MAGNITUDE AND FREQUENCY OF WIND SPEED SHEARS AND ASSOCIATED DOWNDRAFTS

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SUMMARY

Information on wind shear and downdraft interaction in the lowest 150 m of the Earth's atmosphere is required for simulating their effect on ascent and descent of conventional aircraft under hazardous conditions. Both of these wind conditions have similar effects on aircraft. Previous studies indicate that a 5 knot downdraft is comparable to a 5 knot per 30.5 m (100 ft) wind shear with regard to the effect on large sweptwing transport-type aircraft. Magnitudes equal to or in excess of these values can have a significant effect on aircraft during take-off and landing. Data are presented indicating the frequency of occurrence of wind shear and downdrafts together with information on the simultaneous occurrence of these two phenomena. The source of these data is the NASA 150-Meter Ground Winds Tower Facility at the Kennedy Space Center, Florida.

INTRODUCTION

Atmospheric conditions in the vicinity of airports are a primary concern of aviation meteorology. Turbulence, wind shear, and vertical motion (updrafts/downdrafts) are low-level conditions known to be hazardous to high-performance aircraft during takeoff/climbout and approach/landing operations. All can and frequently do occur simultaneously. Thus, a requirement exists for information on these conditions below 150 m (500 ft) relative to magnitude, frequency and simultaneity of occurrence.

Although short-term wind measurement accuracy is vital in the study of low-level conditions, relatively little high-resolution data from aircraft and/or meteorological towers are available. Data acquired at the NASA 150-Meter Ground Winds Tower Facility at Kennedy Space Center, Florida, provided simultaneous horizontal wind speeds at eight levels and vertical speeds at four levels for analysis to determine characteristics of typical horizontal shears and associated downdrafts.

The analysis of meteorological tower data provides a basis for simulating aircraft ascent and descent under adverse conditions. Data of this type are valuable because theoretical model simulation of wind shears, intermittent downdrafts, or turbulence phenomena in the planetary boundary layer is subject to certain technical difficulties. These difficulties relate to the nonisotropy of the turbulence and the failure of the turbulence to conform to Gaussian probability distributions. Multilayer tower data can be used to create realistic approach and departure wind conditions.

The simultaneous occurrence of wind shear and downdrafts can cause serious problems for approaching and departing aircraft. Understanding statistical properties of these simultaneous occurrences enables accurate simulations.

BACKGROUND

A serious problem in aviation meteorology is wind events during airport operations for departing and approaching aircraft. It is known that the danger from shear events encountered by large, sweptwing, jet-powered aircraft increases below an altitude of 150 m (500 ft). Ramsdell and Powell (1973) state that the behavior of the wind in the last 30 m of descent, in particular between 30 and 15 m during which some aircraft travel approximately 300 m in 4 to 5 s, is most important to a descending aircraft. To ascertain the relative effects, Snyder (1968) simulated an aircraft on final approach and subjected it to the three events of sudden horizontal wind shear, downdraft, and an airspeed drop. Using Snyder's analog computer study and a simple flow model, Kalafus (1978) achieved results consistent with Snyder's: That a 5 kphf (0.08 s^{-1}) shear is a typical average shear that would be associated with a 5 kt (2.57 ms^{-1}) downdraft and that a 10 kt (5.15 ms^{-1}) downdraft is comparable to a 10 kphf (0.17 s^{-1}) shear appears to be a reasonable assumption.

The analysis presented here demonstrates the properties of simultaneously occurring wind shears and downdrafts. To this end, high resolution data from the NASA tower facility were analyzed. Downdrafts were measured at 150, 60, 18, and 10 meters, and shear determinations were made for the 150-120, 90-60, 60-30, and 30-3 m layers.

DATA

To understand and describe wind shear effects on the safety of flight operations in the terminal area, available data from aircraft and meteorological towers should be exploited to the fullest. This analysis used high-resolution wind profile measurements recorded at the NASA 150-Meter Ground Winds Tower Facility. The NASA Tower Facility, depicted in Figure 1 and described by Kaufman and Keene (1968), is located at the Kennedy Space Center approximately midway between Launch Complex 39B and the Space Shuttle runway. Placement of the meteorological sensors on the tower is shown in Figure 2. Eight tests acquired in March, July, September and October 1973 between 0800 and 1600 EST provided 5-second data intervals (one interval every 100 s during each approximately 2 h test). Table 1 presents the date, start and end time, number of intervals and measurements per level, and peak horizontal wind speed and downdraft per test.

The data record consisted of 457 intervals from the Automatic Data Acquisition System, described by Traver, et al. (1972). This system sampled each wind sensor at a rate of 10 samples per second, digitally recorded, and real-time processed the 22,800 wind speeds per level. These speeds at six tower levels provided the differences to determine wind shears for four 30 m layers in the lowest 150 m of the Earth's atmosphere, i.e., 150-120, 90-60, 60-30 and 30-3 m. These layers bracketed the simultaneous vertical wind speed (updraft/downdraft) measurements at the 150, 60, 18 and 10 m levels. Table 2 is a tabulation by levels of the frequency and maximum values of the vertical motion. Table 3 presents a percentage frequency distribution of the magnitudes of the downdrafts in Table 2.

Because of the infrequent occurrence of downdrafts $\geq$10 kts ($\geq$5.15 ms^{-1}) in the eight tests, results from a previous analysis (Alexander 1977) of maximum vertical gusts recorded at the facility are also included. A continuous record of six 10-minute computational sequences per hour for one year of maximum horizontal wind speed and maximum updraft and downdraft revealed 274 occurrences of downdrafts $\geq$10 kts for the four levels. Table 4 lists the maximum values of updraft/downdraft by months, seasons and levels for the one-year data record. Table 5 presents the frequency of occurrence of maximum 10-minute interval vertical motion $\geq$10 kts ($\geq$5.15 ms^{-1}) by seasons and levels.

Unfortunately, the 10-minute sampling period did not permit the determination of simultaneous occurrence of shear and associated downdraft. However, for each occurrence of a maximum downdraft $\geq$10 kts in a 10-minute interval at each level, wind shear was determined for the associated layer and interval from the maximum horizontal wind speeds to give some indications relative to the intent of this analysis.

RESULTS

Vertical wind shear is defined to be the change of wind speed with height and is determined by means of two anemometers mounted at different heights on a tower. Spatially varying shears, determined for four layers of the atmosphere from 3 to 150 m, were derived by algebraically subtracting the wind speed at the lower level of the layer from the speed at the upper level and dividing by the distance between levels, i.e.,

$$\frac{WS_U - WS_L}{d_{(U-L)}} = \frac{\Delta WS}{\Delta d} .$$

Previously, Alexander and Camp (1979) derived maximum and mean values and frequency of wind shears greater than 0.1 s^{-1} as a function of the following six vertical layers at the facility:

WIND SPEED SHEAR

Layer (m)	Obs. (f)	Max (s^{-1})	Mean (s^{-1})	>0.1 s^{-1} (f)	>0.1 s^{-1} (%)
150-120	3950	0.160	0.022	72	1.82
120-90	3150	0.173	0.030	75	2.38
90-60	3150	0.327	0.039	184	5.84
60-30	3950	0.387	0.047	602	15.24
30-18	3950	0.792	0.099	1278	32.35
18-3	3950	0.713	0.185	2465	62.39

Simultaneously occurring downdrafts at four levels and associated shears are tabulated. Table 6 presents a percentage frequency distribution of $\geq$3.89 kt (2.0 ms^{-1}) downdrafts at four levels as a function of wind shear for associated layers for the 457 5-second data intervals.

A tabulation was made of maximum downdraft ($\geq$9.7 kts (5.0 ms^{-1})) per 10-minute interval for a one-year data record as a function of maximum horizontal wind speed. It should be noted that surface winds are generally classsified as

Class	Wind Speed (kts)	Wind Speed (ms^{-1})
Low	0<9.7	0<5
Moderate	9.7<19.4	5<10
High	19.4<35.0	10<18
Gale-force	35.0<64.1	18<33
Hurricane	$\geq$64.1	$\geq$33 .

Table 7 presents a frequency distribution of this tabulation of 274 downdrafts $\geq$9.7 kts (5.0 ms^{-1}) by levels and wind speed classes. Table 8 is a percentage frequency distribution of these downdrafts as a function of wind shear derived from maximum wind speed per interval.

An additional analysis of the joint probability data was done. The wind shear and downdrafts were checked for independence by comparing the joint probability density with the product of the probability density for downdrafts and the probability density for wind shears. The two are approximately equal. This indicates that wind shear and downdraft are independent quantities; i.e., one does not affect the other. In other words, if a range of values of downdrafts is selected and a corresponding probability density of wind shears measured, and then another range of values of downdrafts selected, the corresponding probability density of wind shears will be the same as before.

To further check these results, correlation coefficients between wind shear and downdrafts were measured. Values less than 0.1 were obtained, with some values positive and some values negative. These small values appear to indicate independence of the two parameters.

CONCLUSIONS

Regarding magnitudes and frequencies of wind speed shears and associated downdrafts in the lowest 150 m of the atmosphere, the conclusions of this analysis are the following:

(1) From instantaneous measurements during horizontal wind speeds of gale-force and below intensity, vertical motion at the 10, 60 and 150 m levels was approximately 60 percent downward and 40 percent upward. At the 18 m level the percentages were reversed. Updraft maxima were an order of magnitude or two greater than downdrafts at all levels.

(2) Frequency of vertical motion ≥ 9.7 kts (≥ 5 ms^{-1}) for a year at four levels was 338 occurrences upward and 274 downward. Approximately 90 percent of these updrafts occurred at the 18 m level almost equally during summer and winter, and 65 percent of the downdrafts were at the 150 m level during summer.

(3) Magnitudes of 83 percent of the 274 downdrafts ≥ 9.7 kts (≥ 5 ms^{-1}) were in the range of $9.7<11.7$ kts ($5<6$ ms^{-1}), with only 1 percent in the highest magnitude range of $15.6<17.5$ kts ($8<9$ ms^{-1}).

(4) Data from sources such as the Kennedy Space Center 150-Meter Ground Winds Tower Facility provide useful information for simulating aircraft approaches and departures under adverse conditions. These data are valuable because of the difficulty of theoretical model wind simulations near the ground.

(5) Models for simulating aircraft ascent and descent under adverse conditions should show simultaneously occurring wind shears and downdrafts to be independent and uncorrelated.

This analysis certainly lends support to the beliefs that the need for information concerning atmospheric conditions is most important over the lowest 150 m and that short-term wind measurement accuracy is vital in detecting and identifying hazards to aircraft flight operations in terminal areas.

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TABLE 1.- FIVE-SECOND DATA INTERVAL TESTS SUMMARY

Date 1973	Time LST Start	Time LST End	Number Intervals	5 s Obs./ Level	Maximum Wind Speed Horizontal (kts)	Horizontal (ms^{-1})	Downward (kts) (<)	Downward (ms^{-1})
March 13	0842	1144	74	3700	31	16	12	6
March 14	0932	1234	73	3650	35	18	8	4
July 3	1606	1752	28	1400	51	26	10	5
July 3	1431	1655	50	2500	39	20	8	4
Sept 20	1025	1310	61	3050	20	10	6	3
Sept 24	0812	0945	21	1050	20	10	6	3
Sept 26	1552	1856	75	3750	33	17	8	4
Oct 5	1214	1518	75	3750	30	15	8	4

TABLE 2.- FREQUENCY AND MAXIMUM VALUES OF VERTICAL MOTION IN FIVE-SECOND INTERVAL TESTS

Level (m)	Frequency (f) Up	Frequency (f) Down	Percent (%) Up	Percent (%) Down	Maximum (kts) Up	Maximum (kts) Down	Maximum (ms^{-1}) Up	Maximum (ms^{-1}) Down
150	9657	13143	42.36	57.64	7.04	9.93	3.62	5.11
60	9952	12848	43.65	56.36	7.85	7.25	4.04	3.73
18	13721	9079	60.18	39.82	10.34	7.48	5.32	3.85
10	8296	14504	36.39	63.61	5.77	5.17	2.97	2.66

TABLE 3.- PERCENTAGE FREQUENCY DISTRIBUTION OF DOWNWARD MAGNITUDES

Level (m)	Frequency (f)						Percent (%)					
kts	0<2	2<4	4<6	6<8	8<10	10<12	0<2	2<4	4<6	6<8	8<10	10<12
ms^{-1}	0<1	1<2	2<3	3<4	4<5	5<6	0<1	1<2	2<3	3<4	4<5	5<6
150	10074	2782	252	26	6	3	76.65	21.17	1.92	0.20	0.05	0.02
60	9651	2571	549	77	0	0	75.12	20.01	4.27	0.60	0	0
18	7314	1667	94	4	0	0	80.56	18.36	1.04	0.04	0	0
10	10366	3983	155	0	0	0	71.47	27.46	1.07	0	0	0

TABLE 4.- MAXIMUM VALUES OF VERTICAL MOTION IN 10-MINUTE INTERVALS DATA BY MONTHS, SEASONS, AND LEVELS

Season / Month	Updrafts (kts)	(ms^{-1})							Downdrafts (kts)	(ms^{-1})						
Level (m)	150		60		18		10		150		60		18		10	
Winter																
Oct	9.5	4.9	9.1	4.7	11.5	5.9	7.6	3.9	10.7	5.5	10.3	5.3	9.9	5.1	7.4	3.8
Nov	9.7	5.0	5.8	3.0	11.5	5.9	8.0	4.1	8.0	4.1	10.9	5.6	10.7	5.5	9.3	4.8
Dec	12.4	6.4	9.5	4.9	11.9	6.1	8.6	4.4	8.7	4.5	9.9	5.1	9.9	5.1	5.4	2.8
Jan	11.7	6.0	7.0	3.6	16.1	8.3	8.2	4.2	7.6	3.9	9.5	4.9	8.4	4.3	6.0	3.1
Feb	5.4	2.8	8.9	4.6	18.1	9.3	10.3	5.3	11.1	5.7	16.7*	8.6	10.3	5.3	9.9	5.1
Mar	4.9	2.5	8.9	4.6	18.3*	9.4	11.1*	5.7	7.8	4.0	15.0	7.7	12.2*	6.3	10.3*	5.3
Summer																
Apr	16.3*	8.4	8.2	4.2	18.7	8.6	8.9	4.6	12.6	6.5	16.3	8.4	11.1	5.7	8.9	4.6
May	11.5	5.9	9.9	5.1	12.2	6.3	7.0	3.6	13.6	7.0	12.1	6.2	10.1	5.2	7.8	4.0
Jun	11.9	6.1	7.8	4.0	11.9	6.1	8.2	4.2	12.4	6.4	15.0	7.7	10.3	5.3	9.7	5.0
Jul	9.5	4.9	10.7*	5.5	12.2	6.3	8.9	4.6	15.2*	7.8	11.1	5.7	9.3	4.8	6.6	3.4
Aug	11.5	5.9	8.6	4.4	12.1	6.2	8.2	4.2	12.2	6.3	9.3	4.8	8.9	4.6	7.2	3.7
Sep	13.0	6.7	7.8	4.0	11.7	6.0	7.2	3.7	11.7	6.0	10.3	5.3	10.3	5.3	8.9	4.6

*Level Maximum

TABLE 5.- FREQUENCY OF OCCURRENCE OF MAXIMUM VERTICAL MOTION ≧10 KTS (≧5.15 ms^{-1}) IN 10-MINUTE INTERVALS DATA.

	Updrafts		(f)	Downdrafts		
Level (m)	Winter (Oct-Mar)	Summer (Apr-Sep)	Total	Winter (Oct-Mar)	Summer (Apr-Sep)	Total
150	13	18	31	2	179	181
60	1	3	4	23	55	78
18	160	141	301	6	5	11
10	2	0	2	3	1	4
Total	176	162	338	34	240	274

TABLE 6.- PERCENTAGE FREQUENCY DISTRIBUTION OF SHEARS VERSUS DOWNDRAFTS

≧3.89 KTS (≧2.0 ms^{-1}) IN 5-SECOND INTERVALS

Layer (m)	SHEARS ΔWS (kts)	ΔWS (ms^{-1})	ΔWS/Δd (s^{-1})	Level	Freq.	DOWNDRAFTS (kts) 3.89<5.00 / (ms^{-1}) 2.00<2.57	5.00<6.01 / 2.57<3.09	6.01<7.00 / 3.09<3.60	7.00<8.01 / 3.60<4.42	8.01<9.00 / 4.42<4.63	9.00<9.99 / 4.63<5.14	TOTAL
150-120	0<1.9	0<1.0	0<.033	150	287	48.43	11.15	1.05	4.88	0.35	1.39	67.25
	1.9<3.9	1.0<2.0	.033<.067			14.29	8.01	1.39	0.70	0.70		25.09
	3.9<5.8	2.0<3.0	.067<.100			5.23	1.39	0.35				6.97
	5.8<7.8	3.0<4.0	.100<.133			0.70						0.70
90-60	0<1.9	0<1.0	0<.033	60	626	28.12	8.15	5.75	0.64			42.66
	1.9<3.9	1.0<2.0	.033<.067			26.20	6.87	3.19				36.26
	3.9<5.8	2.0<3.0	.067<.100			14.70	1.44	0				16.14
	5.8<7.8	3.0<4.0	.100<.133			1.92	0.32	0				2.24
	7.8<9.7	4.0<5.0	.133<.167			0.96	0	0				0.96
	9.7<11.7	5.0<6.0	.167<.200			0.64	0.64	0.48				1.76
60-30				60	626							
	0<1.9	0<1.0	0<.033			27.80	6.07	3.19	0			37.06
	1.9<3.9	1.0<2.0	.033<.067			26.84	6.87	3.04	0.32			37.07
	3.9<5.8	2.0<3.0	.067<.100			6.87	2.40	1.92	0.32			11.51
	5.8<7.8	3.0<4.0	.100<.133			5.43	0.96	0.80				7.19
	7.8<9.7	4.0<5.0	.133<.167			3.99	0.64	0.16				4.79
	9.7<11.7	5.0<6.0	.167<.200			1.60	0.64					2.24
	11.7<13.6	6.0<7.0	.200<.233			0.16	0					0.16
30-3												
	0<1.9	0<1.0	0<.033	18	98	0	0					0
	1.9<3.9	1.0<2.0	.033<.067			16.33	1.02					17.35
	3.9<5.8	2.0<3.0	.067<.100			22.45	1.02	1.02	2.04			26.53
	5.8<7.8	3.0<4.0	.100<.133			13.27	0					13.27
	7.8<9.7	4.0<5.0	.133<.167			12.24	0					12.24
	9.7<11.7	5.0<6.0	.167<.200			12.24	1.02					13.26
	11.7<13.6	6.0<7.0	.200<.233			11.22	5.10					16.32
	13.6<15.6	7.0<8.0	.233<.267			1.02	0					1.02
30-3												
	0<1.9	0<1.0	0<.033	10	155	9.68	0					9.68
	1.9<3.9	1.0<2.0	.033<.067			16.77	0.65					16.77
	3.9<5.8	2.0<3.0	.067<.100			25.16	1.94					25.81
	5.8<7.8	3.0<4.0	.100<.133			24.52	0.65					26.46
	7.8<9.7	4.0<5.0	.133<.167			12.90	1.94					13.55
	9.7<11.7	5.0<6.0	.167<.200			3.87						5.81
	11.7<13.6	6.0<7.0	.200<.233			0.65						0.65
	13.6<15.6	7.0<8.0	.233<.267			1.29						1.29

TABLE 7.- MAXIMUM HORIZONTAL WIND SPEED CLASSES VERSUS DOWNDRAFTS

≧9.7 KTS (≧5.0 ms^{-1}) IN 10-MINUTE INTERVALS DATA

Level (m)	Maximum WS Class	(kts)	(ms^{-1})	Downdrafts (kts) 9.7<11.7 / (ms^{-1}) 5<6	11.7<13.6 / 6<7	13.6<15.6 / 7<8	15.6<17.5 / 8<9
150	Low	0<9.7	0<5	2	0	0	
	Moderate	9.7<19.4	5<10	93	16	0	
	High	19.4<35.0	10<18	53	12	2	
	Gale-force	35.0<64.1	18<33	2	0	1	
60	Low	0<9.7	0<5	0	0	0	0
	Moderate	9.7<19.4	5<10	24	2	1	1
	High	19.4<35.0	10<18	36	5	2	1
	Gale-force	35.0<64.1	18<33	4	0	1	1
18	Low	0<9.7	0<5	0	0		
	Moderate	9.7<19.4	5<10	1	1		
	High	19.4<35.0	10<18	6	0		
	Gale-force	35.0<64.1	18<33	3	0		
10	Low	0<9.7	0<5	0			
	Moderate	9.7<19.4	5<10	1			
	High	19.4<35.0	10<18	2			
	Gale-force	35.0<64.1	18<33	1			

TABLE 8.- PERCENTAGE FREQUENCY DISTRIBUTION OF SHEARS VERSUS DOWNDRAFTS

≥9.7 KNOTS (≥5.0 ms^{-1}) IN 10-MINUTE INTERVALS DATA

Layer (m)	ΔWS (kts)	ΔWS (m/sec)	ΔWS/Δd (s^{-1})	Level (m)	Freq. (f)	(kts) 9.7<11.7	11.7<13.6	13.6<15.6	15.6<17.5	Total
						(m/sec) 5<6	6<7	7<8	8<9	
150-120				150	181					
	0<1.9	0<1.0	0<.033			72.93	12.71	1.66		87.30
	1.9<3.9	1.0<2.0	.033<.067			8.84	2.21			11.05
	3.9<5.8	2.0<3.0	.067<.100			1.10	0.55			1.65
	5.8<7.8	3.0<4.0	.100<.133							
90-60										
	0<1.9	0<1.0	0<.033	60	78	60.26	7.69	3.85	0	71.80
	1.9<3.9	1.0<2.0	.033<.067			17.95	0	1.28	2.56	21.79
	3.9<5.8	2.0<3.0	.067<.100			3.85	0	0	0	3.85
	5.8<7.8	3.0<4.0	.100<.133			0	1.28	0	1.28	2.56
60-30										
	0<1.9	0<1.0	0<.033	60	78	50.00	5.13	1.28	2.56	58.97
	1.9<3.9	1.0<2.0	.033<.067			25.64	2.56	0	1.28	29.48
	3.9<5.8	2.0<3.0	.067<.100			6.41	1.28	3.85	0	11.54
	5.8<7.8	3.0<4.0	.100<.133							
30-3										
	0<1.9	0<1.0	0<.033	18	11	9.09	0			9.09
	1.9<3.9	1.0<2.0	.033<.067			9.09	9.09			18.18
	3.9<5.8	2.0<3.0	.067<.100			27.27				27.27
	5.8<7.8	3.0<4.0	.100<.133			9.09				9.09
	7.8<9.7	4.0<5.0	.133<.167			18.18				18.18
	9.7<11.7	5.0<6.0	.167<.200			18.18				18.18
30-3										
	0<1.9	0<1.0	0<.033	10	4	0				0
	1.9<1.9	1.0<2.0	.033<.067			25.00				25.00
	3.9<5.8	2.0<3.0	.067<.100			25.00				25.00
	5.8<7.8	3.0<4.0	.100<.133			0				0
	7.8<9.7	4.0<5.0	.133<.167			50.00				50.00
	9.7<11.7	5.0<6.0	.167<.200			0				0

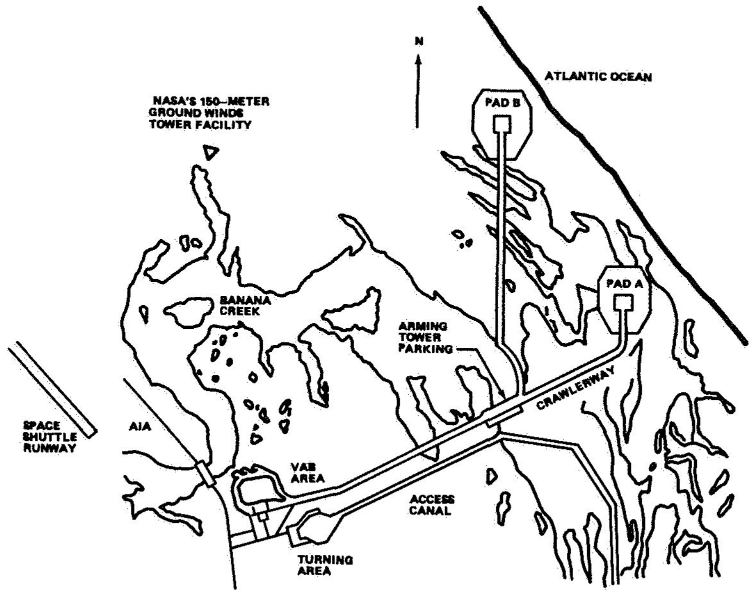

Figure 1.- NASA's 150-Meter Ground Winds Tower Facility and Launch Complex 39B, Kennedy Space Center, Florida.

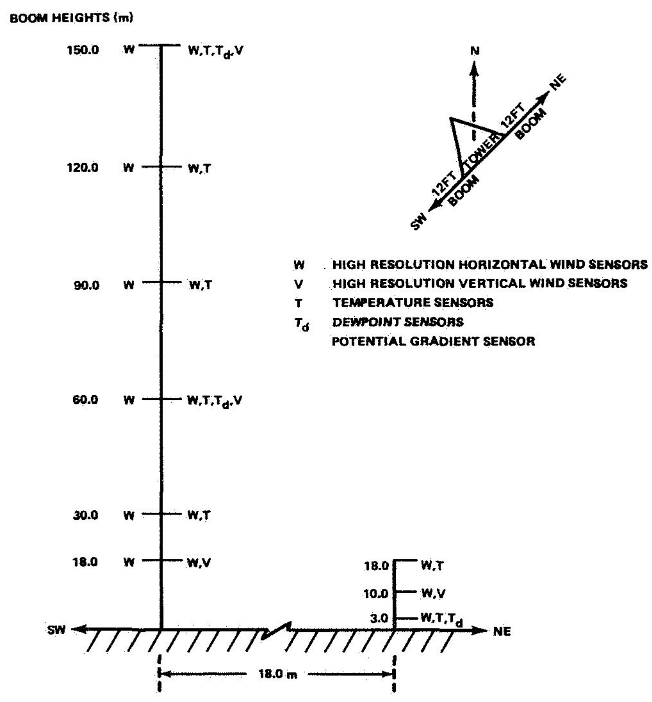

Figure 2.- Placement of sensors on NASA's 150-Meter Ground Winds Tower Facility at Kennedy Space Center, Florida. (Note: 1 ft = 0.3048 m.)