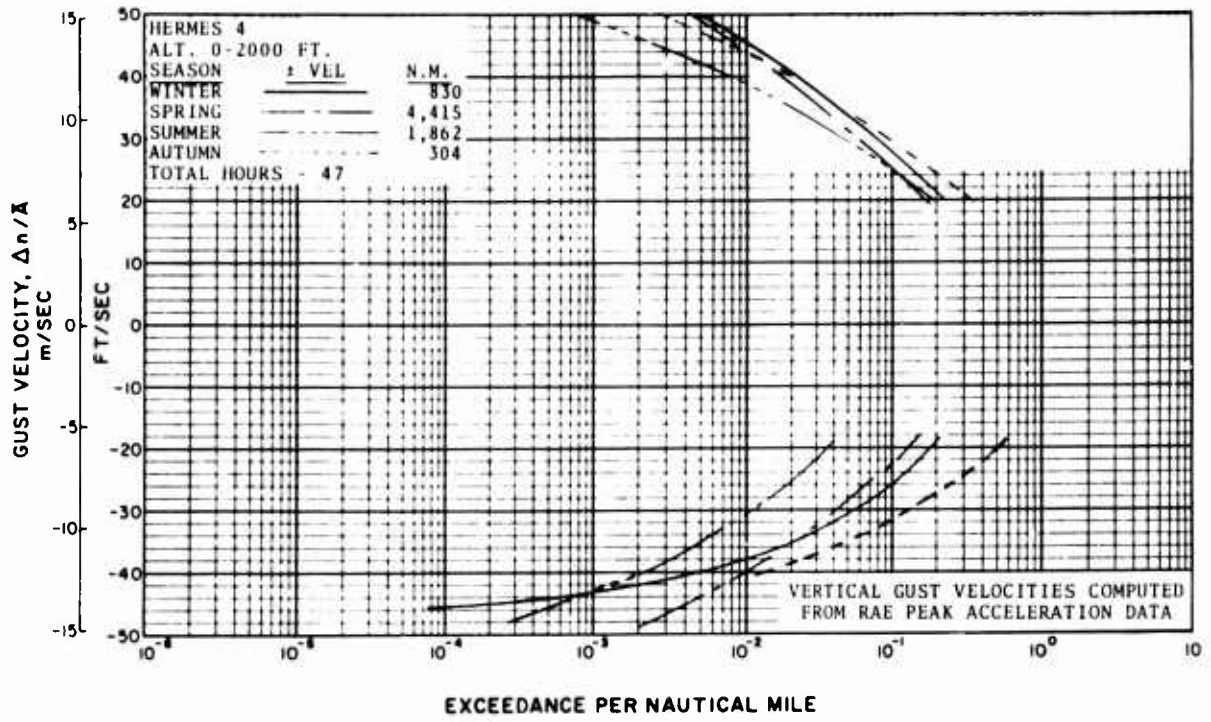


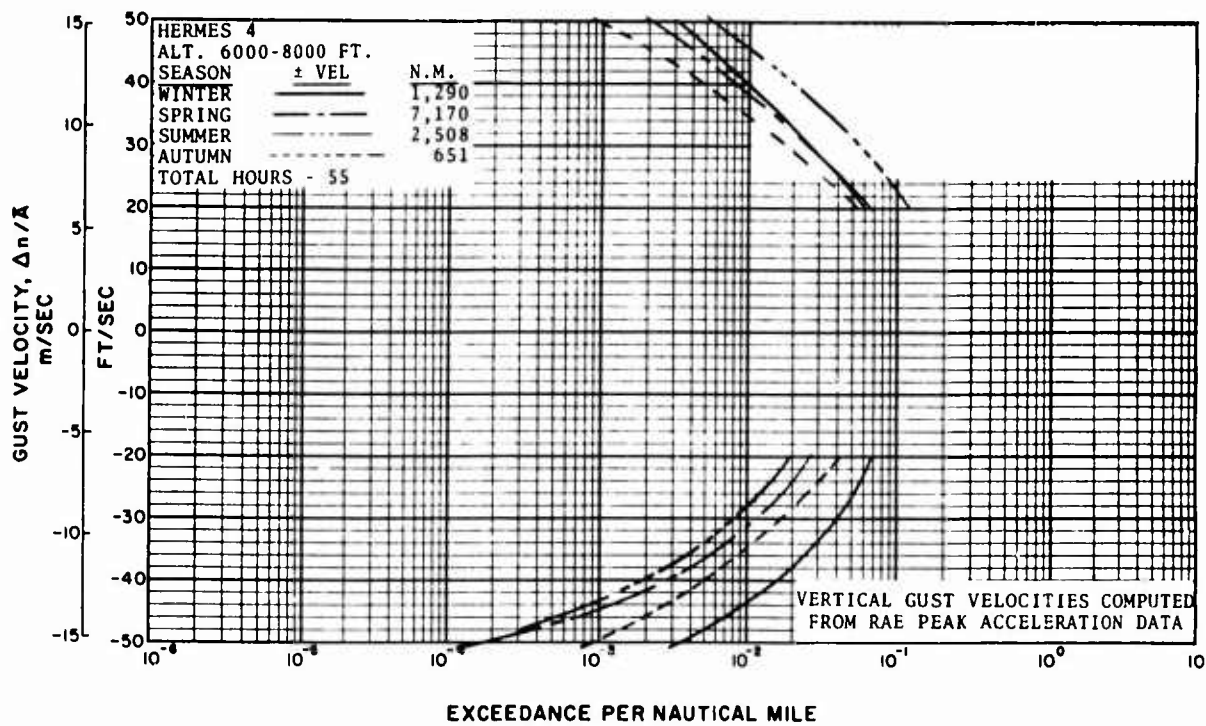
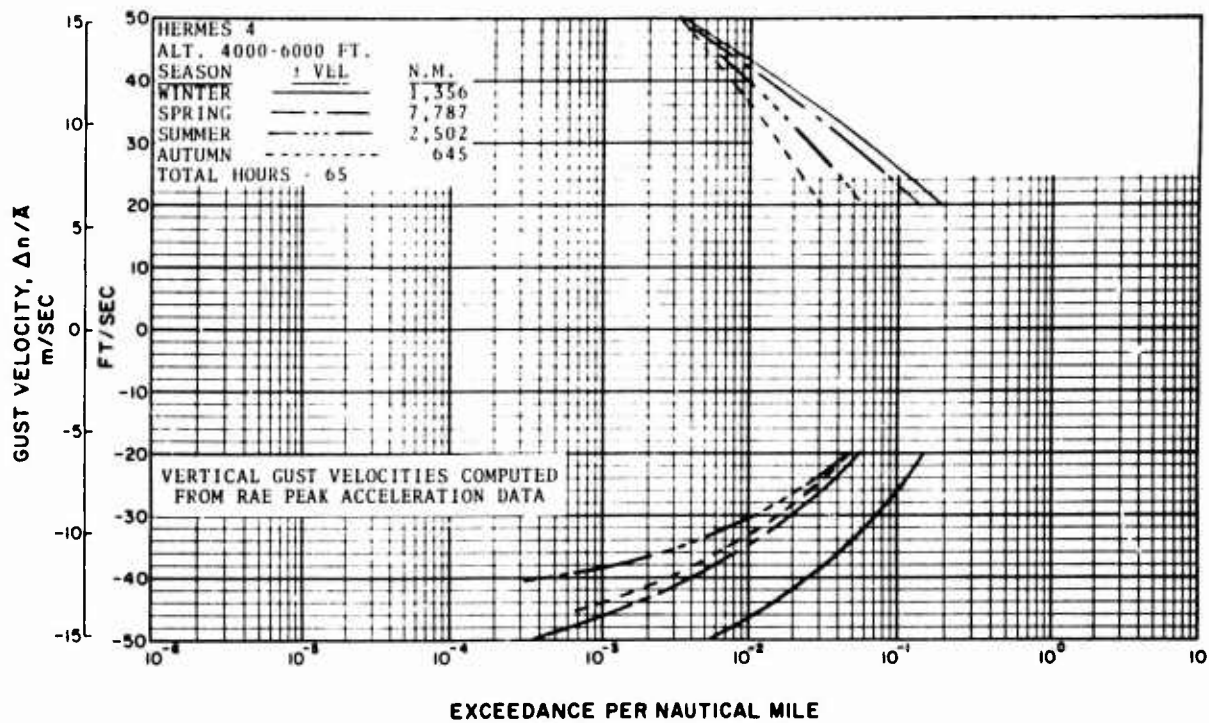


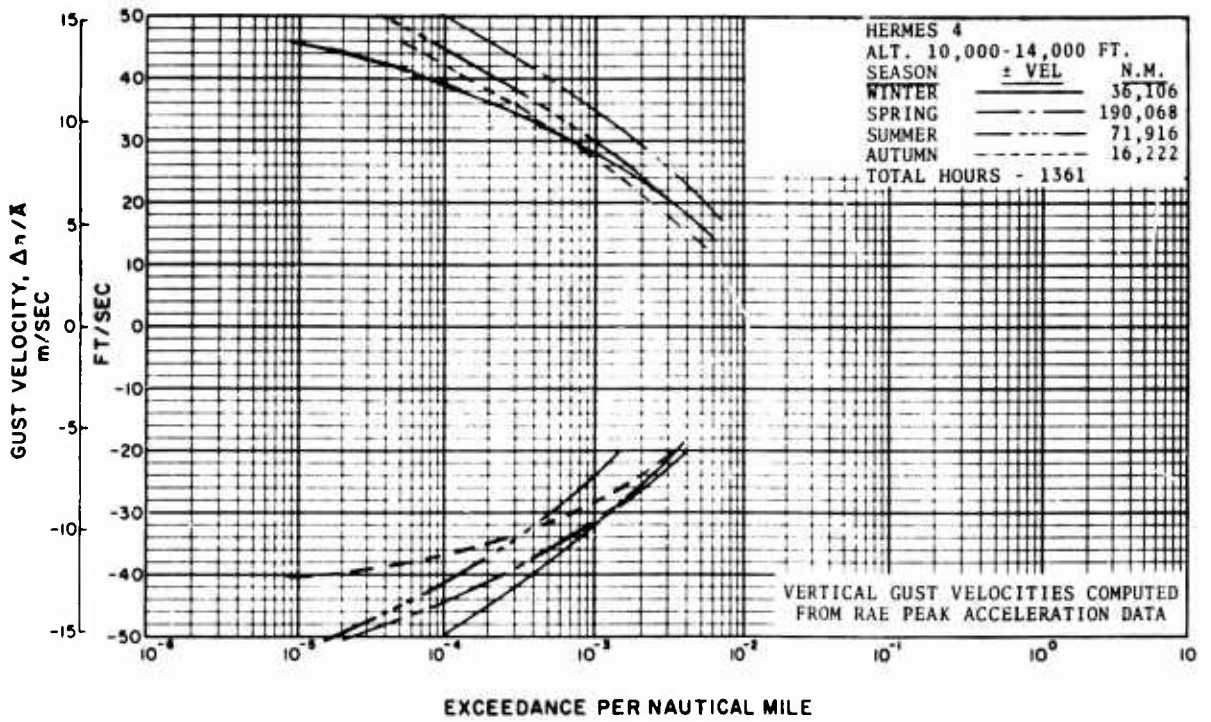
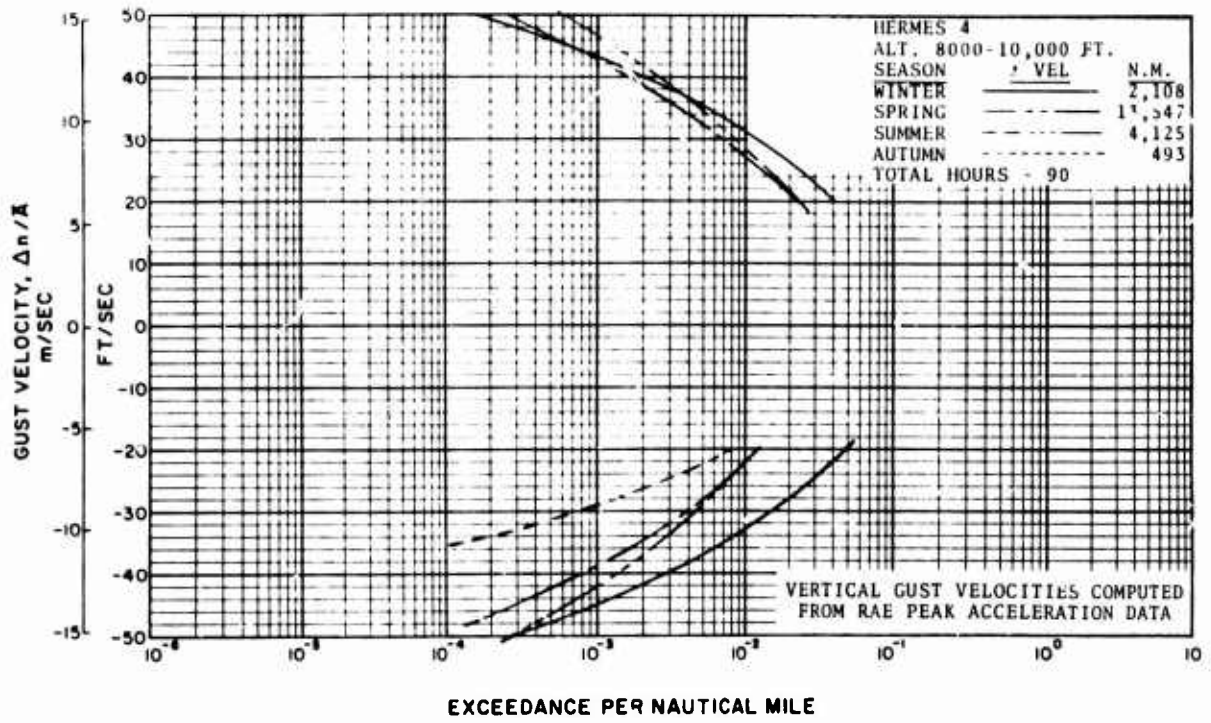


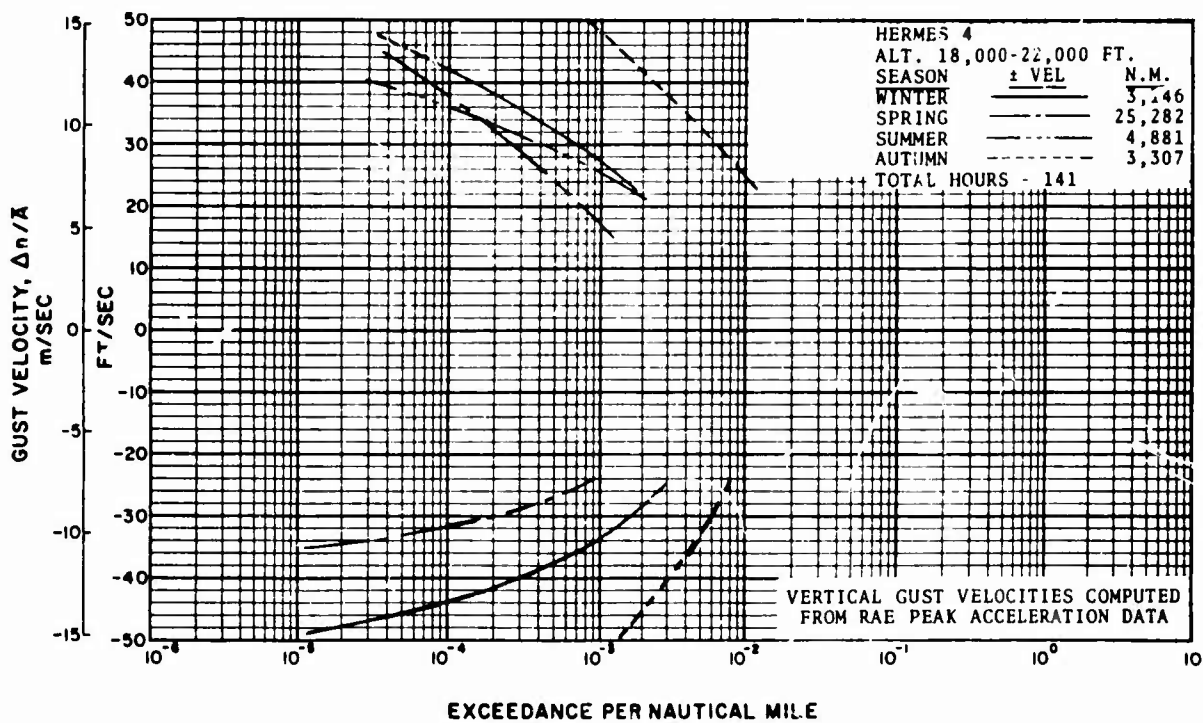
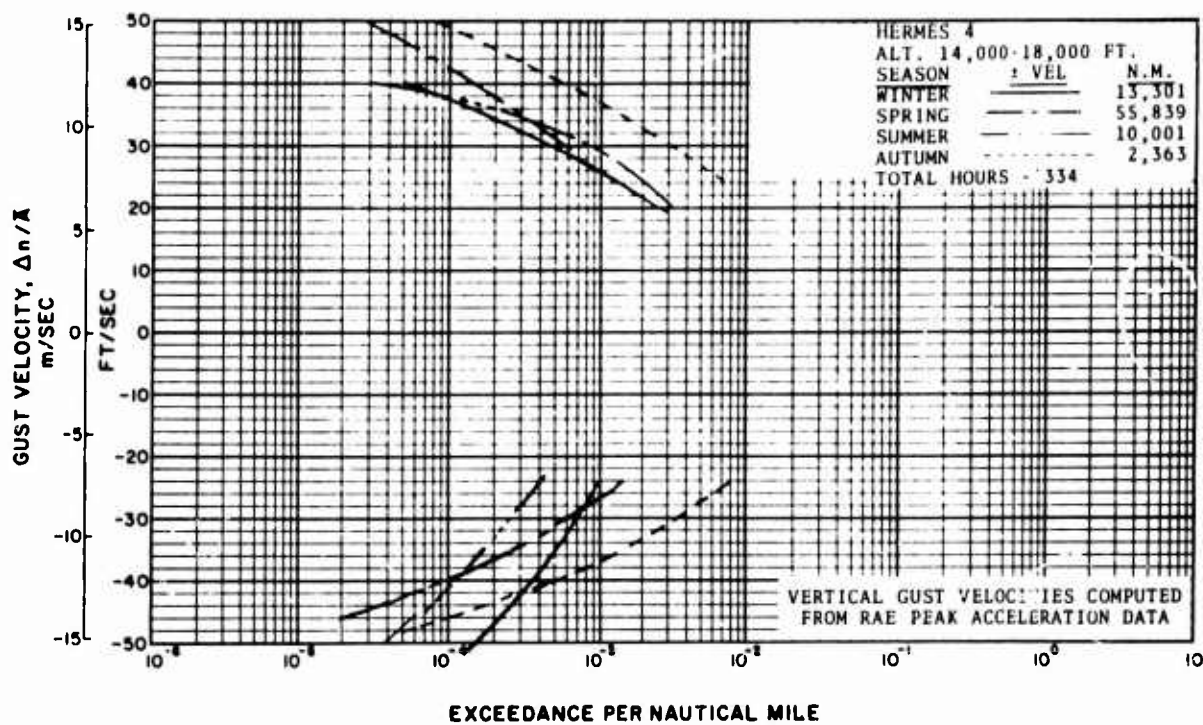


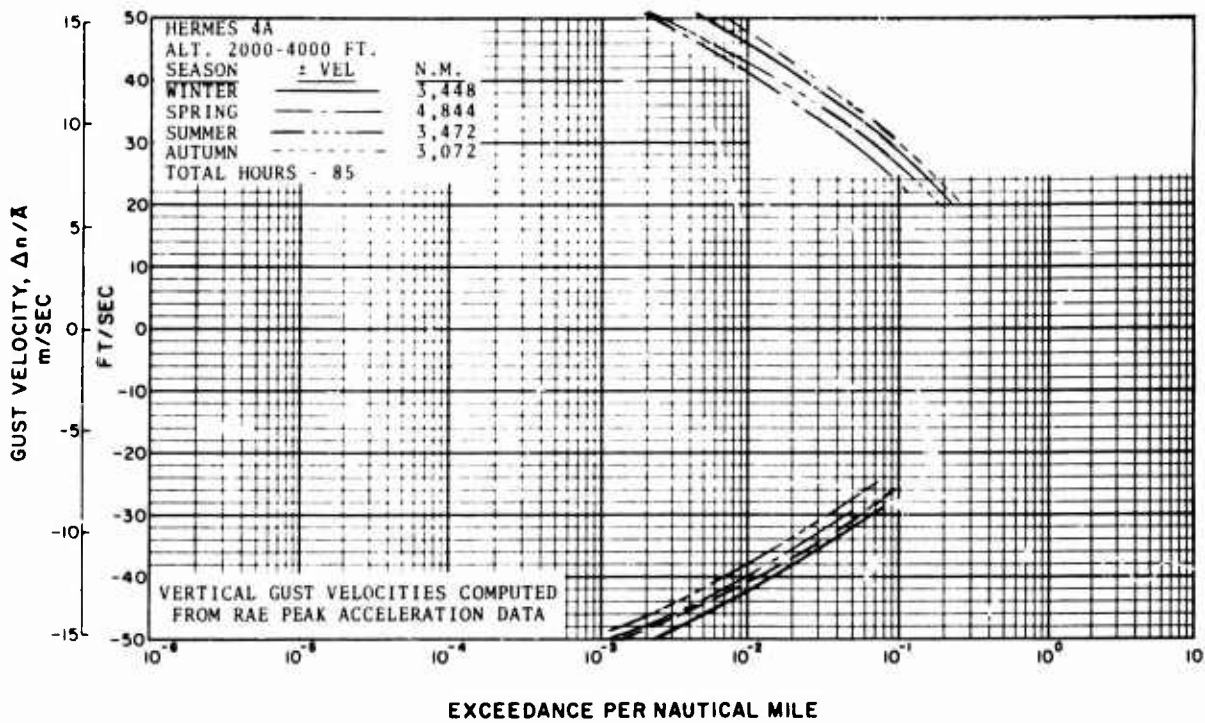
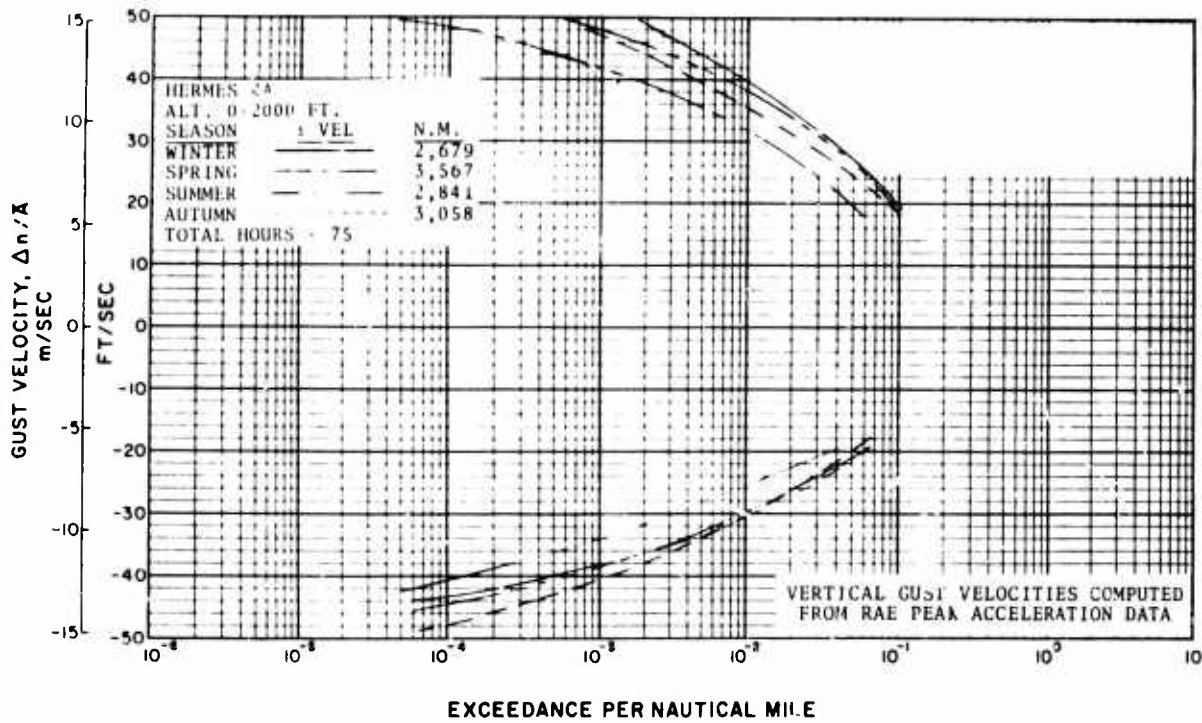


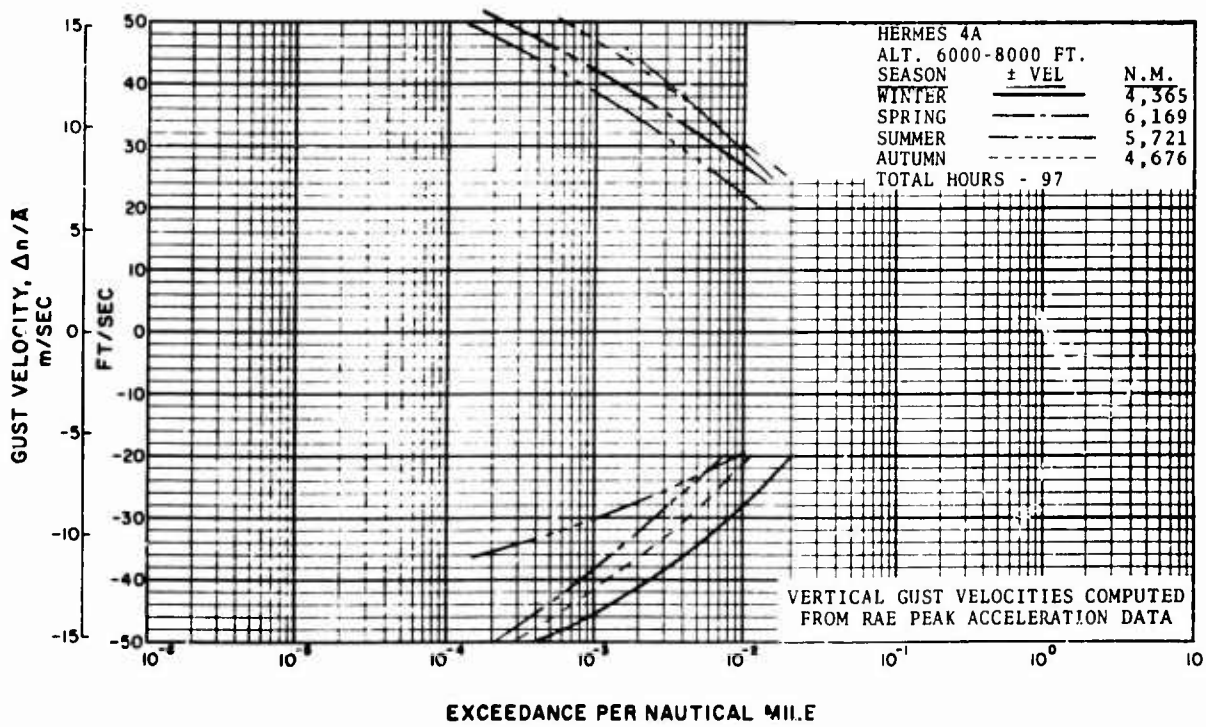
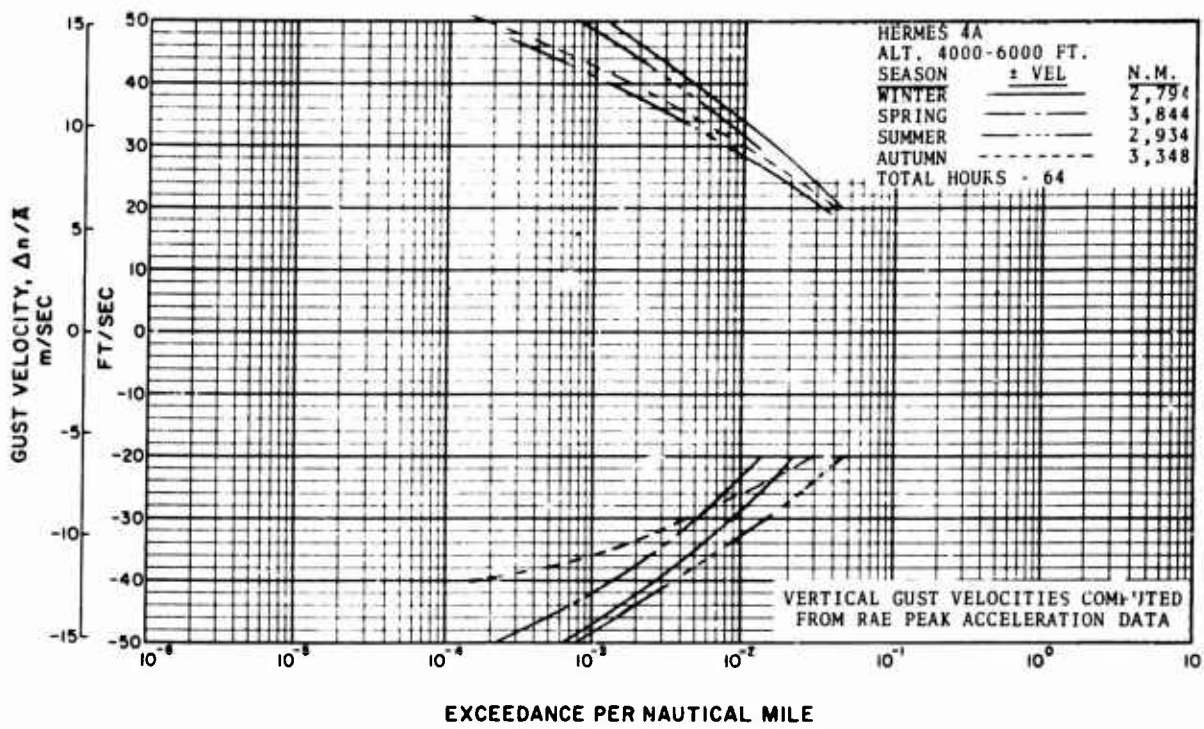


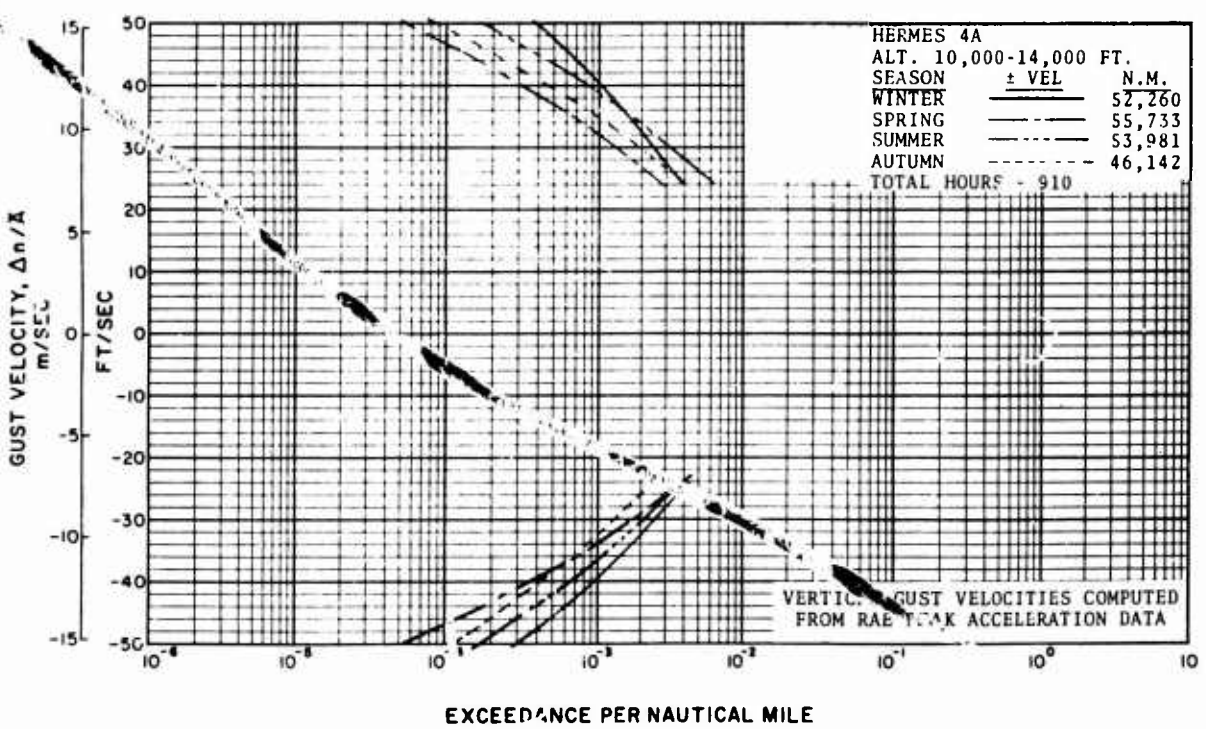
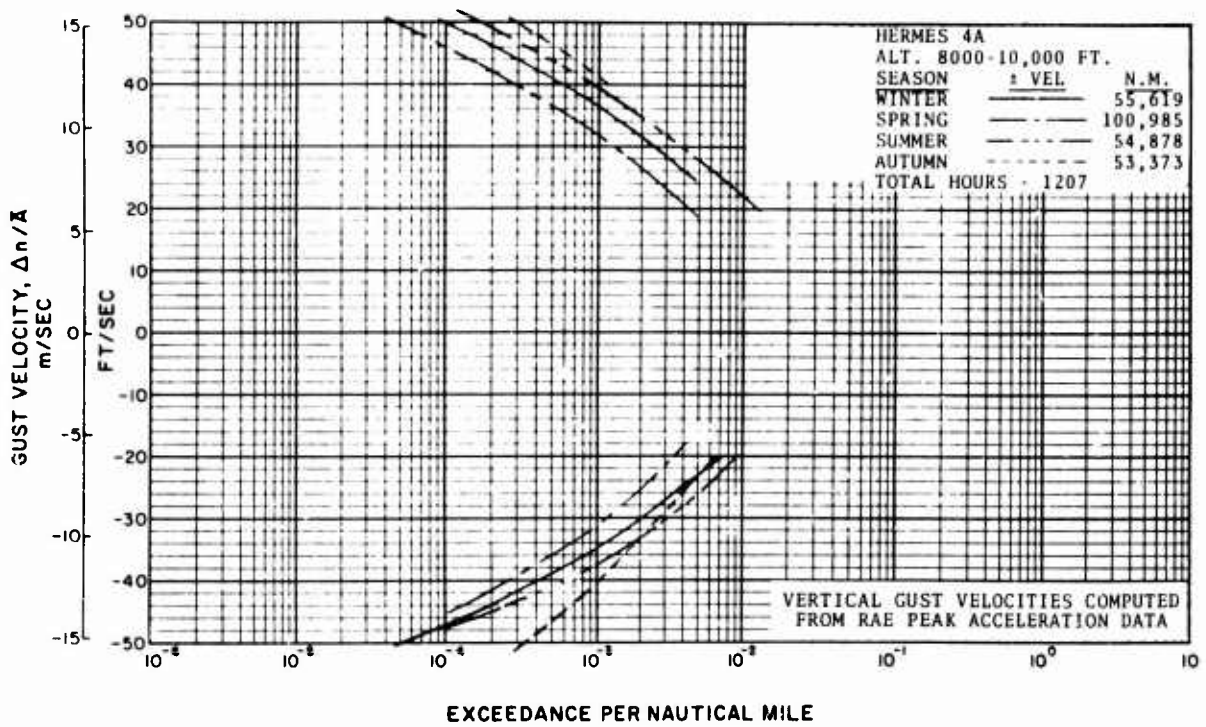


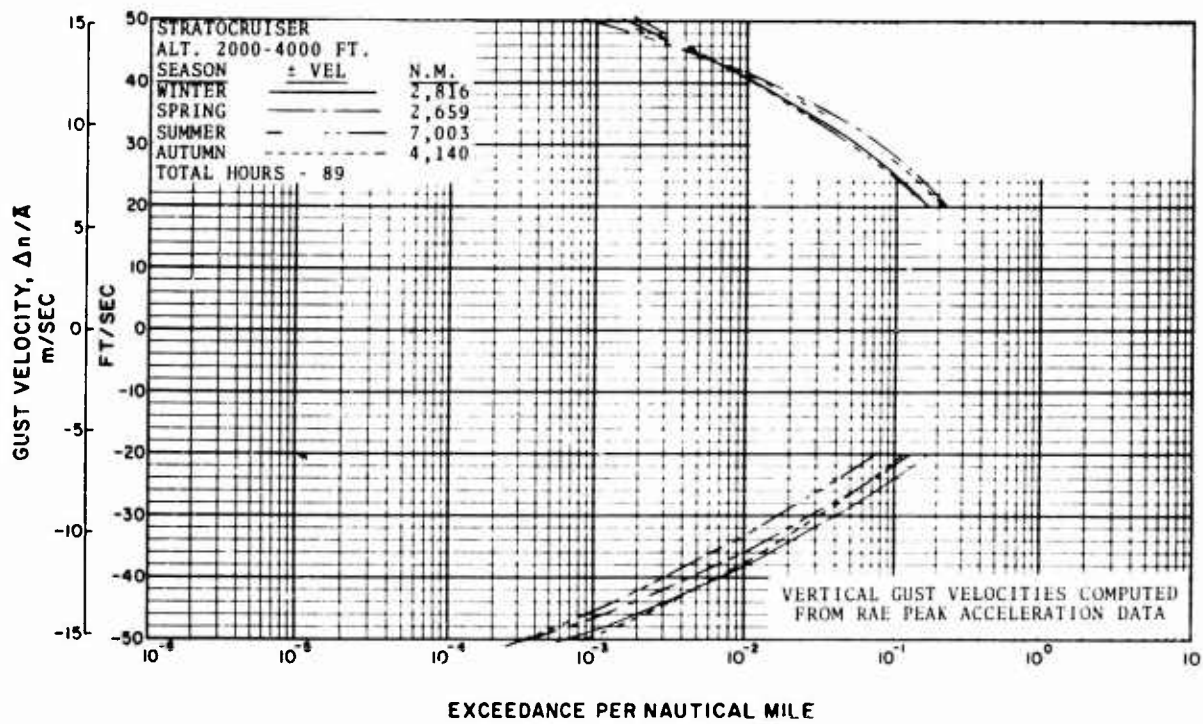
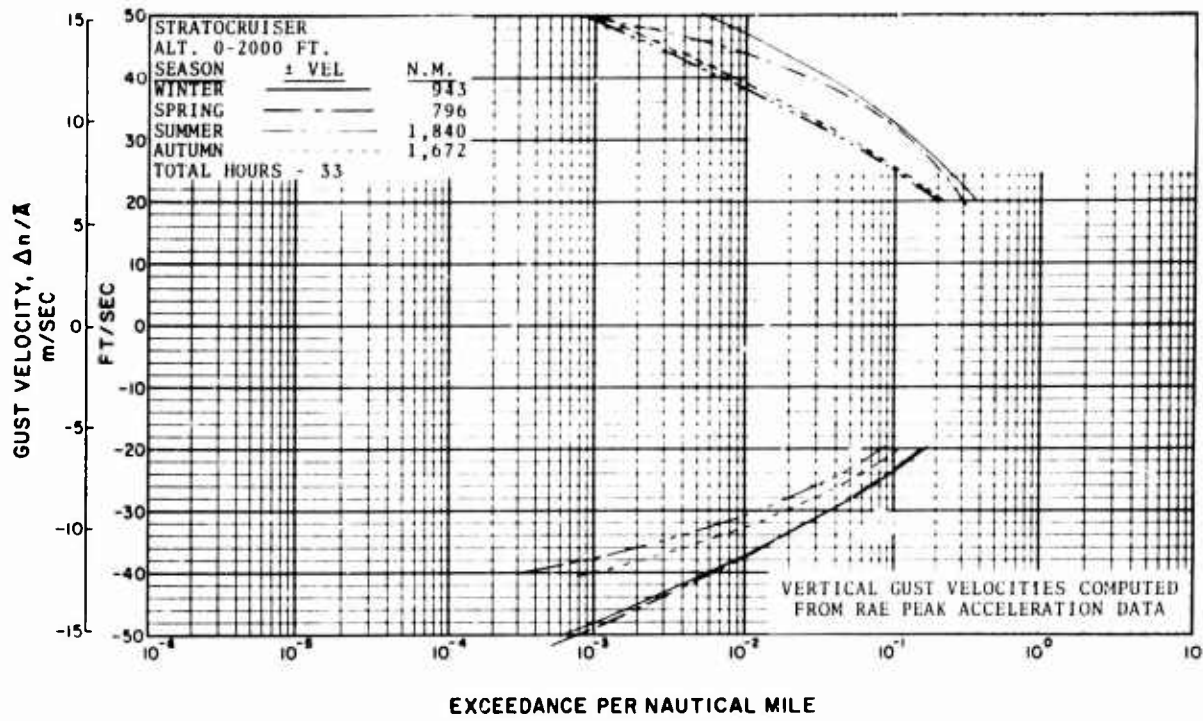


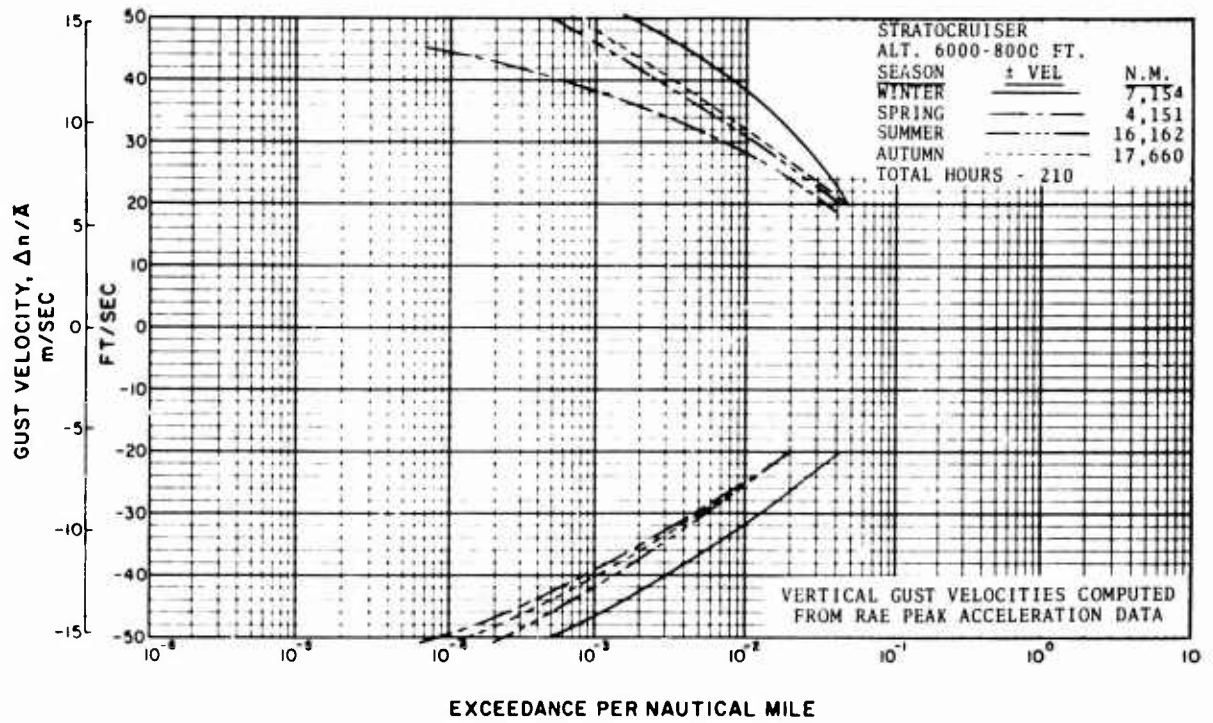
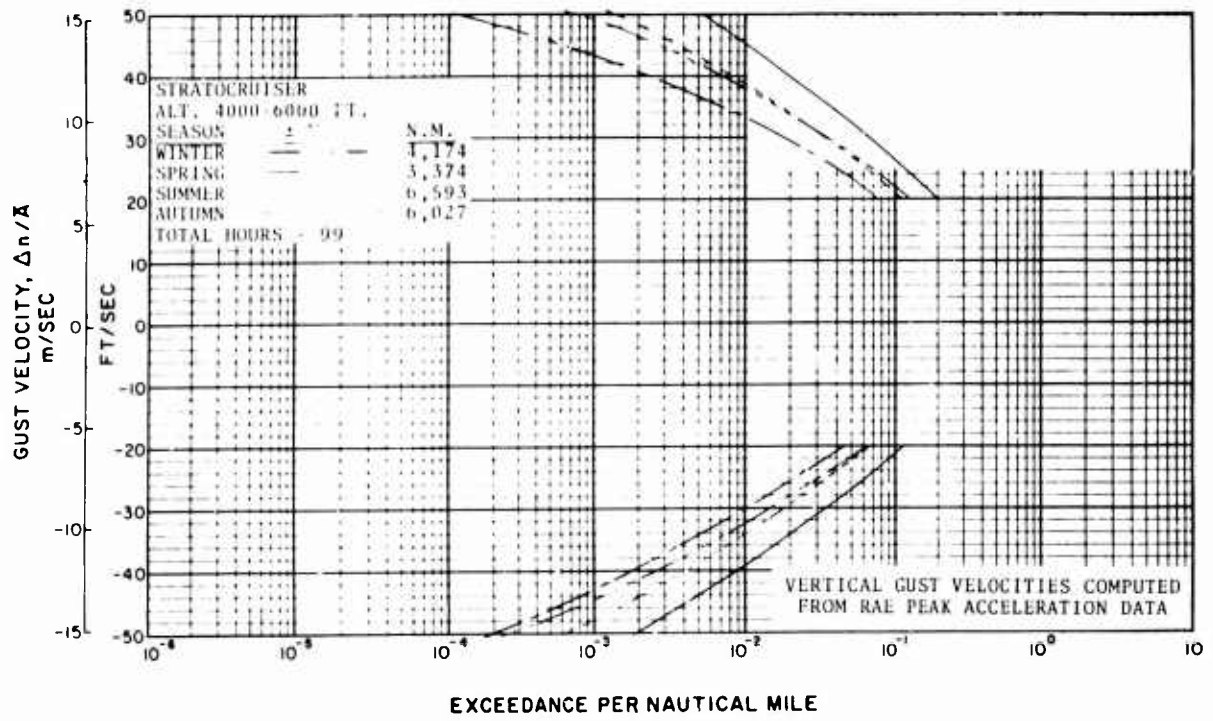


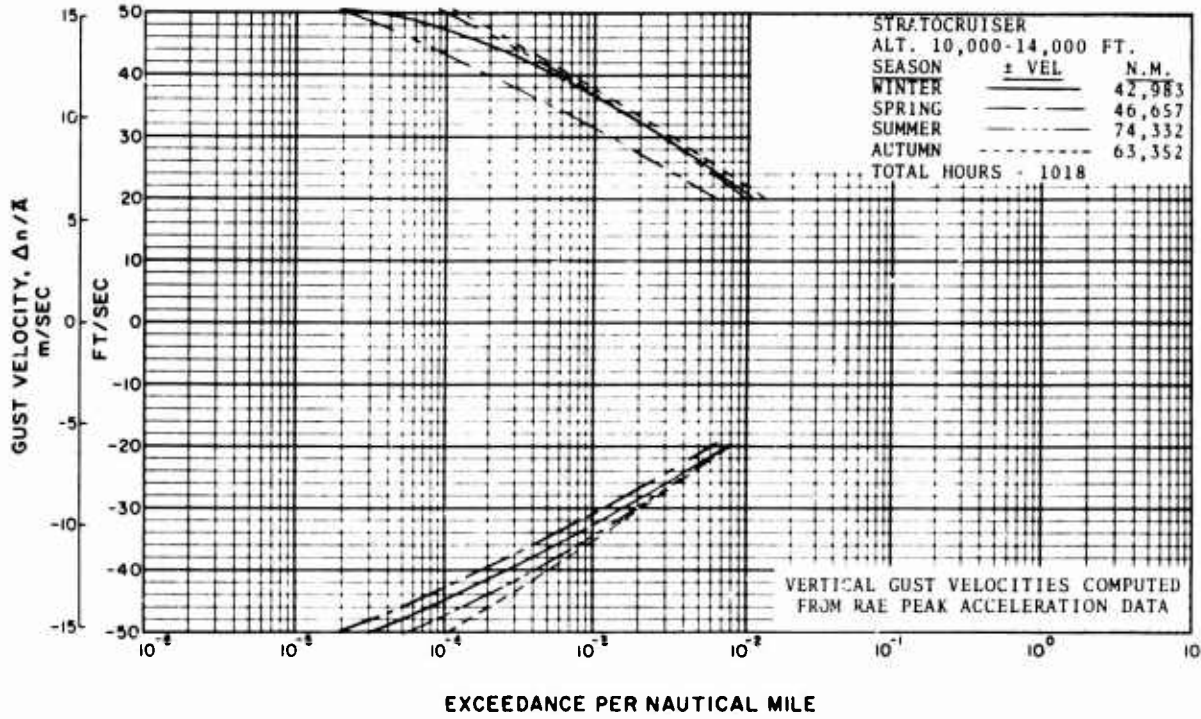
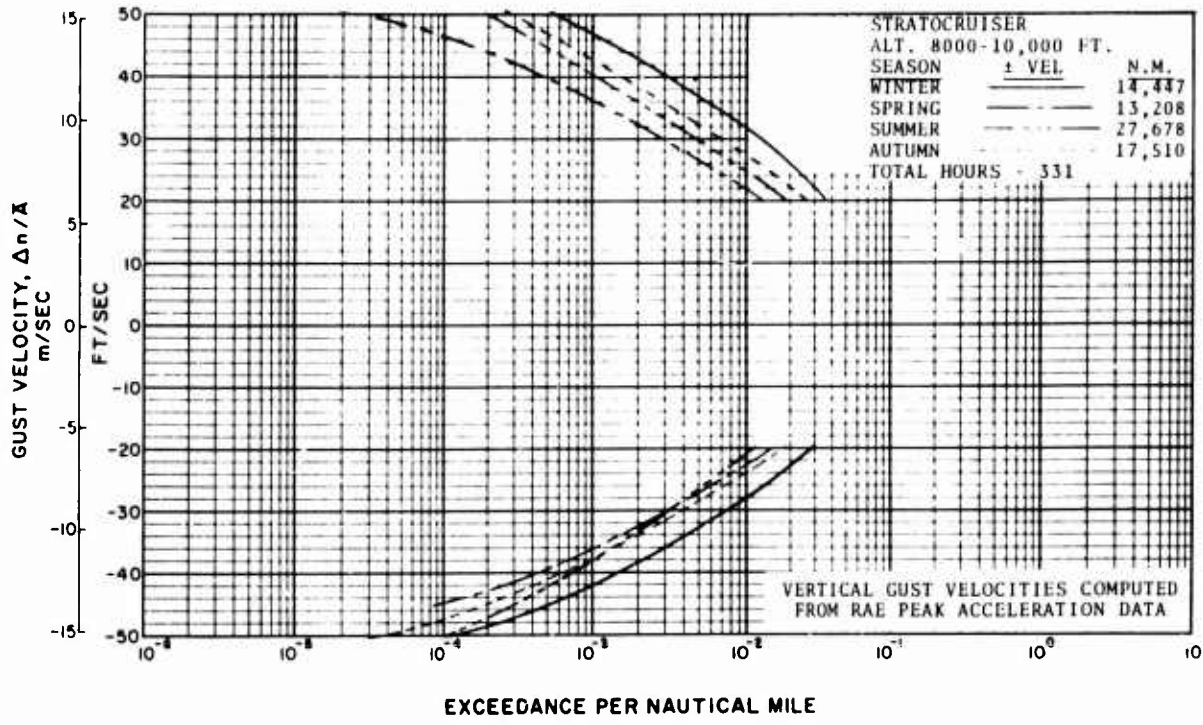


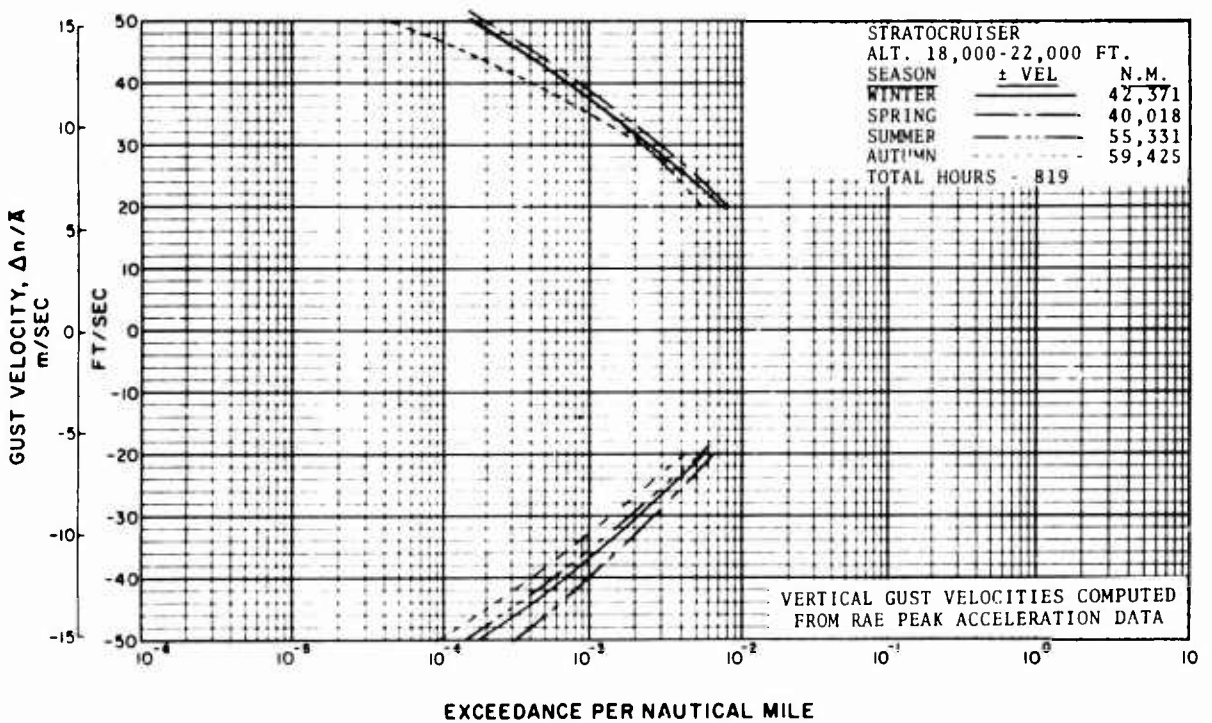
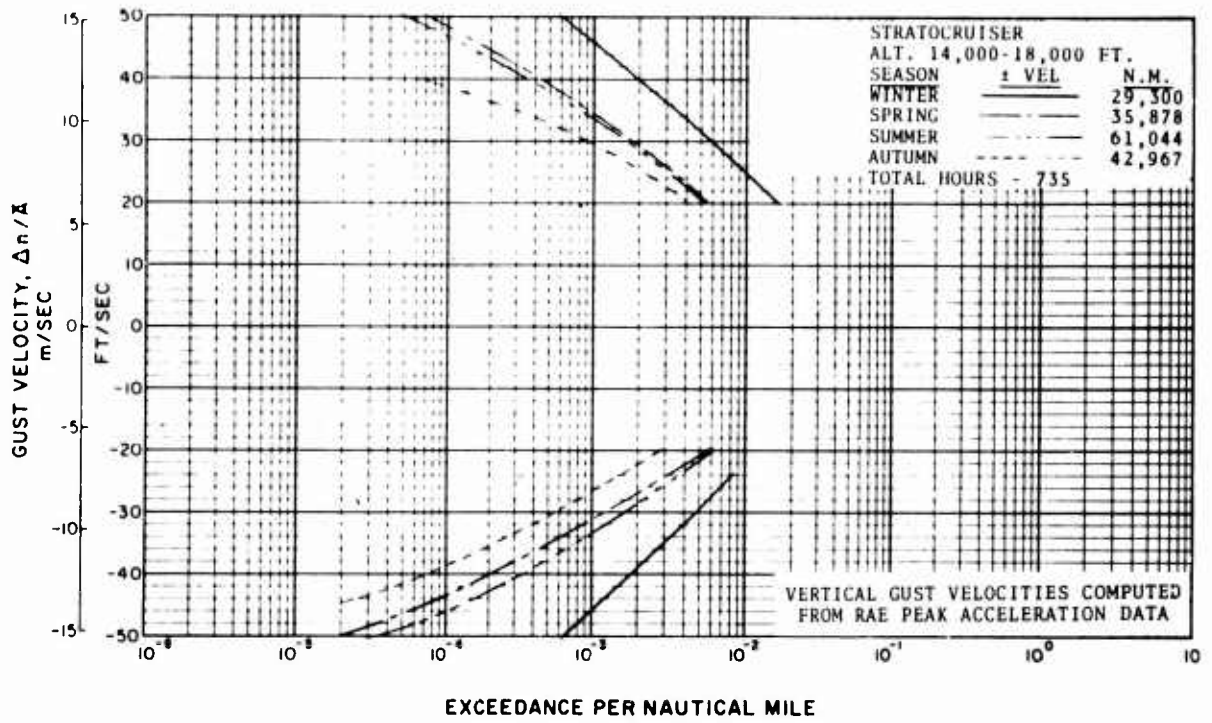


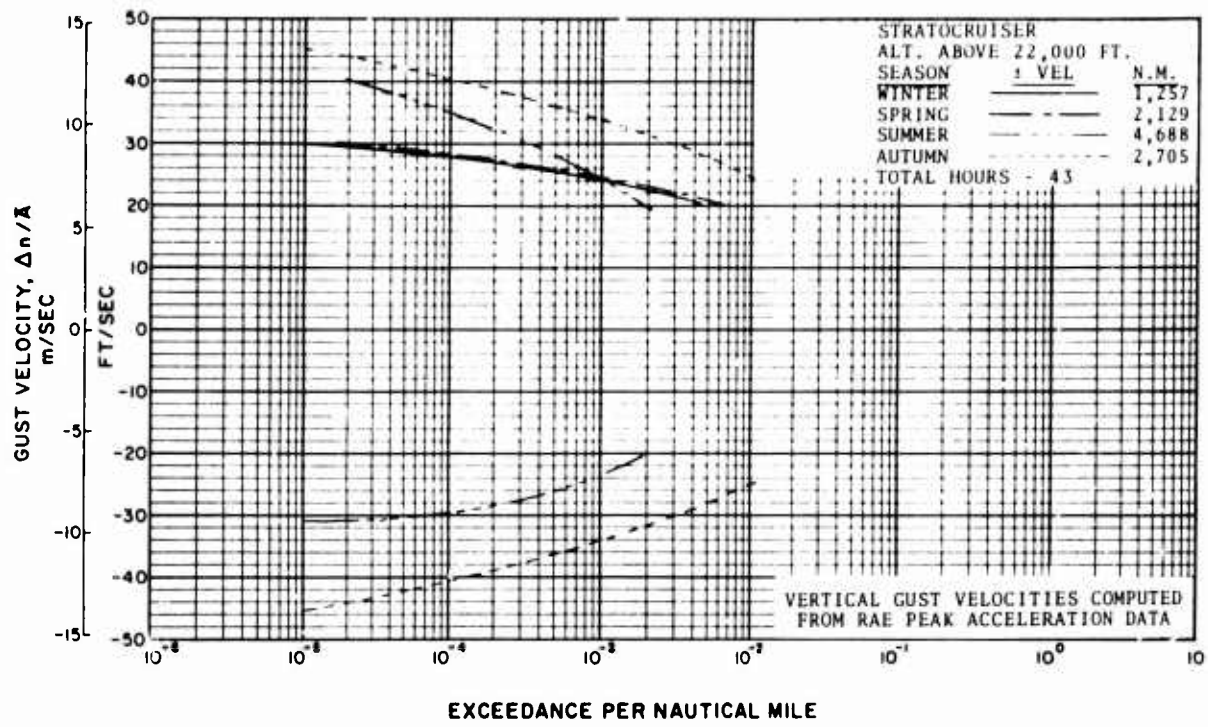


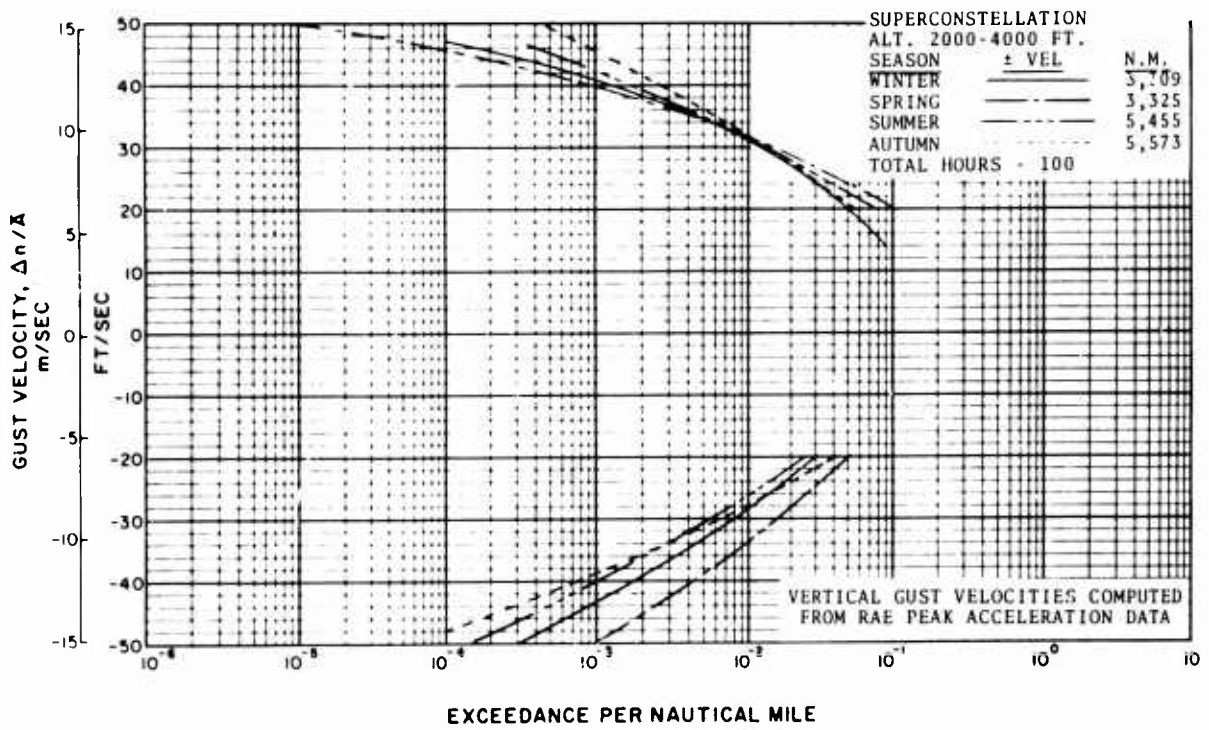
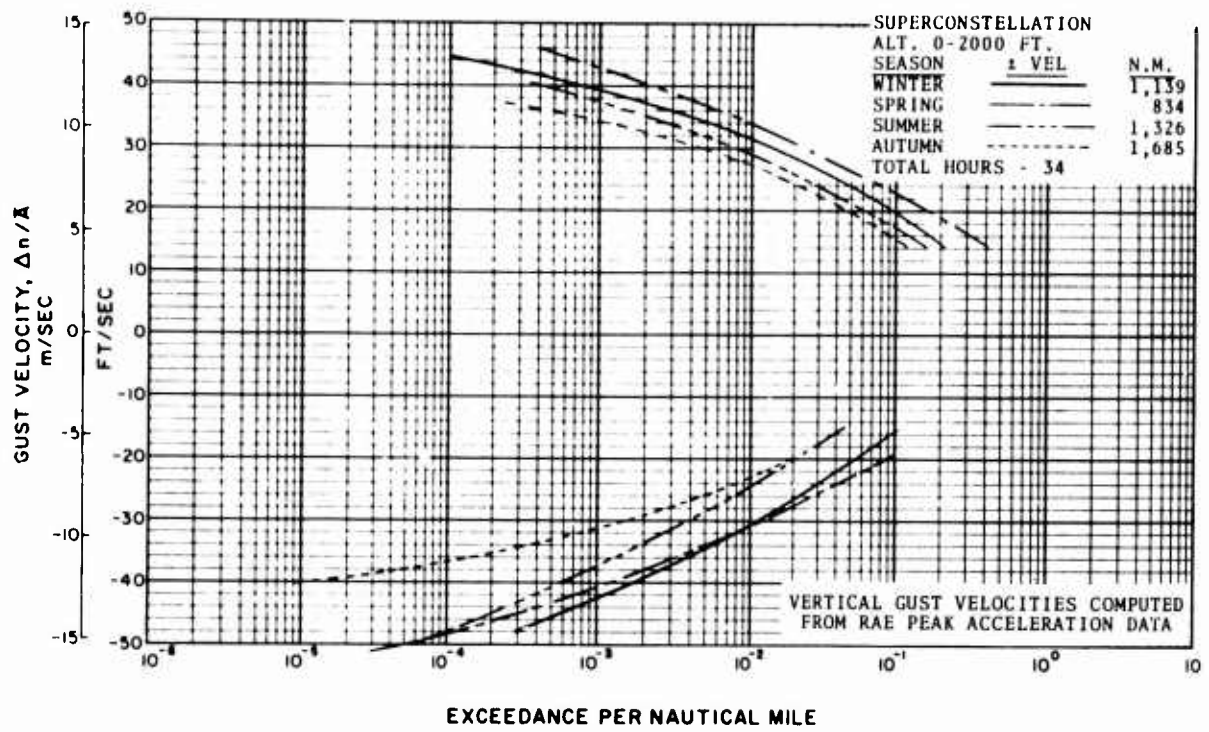


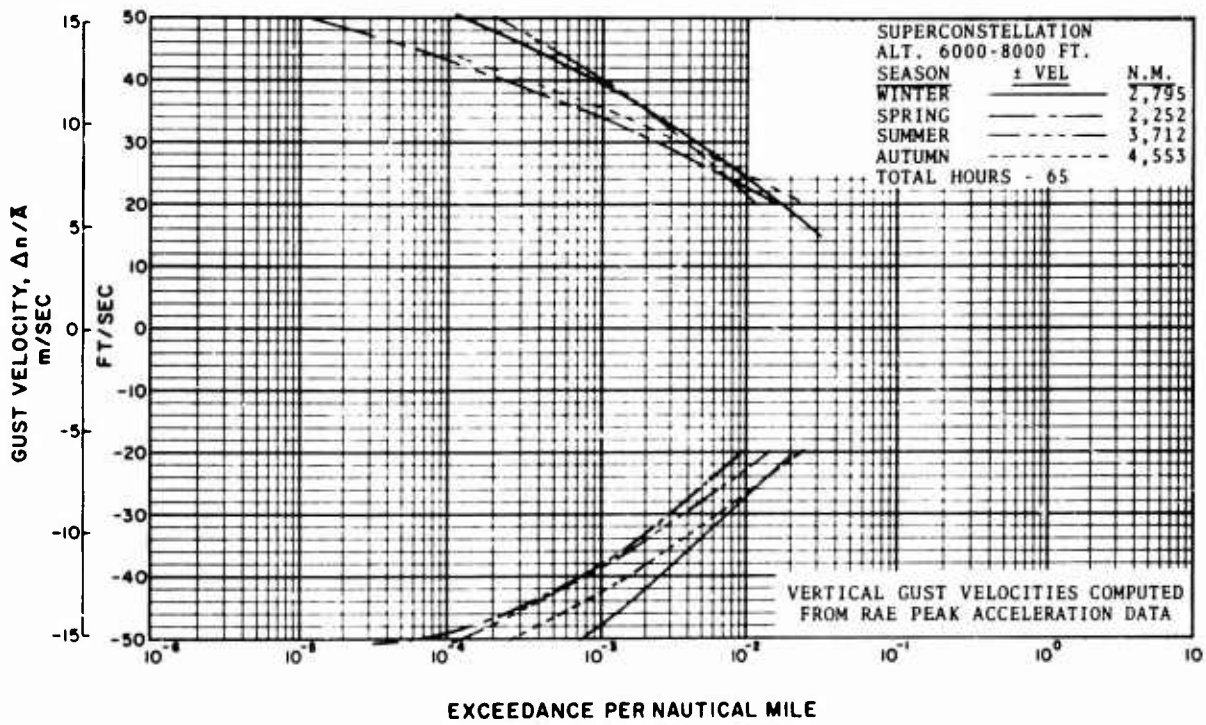
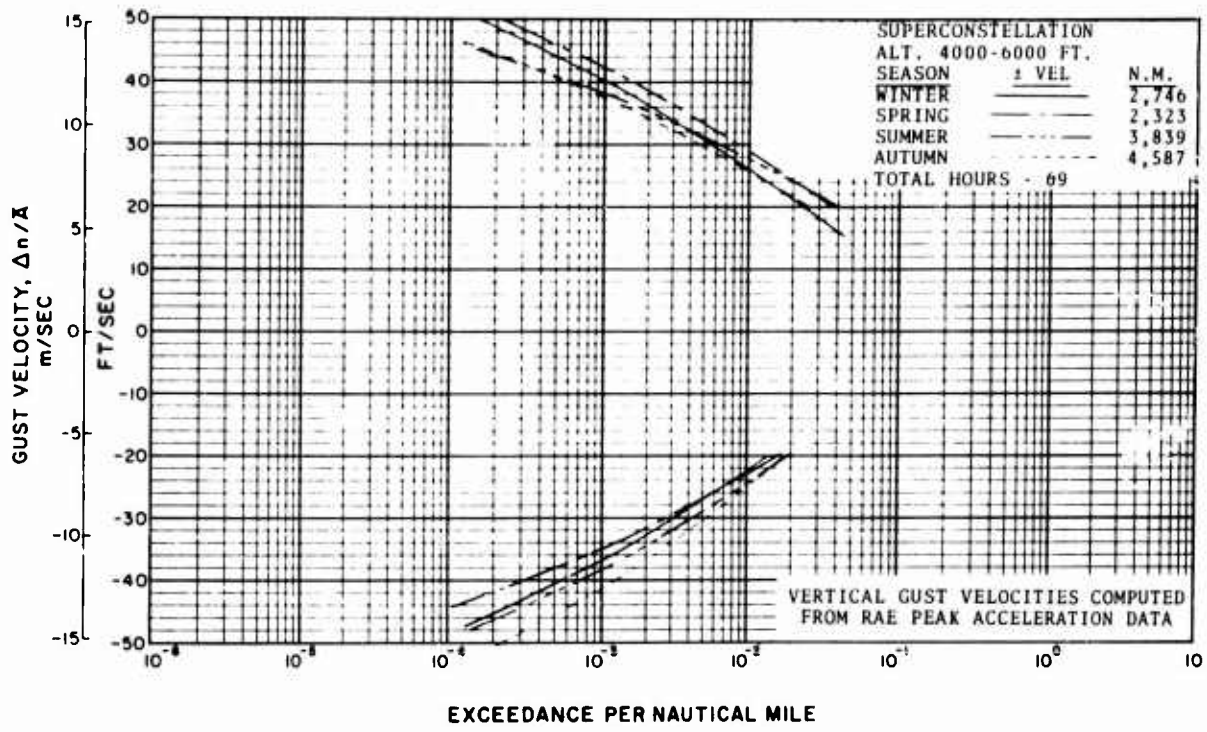


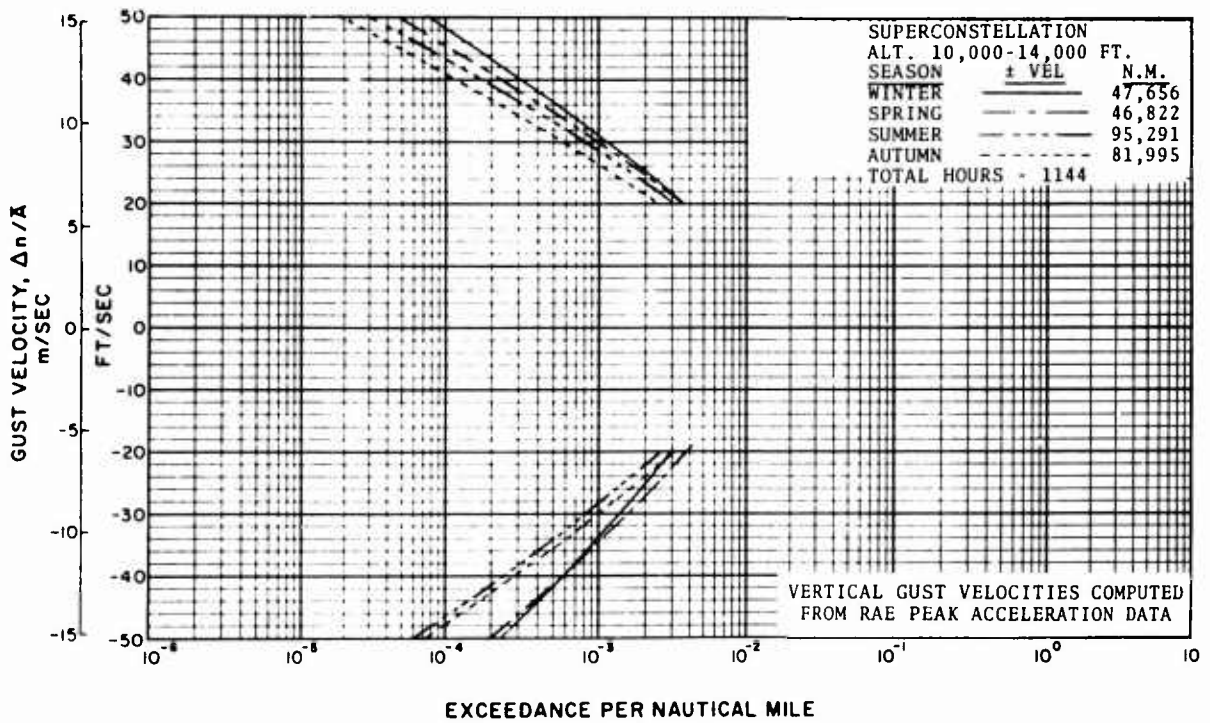
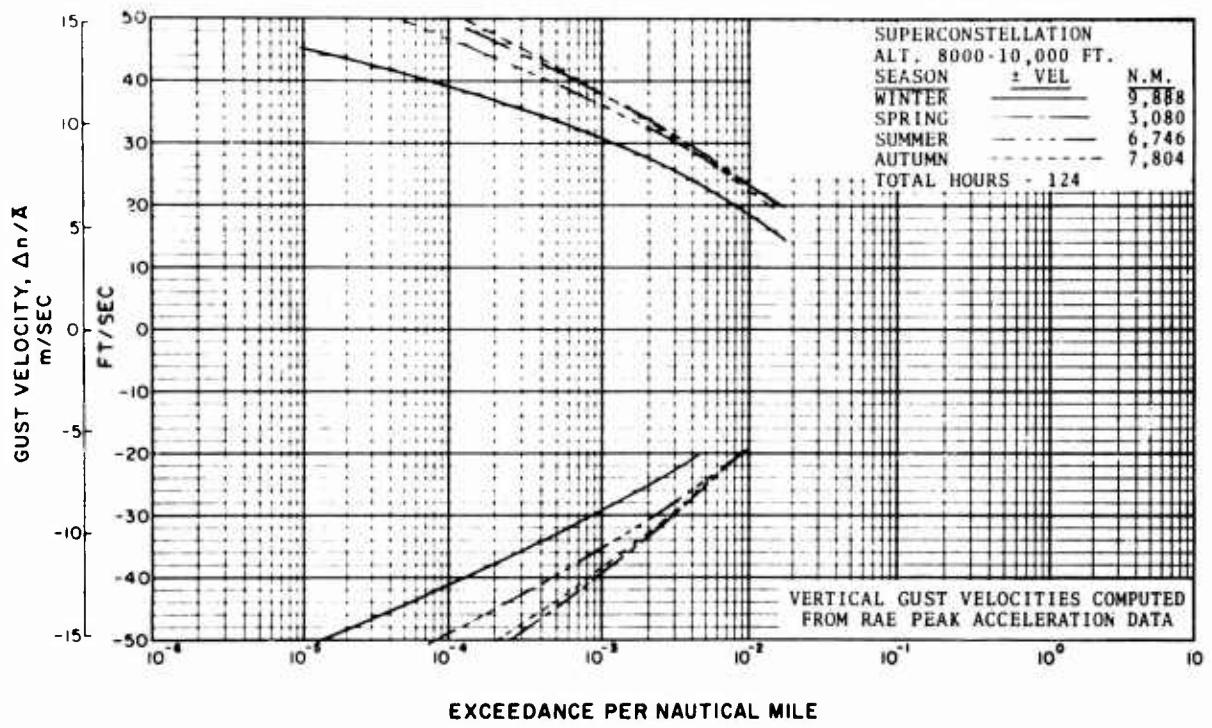


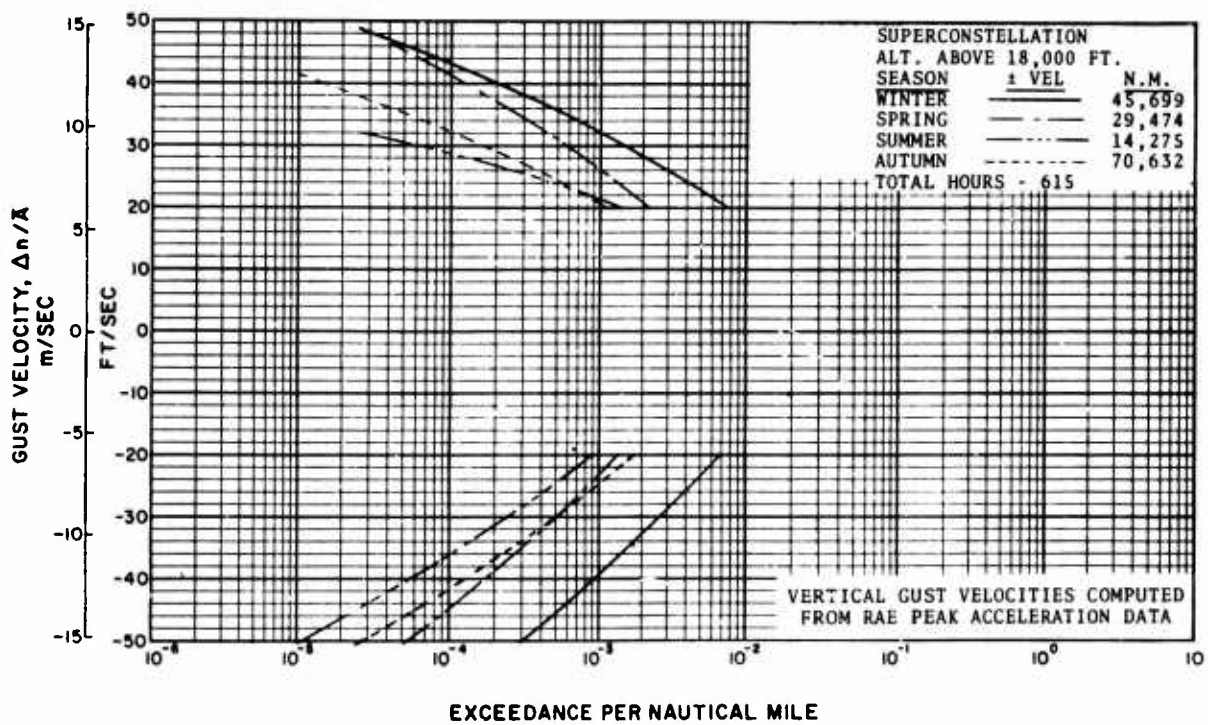
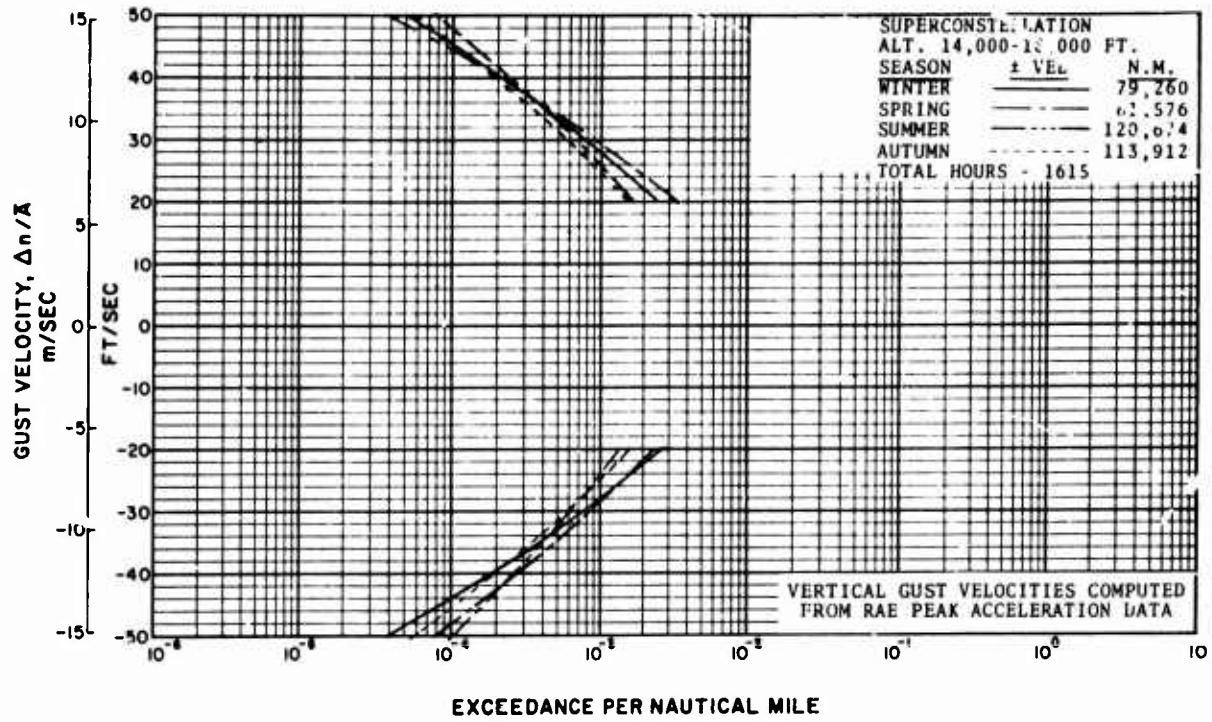


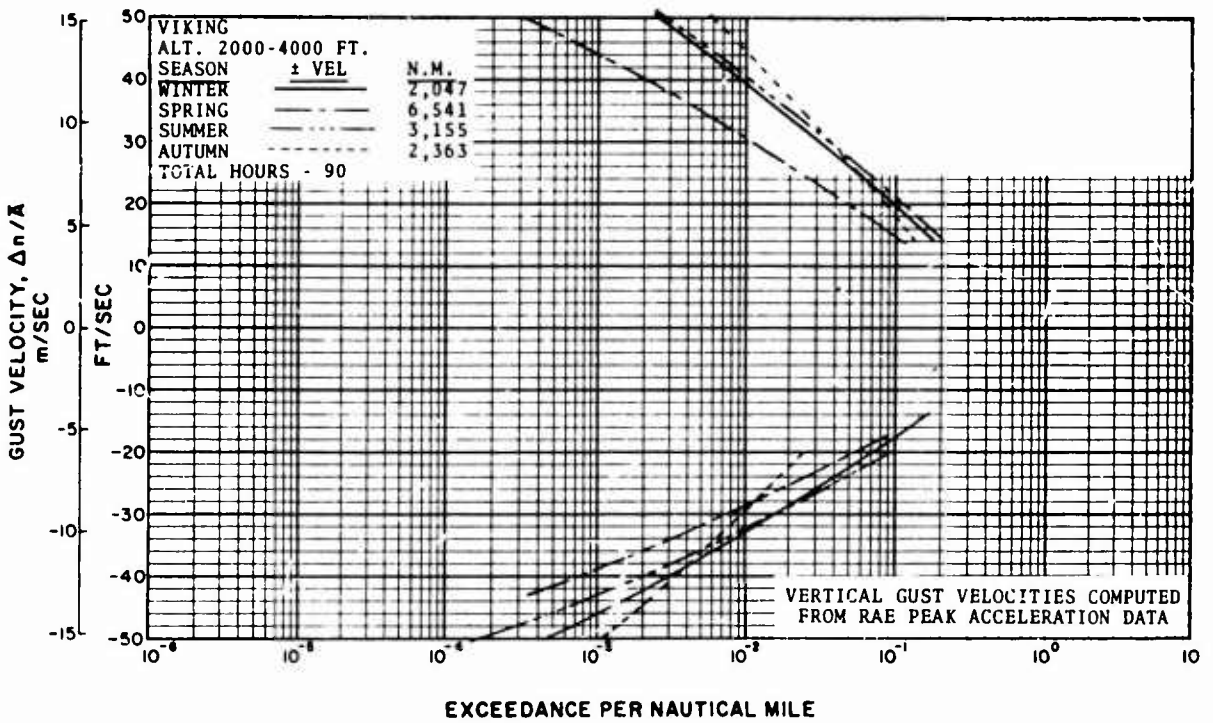
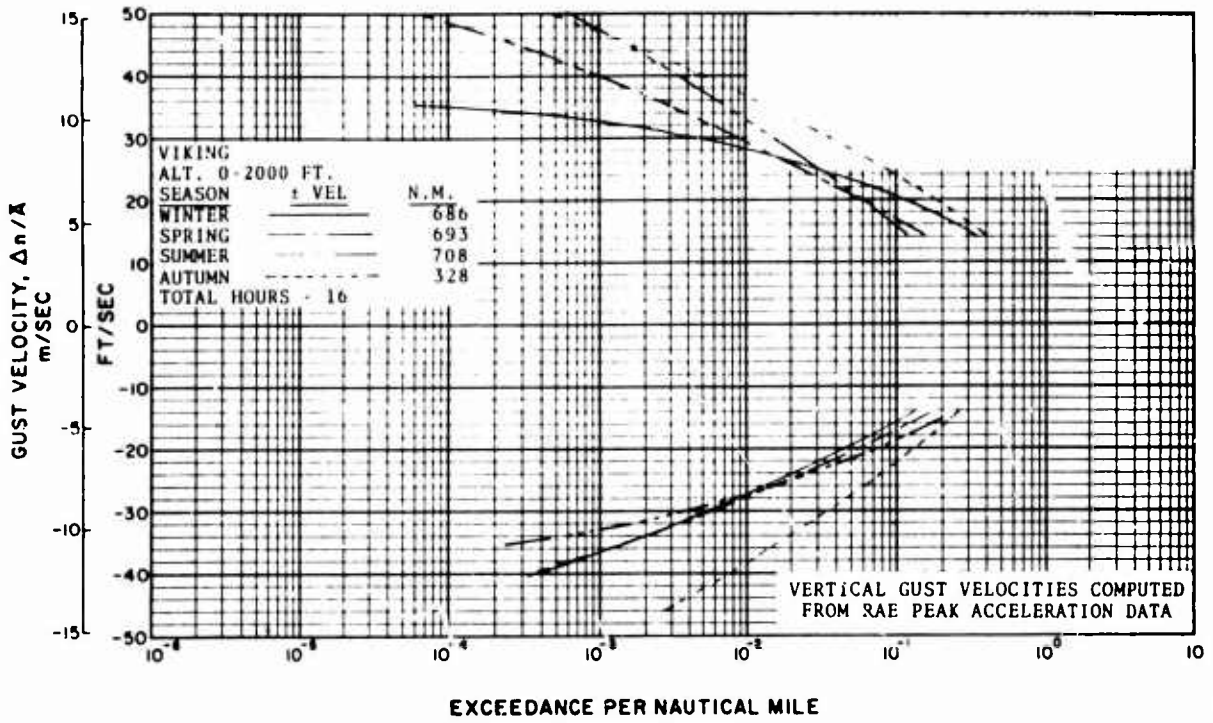


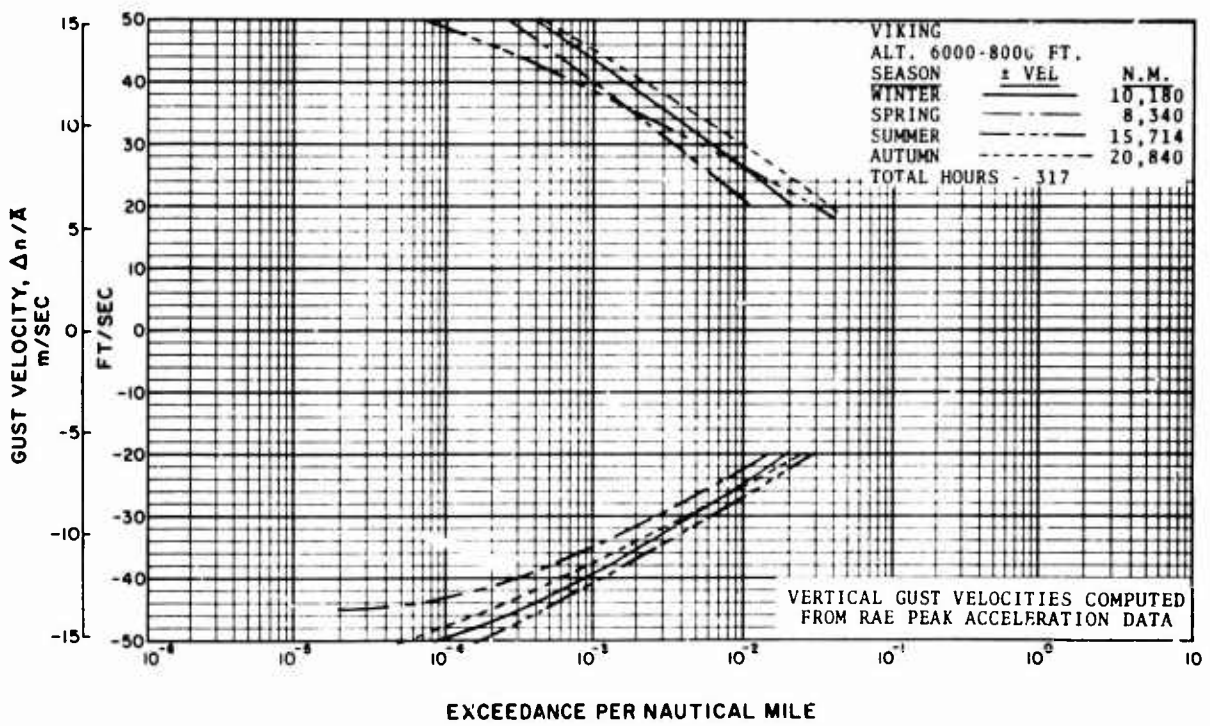
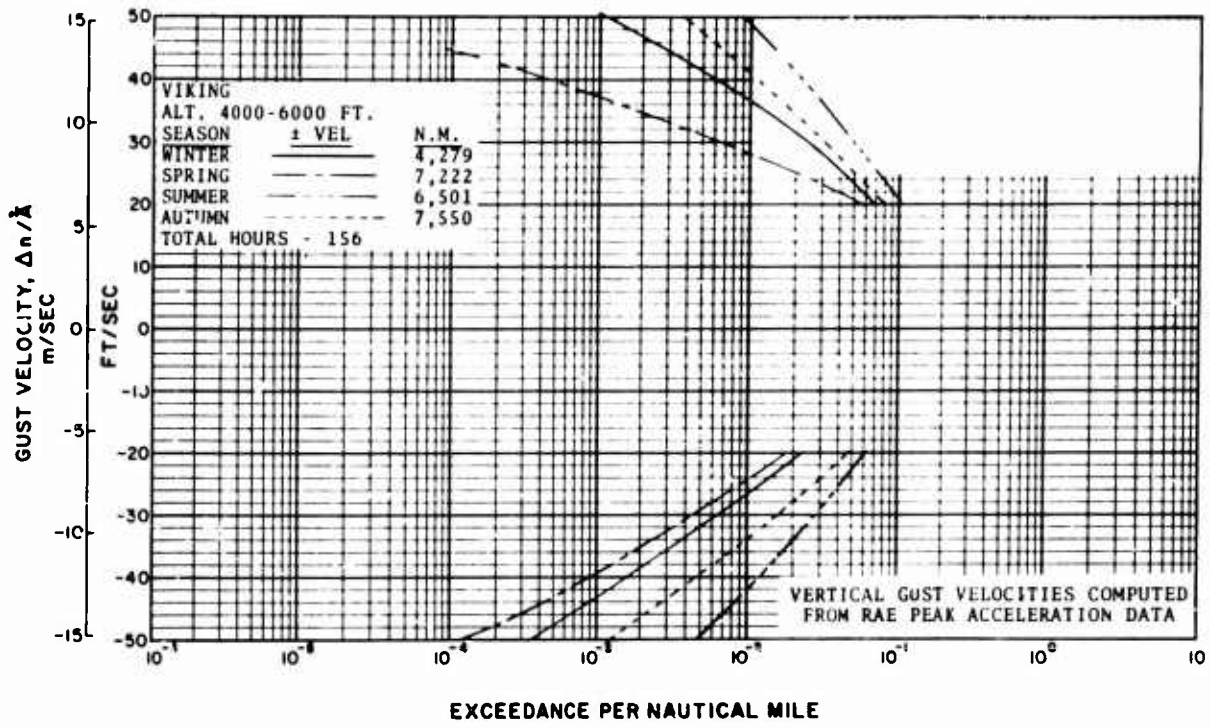


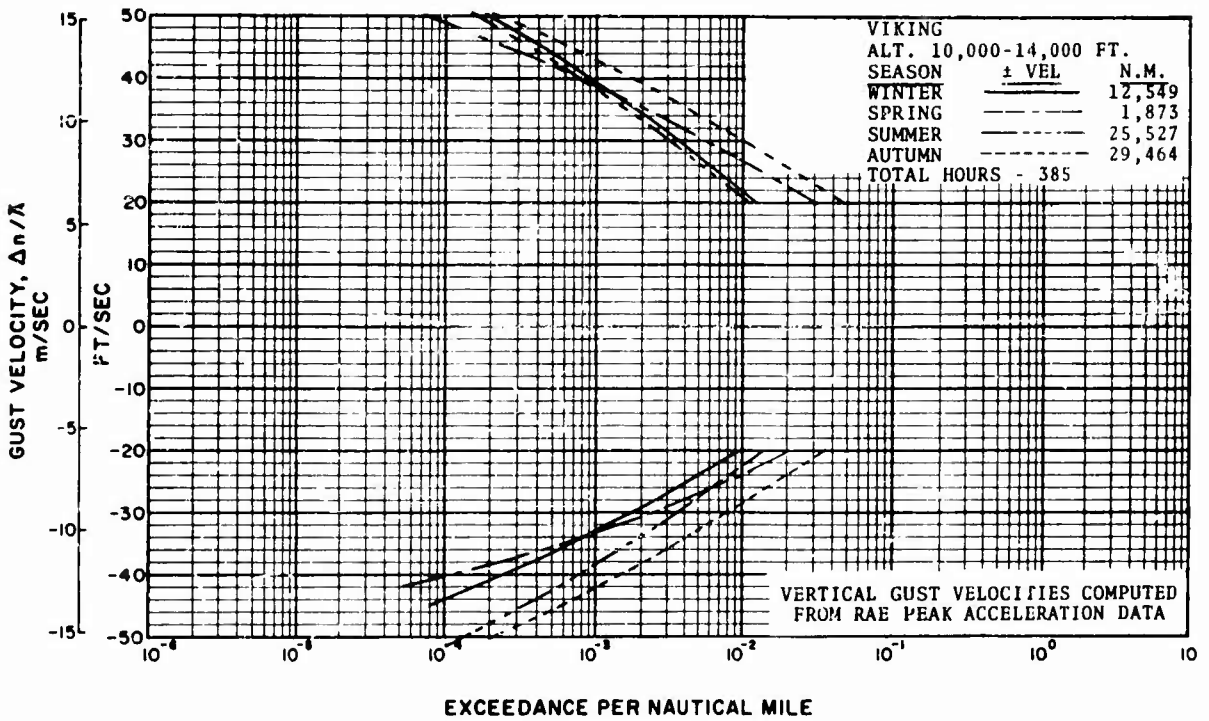
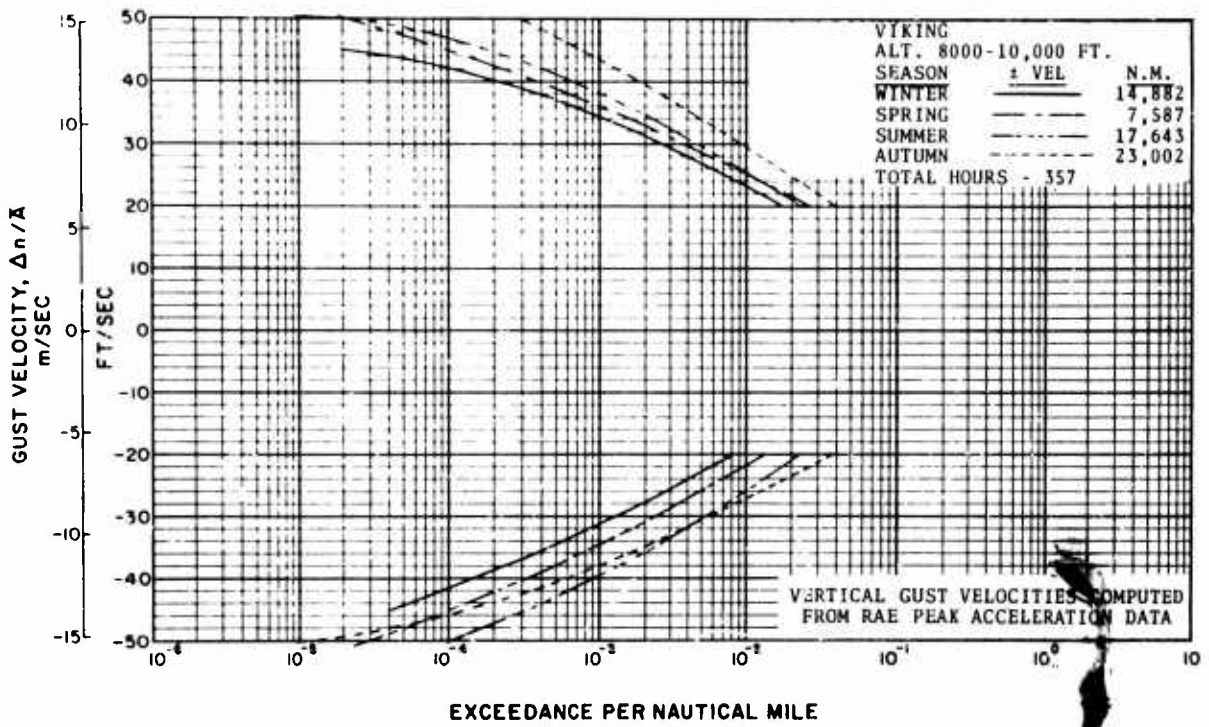


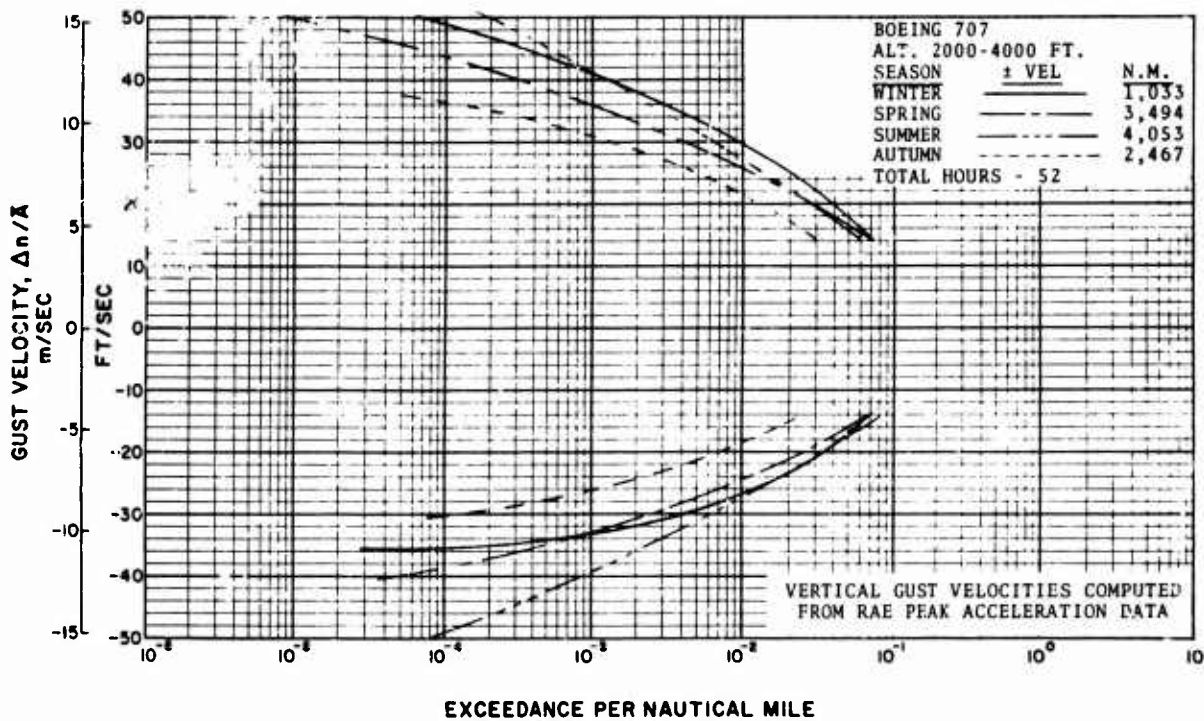
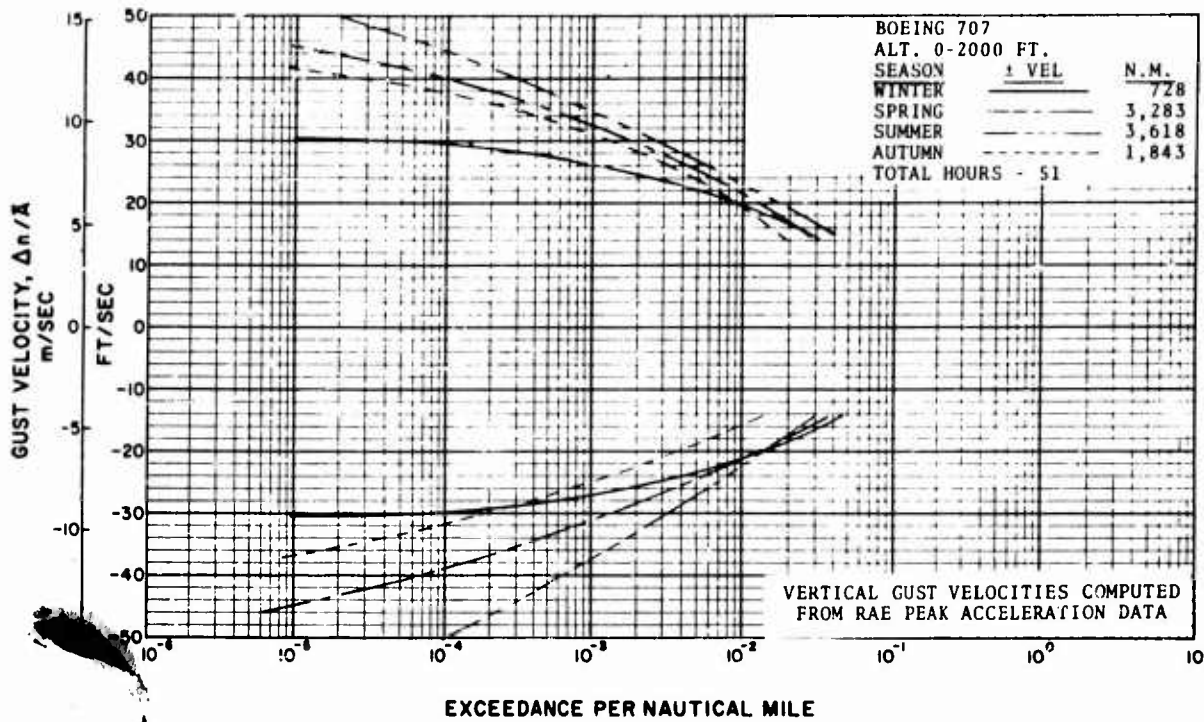


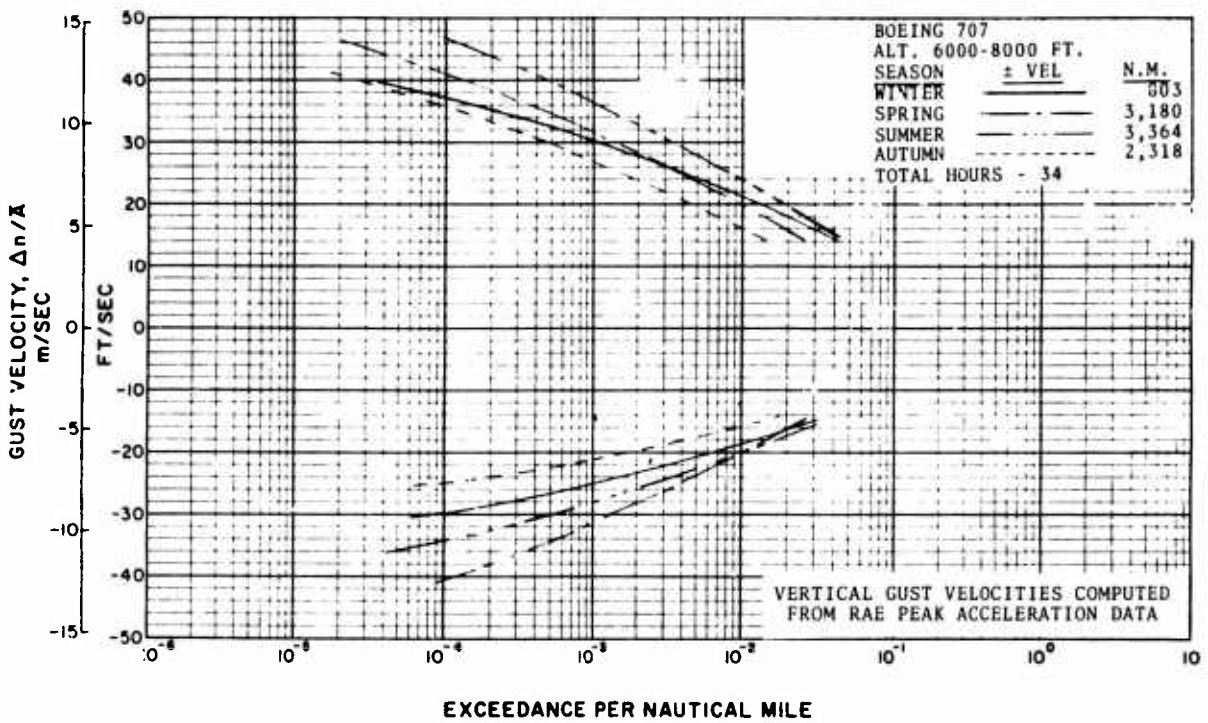
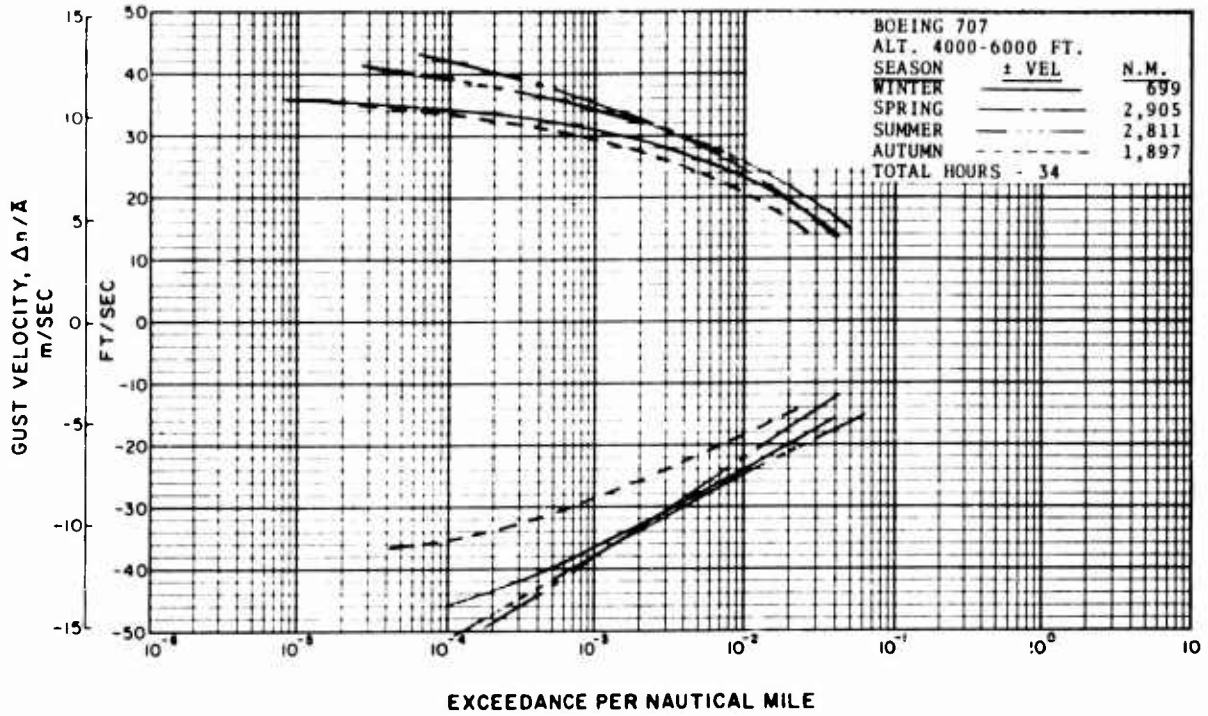


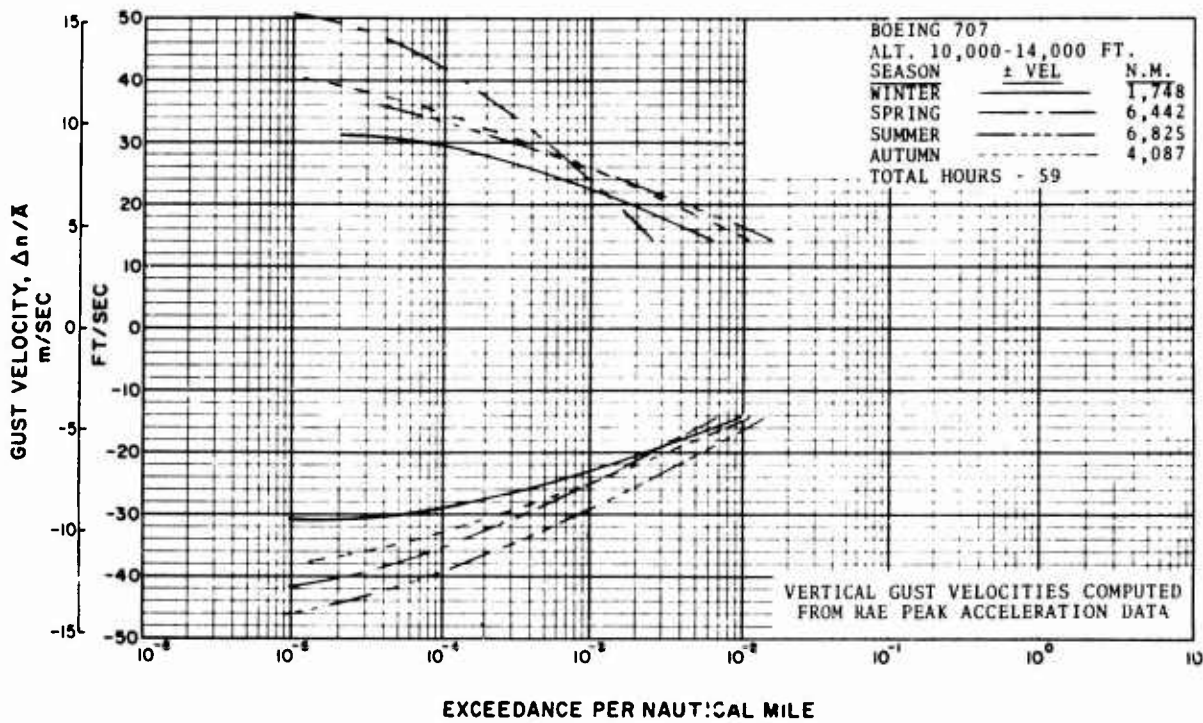
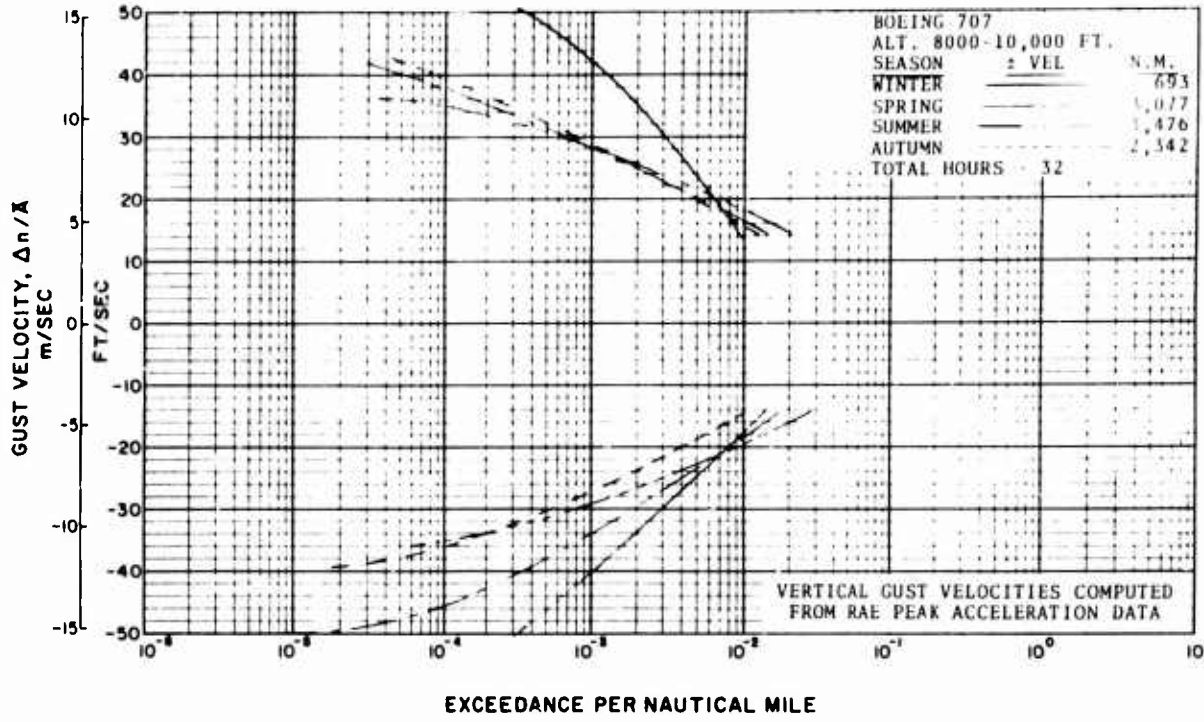


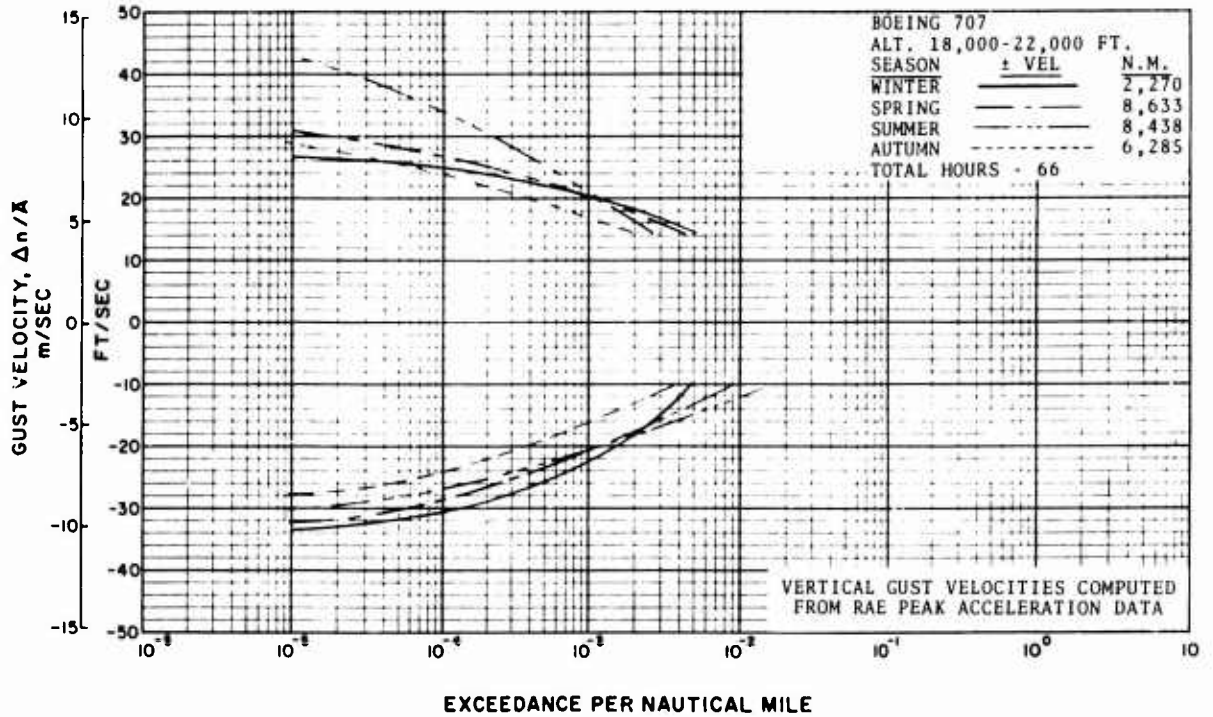
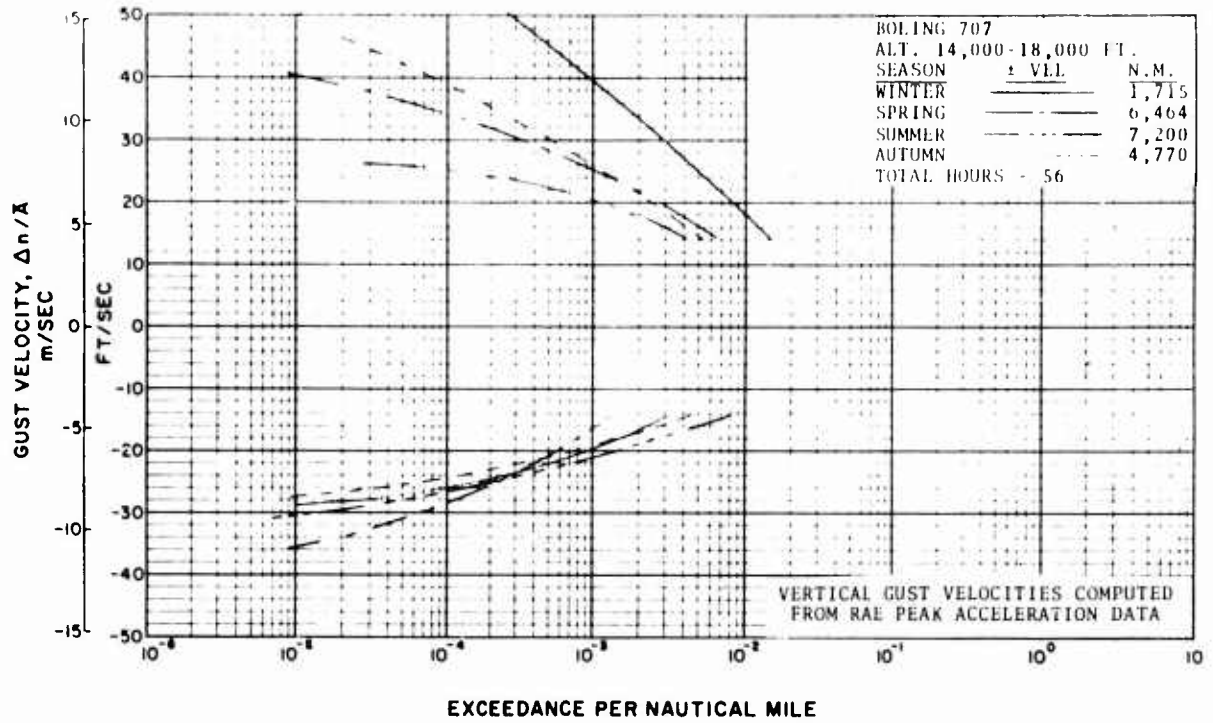


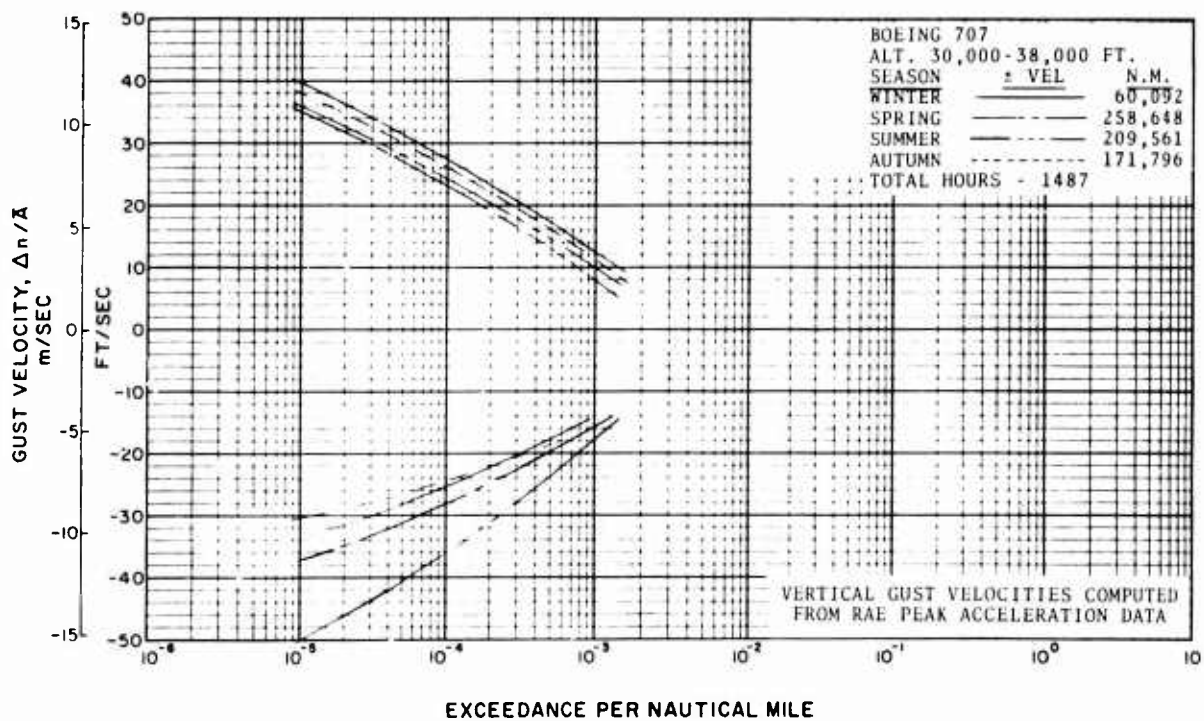
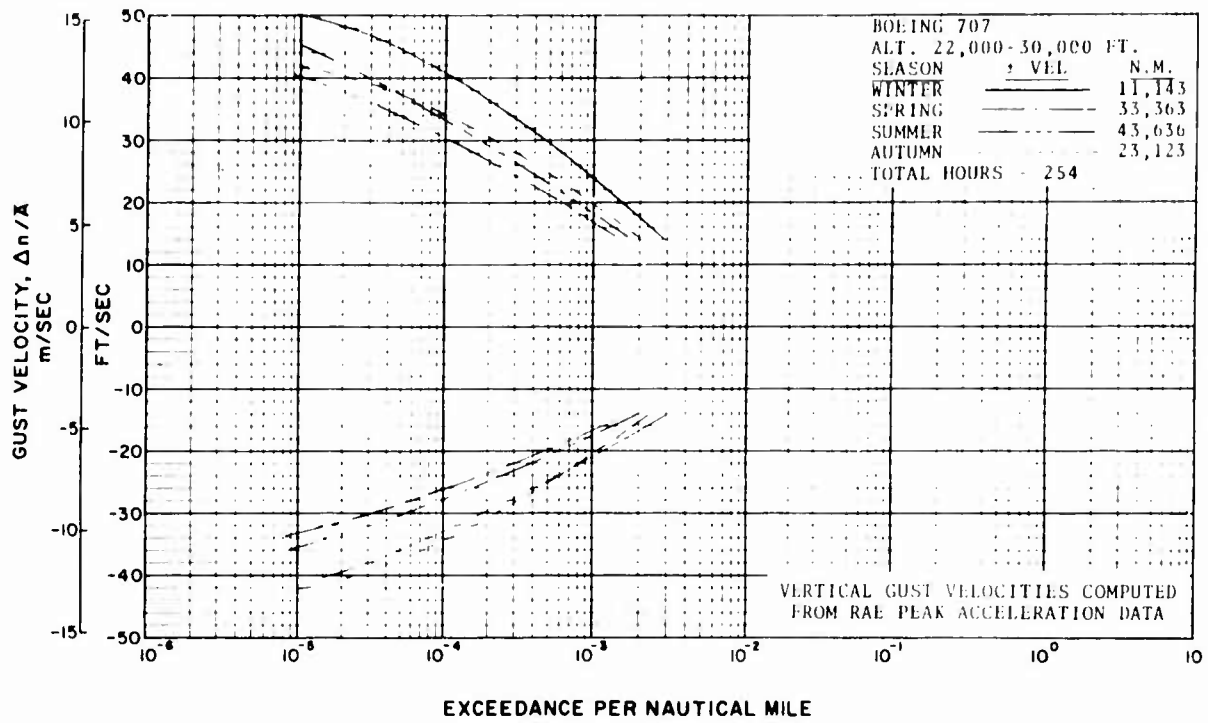


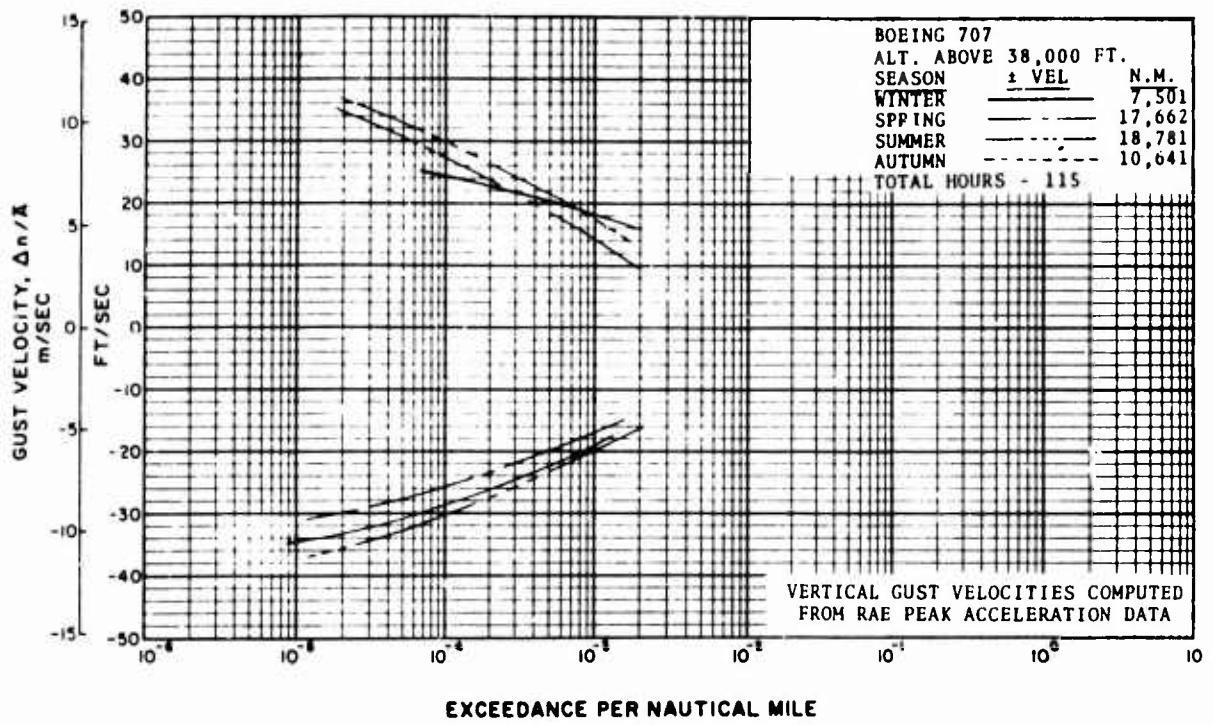


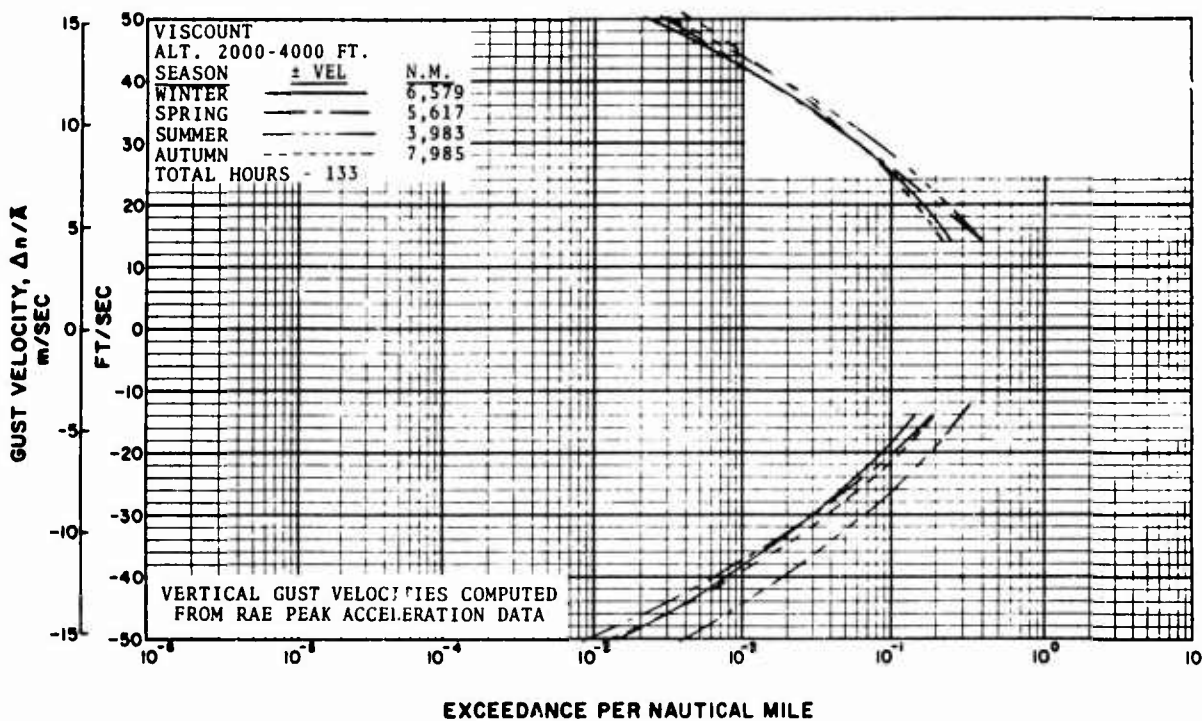
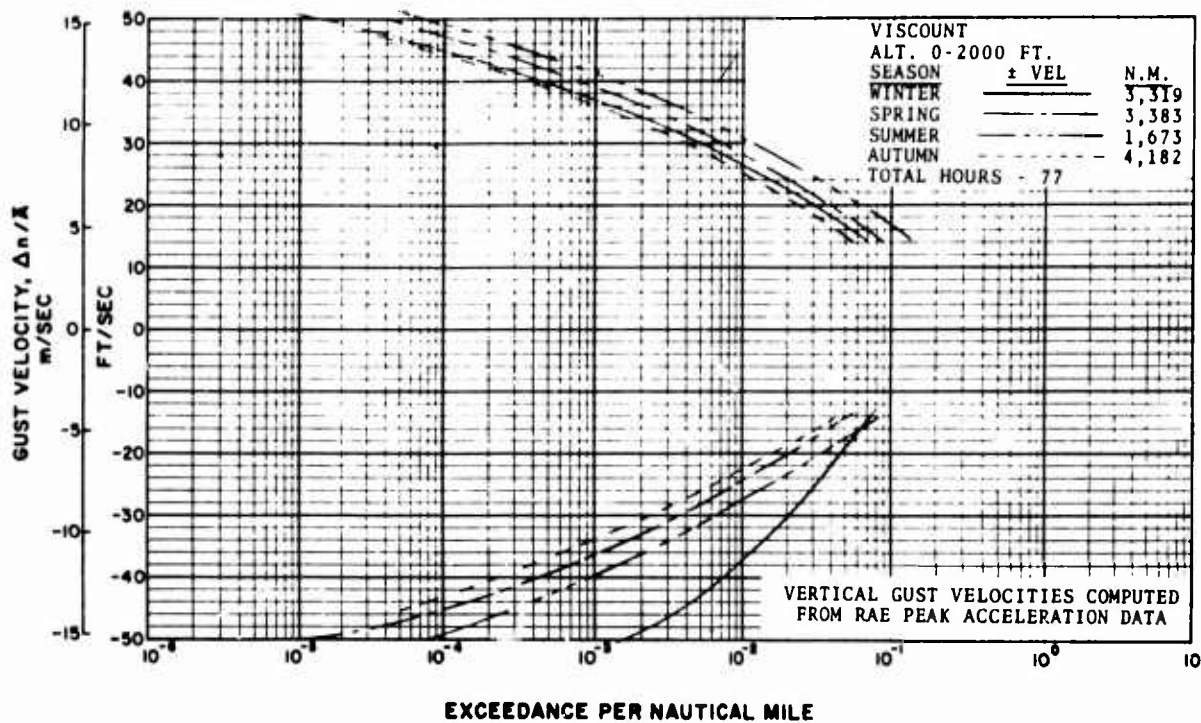


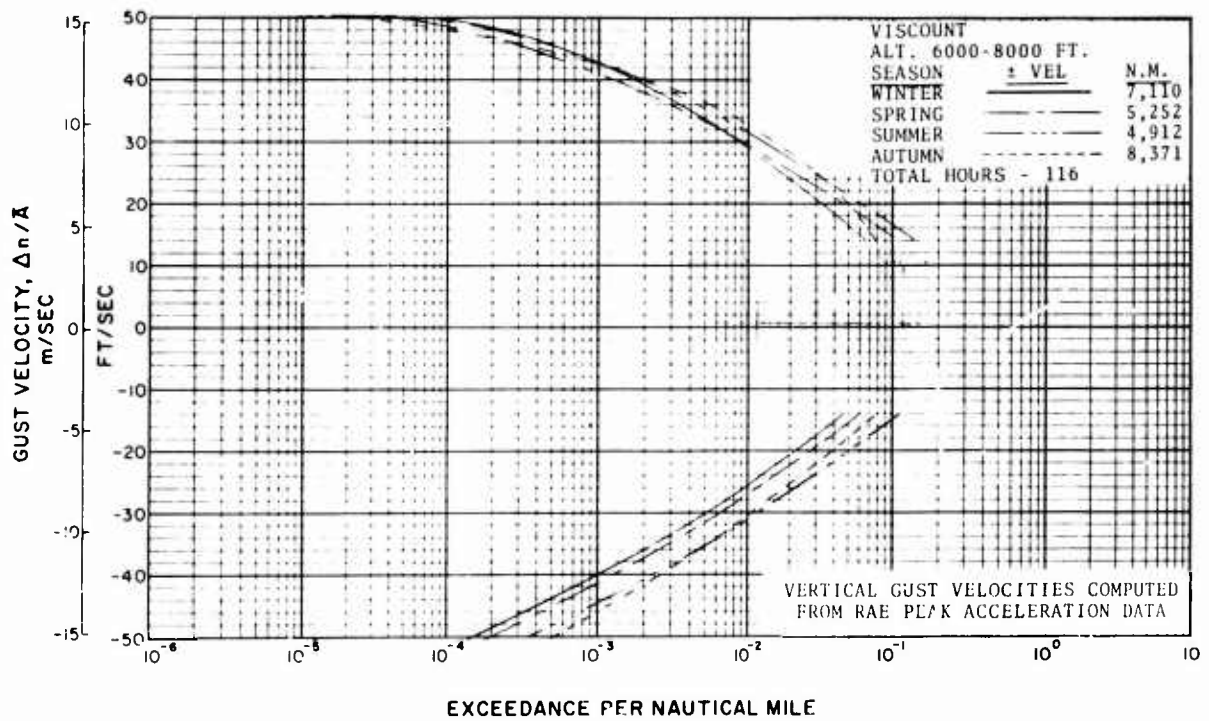
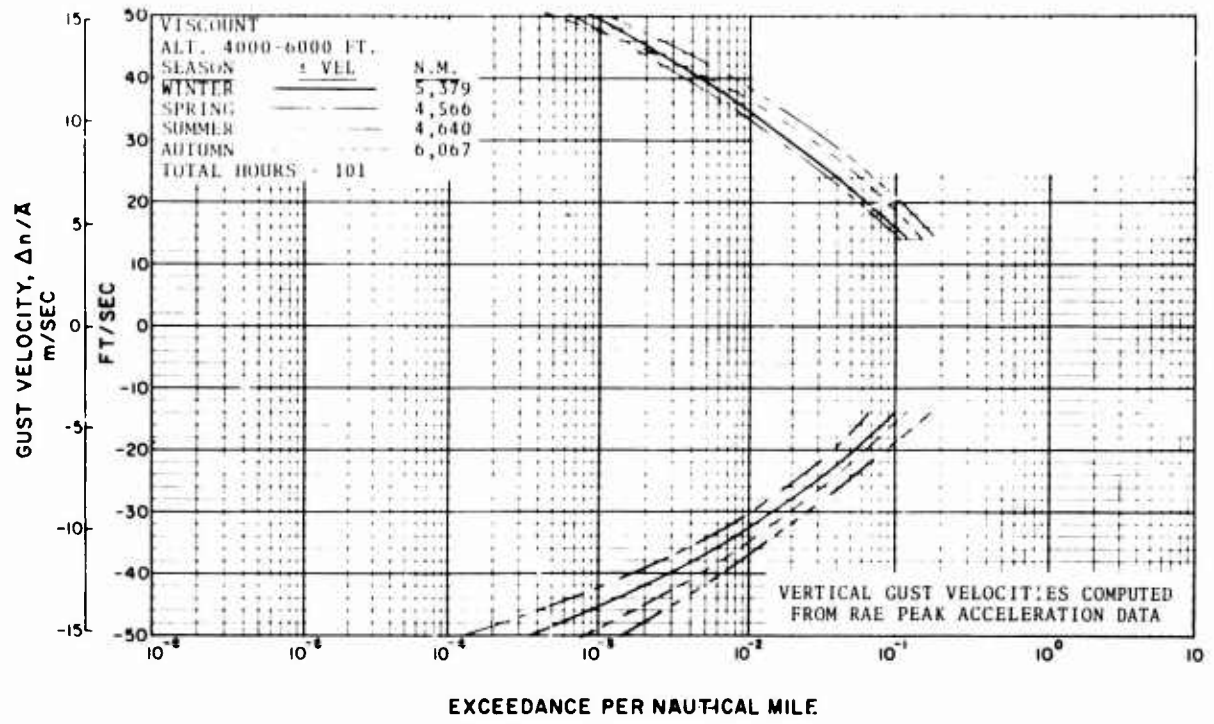


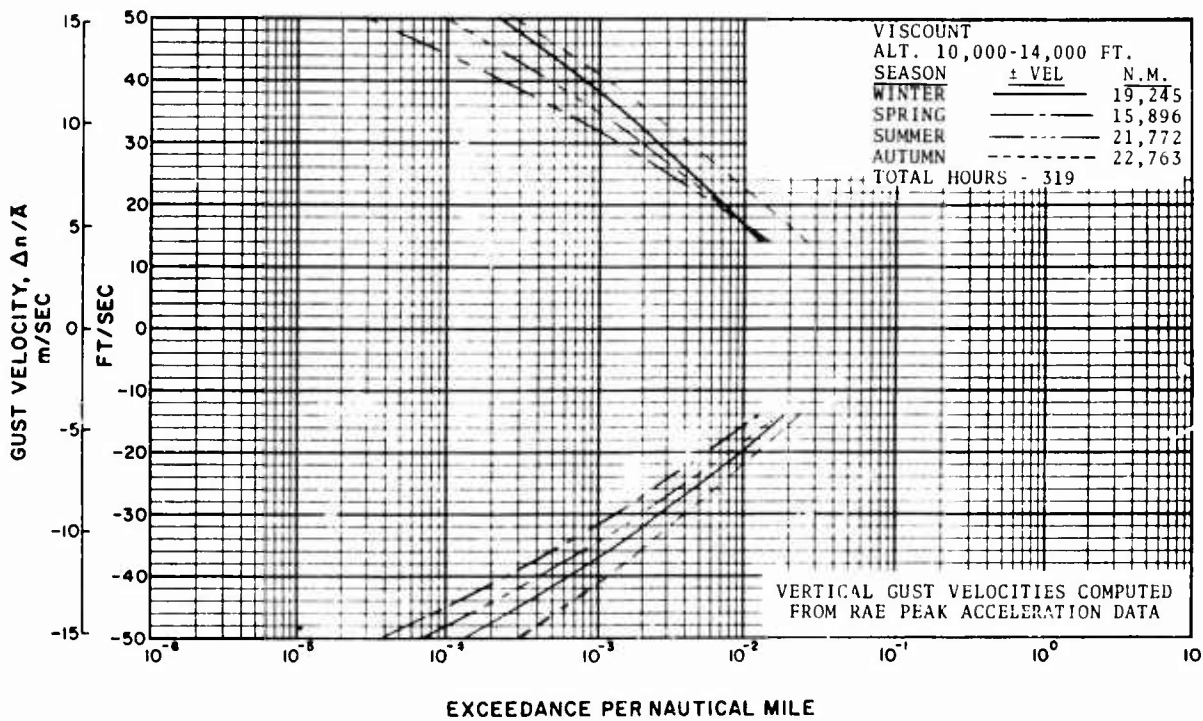
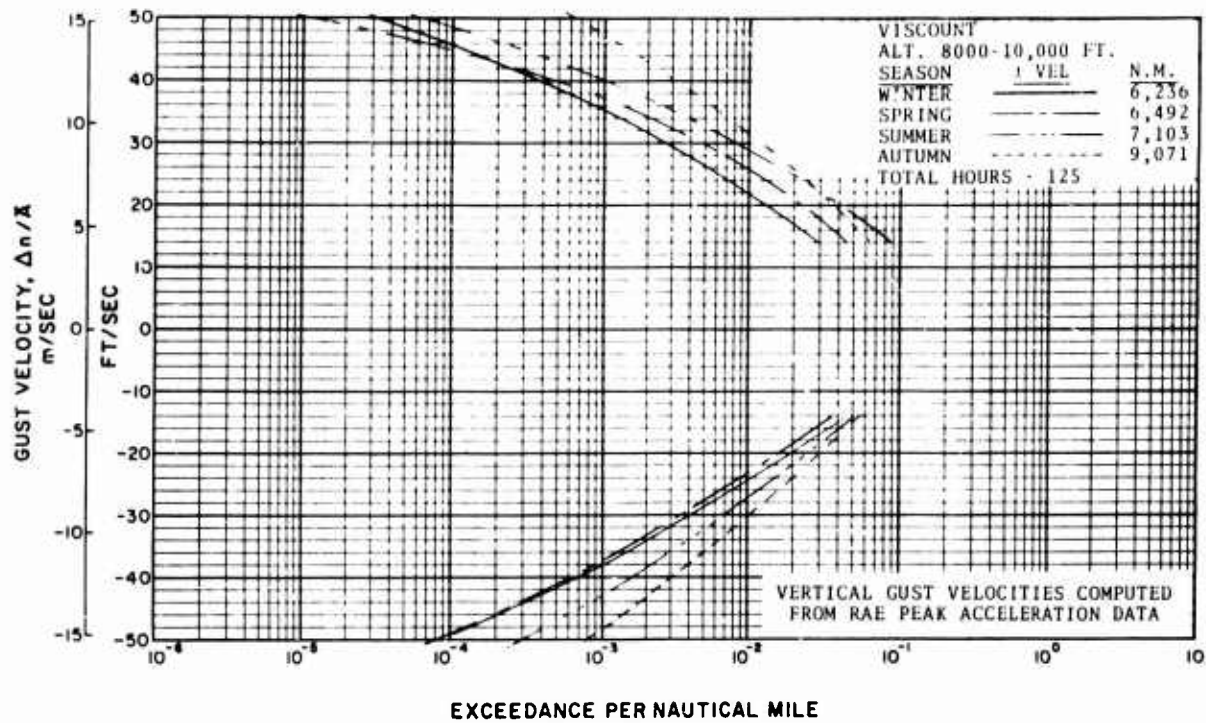


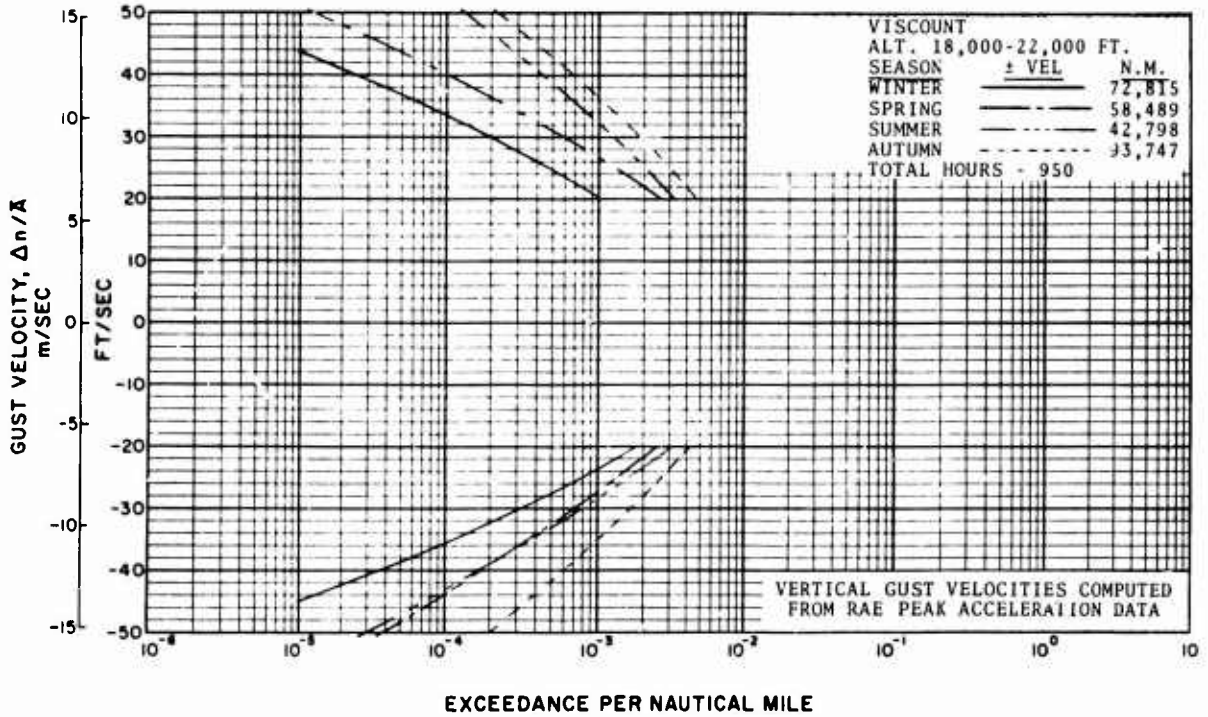
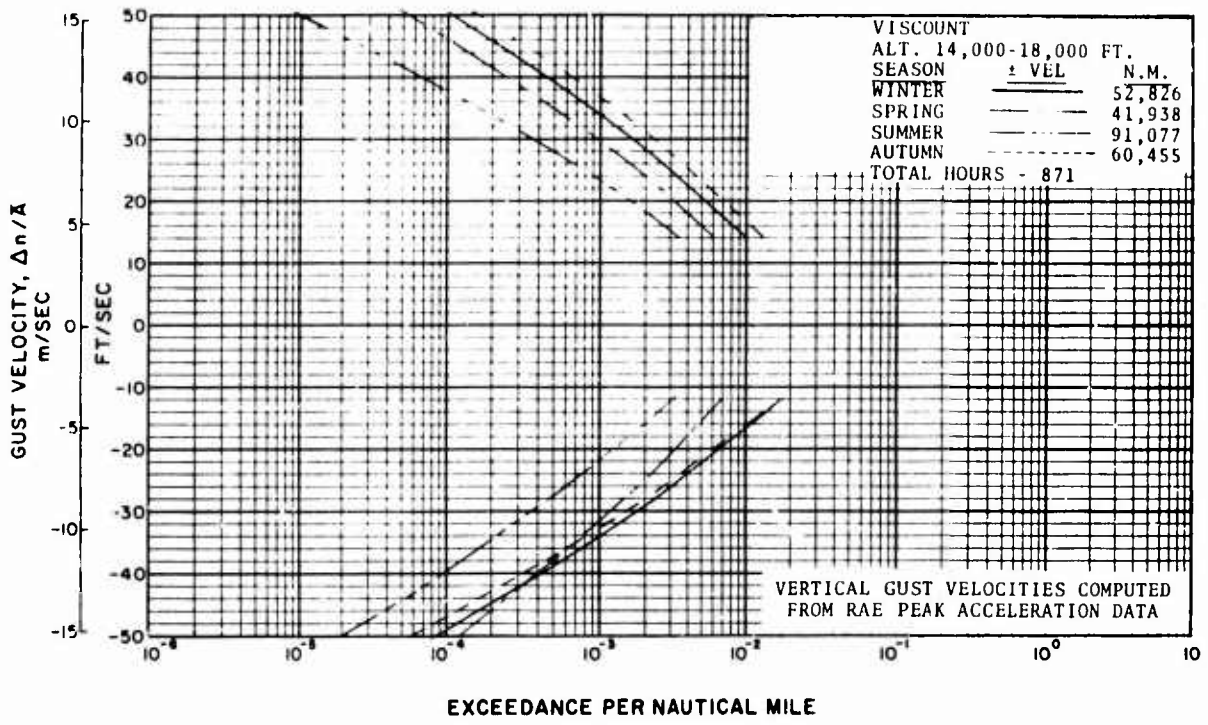


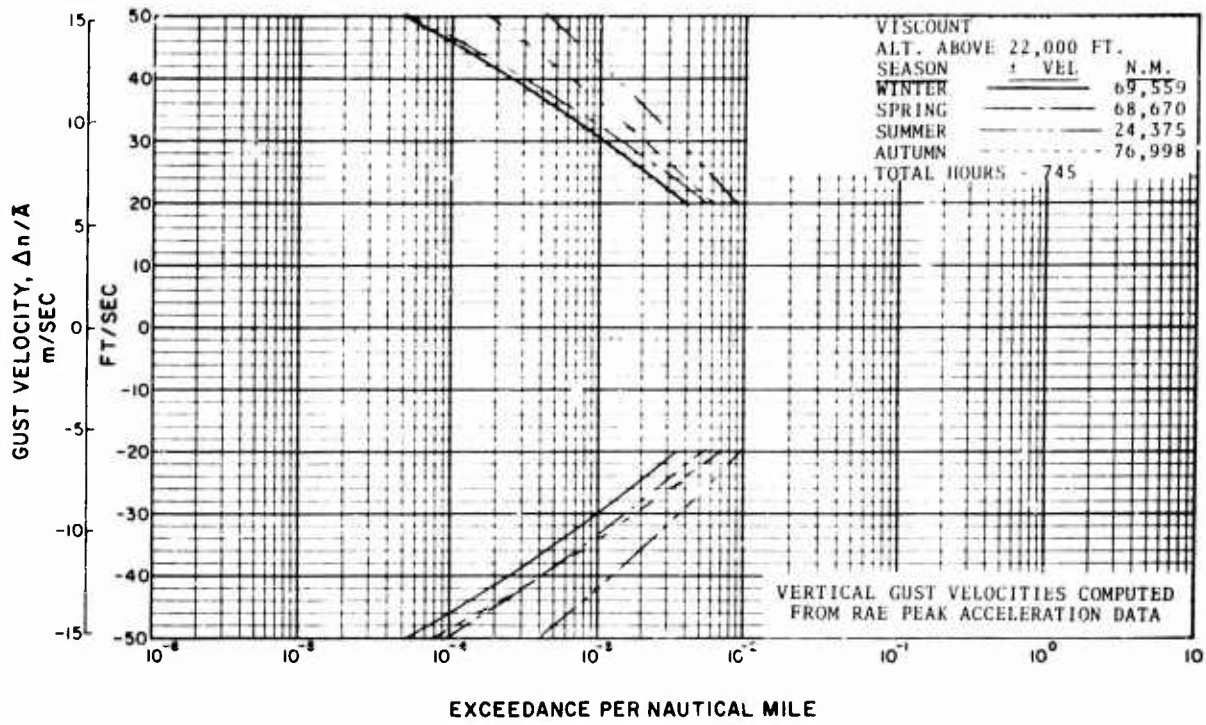












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APPENDIX A
RECORDING SYSTEMS

The bulk of the VGH data collected were recorded either on the RAE recorder or on an oscillograph system. However, brief descriptions of all recorders used, the methods of processing the data, and the means of separating the turbulence are given. More extensive treatments are readily available in References 19 to 23.

U.S. Air Force System

The oscillograph system recorded each parameter as a trace on a photosensitive paper; the amplitude was modified by the rotation of a mirror called a galvanometer, the rotation being proportional to the amplitude. Airspeed and altitude are recorded as differential and static pressure sensed from the aircraft pitot system. The vertical acceleration was sensed at (or near) the aircraft center of gravity by a bonded strain gage type of accelerometer whose range was determined by the aircraft type. For large aircraft of the bomber or cargo type, the range was $\pm 5g$ and, for fighter type aircraft, $-3g$ to $12g$. The galvanometer had a natural frequency of 100 Hz with a damping ratio of 0.9. The accelerometer had a natural frequency of 15 Hz and a damping of 0.7 of critical damping. No other electrical filtering was used in the measuring of the normal acceleration. Using standard accelerometer response curves to sinusoidal acceleration, the accelerometer was flat to approximately 4.5 Hz and down 3db at approximately 11 Hz and then a roll-off at 12db per octave.

Accelerations were read at the maximum excursion between successive crossings of the 1.0g line. Only readings greater than an increase (or decrease) of 0.1g were read. Each individual reading was identified as being caused by turbulence or maneuver. The criteria for turbulence cause was:

1. A rough or jagged airspeed trace.
2. A rough acceleration with sharp irregular peaks.
3. A rapid rise and exponential decay of the peaks.
4. Short peak duration, generally 2 to 4 seconds or less.

Along with acceleration the corresponding airspeed and altitude values were read, but these values were also read often enough to give a time history of both parameters.

During the processing run which calibrated airspeed, altitude, and acceleration into the desired units, weight was calculated and associated with the coincident values of airspeed and altitude. The weight calculation accounted for fuel usage, cargo, and store drops.

NASA VGH Recorder

Each element in the recorder employed a tilting mirror and lens arranged to focus the image of a straight-filament source lamp on the moving record paper.

Two cells containing pressure-sensitive diaphragms were connected to the airplane pitot-static lines to measure airspeed and altitude. The diaphragms deflected in proportion to the impressed pressures and their motions were magnified and transmitted to the record paper by the tilting mirror in each cell. Also in each cell was a fixed mirror for providing reference lines on the record.

The acceleration transmitter employed wire strain gages mounted on a cantilever beam. These gages were wired in the form of a Wheatstone bridge, the output voltage of which was proportional to the impressed acceleration. The beam was mounted in a sealed case filled with silicone oil which served as the damping medium and also protected the gages from moisture. A natural frequency of about 22 cycles per second was considered low enough to isolate it from engine vibrations but high enough to reproduce faithfully the gust accelerations normally encountered. A 25-watt heater and thermoswitch were built into the transmitter to maintain it at constant temperature. The galvanometer natural frequency was about 8 cycles per second and its damping was set at about 0.7 critical. The response of the combination was flat within about 1% up to an impressed sinusoidal frequency of 4.5 cycles.

In the processing, only peak values between crossings of the 1.0g line were measured, along with the coincident values of airspeed and altitude, and subjectively classified as maneuvers or turbulence. The data were also segmented by flight condition, i.e. ascent, descent, cruise. The data were preserved as Δn by airspeed, Δn by altitude, Δn by record, average true airspeed, and distance traveled for each 5000-foot altitude band.

The recorder was most generally used to monitor commercial flights.

APPENDIX B

SOURCE OF DATA BY COUNTRY

A set of magnetic tapes and a summary data report have been sent to the following persons:

Canada	Richard T. Sewell Structures and Materials Laboratory National Research Council Ottawa 7 Ontario Canada
France	Gabriel Coupry O.N.E.R.A. 29-39 Avenue de la Division Leclerc Chatillon-sous-Bagneux Seine, France
Germany	Otto K. Buxbaum Laboratorium für Betriebsfestigkeit 61 Darmstadt-Eberstadt Muhlthalstrabe 55-57, Germany
Italy	
The Netherlands	J. B. DeJonge National Aerospace Laboratory NLR Voorsterweg 31 Emmeloord, The Netherlands
United Kingdom	Norman I. Bullen Ministry of Aviation Structures Department Royal Aircraft Establishment Farnborough, Hants United Kingdom
United States	Clem J. Schmid Design Criteria Branch Aeronautical Systems Division Wright-Patterson Air Force Base, Ohio USA

APPENDIX C
TAPE DESCRIPTION

The tapes are written with odd parity in the BCD format at 300 BPI on seven-track tape.

To understand the VGH tape data, a detailed description of the data as they are filed is given. A word is defined as six characters (numbers, letters, symbols) or 36 binary bits. The data are written in block sizes of 432 words, each containing four records of 108 words. A block is a convenient portion or set of data, which may be further divided into subsets or records. Masses of data are thus processed by processing individual blocks. The historical record takes up the first two blocks and is, therefore, limited in size. In addition to defining the type of aircraft, the source of the data, and the units used, the record also defines all parameters or constraints and the intervals used to record these parameters.

All succeeding blocks of data for an aircraft type contain four identical records of 108 words each. The first ten words define aircraft type, model, flap position, season, gross weight, altitude, equivalent airspeed, flight condition or segment, and fuel weight. These items are represented by codes or numbers whose meaning is given to the historical record. In addition to this identification, these ten words contain the total number of hours (to four decimal places) represented by the data and the distance traveled in nautical miles (to two decimal places). The next 18 words contain the original acceleration frequencies presented in twenty intervals of incremental acceleration (Δn) - ten positive and a symmetrical 10 negative. The field sizes (maximum frequency) range from three to seven digits. The next 40 words represent the Δn intervals converted to 20 intervals of gust velocity ($\Delta n/A$) of either 5 feet/second or 2 meters/second versus cumulative frequency of occurrence.

The next 40 words contain the modified frequencies, i.e., frequencies multiplied by the characteristic frequency of the input (Von Karman spectrum of turbulence) and divided by the characteristic frequency of the output (aircraft acceleration), of the gust velocity. These frequencies are modified cumulative distributions and must be divided by the number of nautical miles to obtain frequency per mile. Sets of data can be readily combined if the division is not made. The division is performed prior to printing the data.

The data in the last two records are carried in floating point, i.e., as an integer multiplied by ten to a power, to maintain the maximum number of significant non-zero digits.