Engineering Notes

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Magnitude and Frequency of Wind Speed Shears from 3 to 150 Meters

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WIND shear is an expected feature of the atmosphere. Because severe changes in wind speed with altitude or horizontal distance are hazardous to the ascent and descent of conventional aircraft and Space Shuttle, a requirement exists for shear information over the lowest 150 m of the Earth's atmosphere. However, relatively little high resolution data from aircraft and/or meteorological towers are available for the determination of low-level shears.

A study by Snyder showed vertical shears greater than 0.1 s^{-1} in the lowest 100 m to be hazardous to large, swept-wing, jet-powered aircraft.[1] Ramsdell and Powell stated that the behavior of the wind in the last 30 m of descent, in particular between 30-15 m during which some aircraft travel approximately 300 m in 4-5 s, is most important to a descending aircraft.[2]

This analysis of high resolution wind profile measurements recorded at the NASA 150-m ground winds tower facility presents magnitude and frequency distributions of wind speed shears for six vertical layers of the atmosphere and one horizontal distance. The 150- and 18-m towers (Fig. 1) described by Kaufman and Keene, are located on Merritt Island approximately midway between Launch Complex 39B and the Space Shuttle runway at the Kennedy Space Center, Florida.[3]

Spatial and temporal variations occur in near surface winds encountered along ascending and descending aircraft flight paths. Surface winds, in general, are classified as low ($0<5$ ms^{-1}), moderate ($5<10$ ms^{-1}), high ($10<18$ ms^{-1}), gale-force ($18<33$ ms^{-1}), and hurricane (≥ 33 ms^{-1}). Since low wind speeds and subsequent light shears present little or no hazards to aircraft operations, interest is naturally greatest in high speeds, large differences, and strong shears.

In this analysis, 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 single tower. Vertical shear magnitudes were derived by algebraically subtracting the wind speed at the lower level from the speed at the upper and dividing by the distance between levels, i.e., $WS_U - WS_L / d_{U-L} = \Delta WS / \Delta d$.

Horizontal wind shear is the change of wind speed with horizontal distance and is determined by two anemometers mounted at the same height on different towers. Horizontal shear magnitudes were derived by algebraically subtracting the wind speed at the short tower from the speed at the tall and dividing by the distance between towers, i.e., $WS_T - WS_S / d_{T-S} = \Delta WS / 18$.

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Because high surface winds often persist for periods of several hours or come and go quickly, short-term wind measurement accuracy is important in wind shear detection. This analysis is made from a NASA tower facility data record on July 3, 1973 during low to gale-force wind conditions and consists of 79 five-second intervals (one interval every 100 s from 1931 through 2152 GMT) from the automatic data acquisition system described by Traver et al.[4] The system samples at a rate of 10 speeds per second, digitally records and real-time processes wind speeds at all levels on the towers. This record is complete with the exception of the 90-m level from 2106 to 2133 GMT. Vertical shears were determined for two approximately 15-m layers below 30 m and for four 30-m layers above 30 m with horizontal shears for one distance of 18 m at the 18-m level.

Regarding magnitudes and frequencies of shears below 150 m, results (Tables 1 and 2) and conclusions are 1) vertical wind speed shears decrease with altitude into three clearly defined regions with explicit maximum and mean magnitudes,

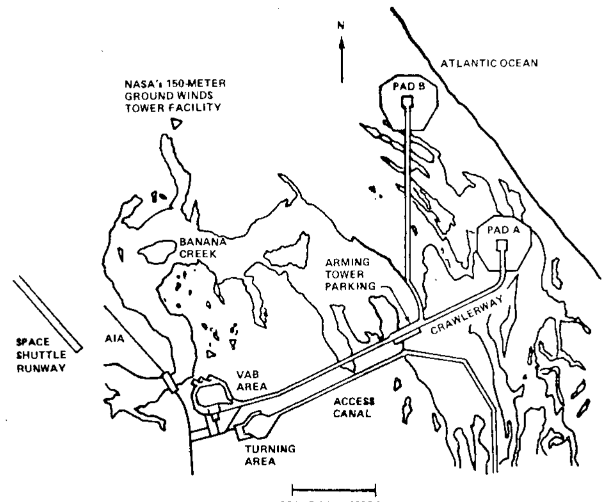

Fig. 1 NASA's 150-m ground winds tower facility and launch complex 39, Kennedy Space Center, Florida.

Table 1 Maximum and mean wind speed shears and frequency of occurrence of shears >0.1 s^{-1} as a function of layer/distance

Height, m	Obs. f	*WS* Shear, s^{-1} Max	*WS* Shear, s^{-1} Mean	*WS* Shear >0.1 s^{-1} f	*WS* Shear >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
Distance, m 18	3950	0.678	0.078	871	22.05

Table 2 Maximum and mean wind speed shears and frequency of occurrence of shears $>0.1\ s^{-1}$ as a function of layer, distance, and sustained wind speed

Height, m	Int. f	Obs.	Mean *WS* Ref. m	Mean *WS* range ms^{-1}	*WS* Shear, s^{-1} Max	*WS* Shear, s^{-1} Mean	*WS* Shear $>0.1\ s^{-1}$ f	*WS* Shear $>0.1\ s^{-1}$ %
150	15	750	120	0<5	0.040	0.014	0	0
	16	800		5<10	0.143	0.014	9	0.23
	41	2050		10<18	0.160	0.028	57	1.44
	7	350		18<33	0.130	0.030	6	0.15
120								
	6	300	90	0< 5	0.050	0.019	0	0
	14	700		5<10	0.107	0.029	3	0.10
	38	1900		10<18	0.173	0.035	65	2.06
	5	250		18<33	0.127	0.035	7	0.22
90								
	5	250	60	0< 5	0.050	0.016	0	0
	23	1150		5<10	0.143	0.037	33	1.05
	32	1600		10<18	0.327	0.042	132	4.19
	3	150		18<33	0.177	0.059	19	0.60
60								
	16	800	30	0< 5	0.100	0.039	0	0
	41	2050		5<10	0.200	0.041	245	6.20
	22	1100		10<18	0.387	0.062	357	9.04
	0	0		18<33	0	0	0	0
30								
	22	1100	18T	0< 5	0.158	0.059	133	3.37
	45	2250		5<10	0.783	0.102	874	22.13
	12	600		10<18	0.792	0.135	271	6.86
	0	0		18<33	0	0	0	0
18								
	22	1100	18S	0< 5	0.227	0.076	283	7.16
	45	2250		5<10	0.693	0.168	1638	41.46
3	12	600		10<18	0.713	0.310	544	13.77
	0	0		18<33	0	0	0	0
Distance, m 18	22	1100	18T	0< 5	0.122	0.023	8	0.20
	45	2250		5<10	0.356	0.075	565	14.30
	12	600		10<18	0.678	0.136	298	7.54
	0	0		18<33	0	0	0	0

i.e., for 3-30 m 0.7 and 0.14 s^{-1}, for 30-90 m 0.4 and 0.04 s^{-1}, and for 90-150 m 0.2 and 0.03 s^{-1}; 2) percentage frequency of occurrence of magnitudes greater than 0.1 s^{-1} decreases by a factor of 0.5 from the lowest layer to the highest, i.e., 62% for 3-18, 32% for 18-30, 15% for 30-60, 6% for 60-90, 2.4% for 90-120, and 1.8% for 120-150 m layer; 3) maximum and mean horizontal shear magnitudes at 18 m are slightly less than the vertical counterparts below 30 m and have a 22% frequency of occurrence for shears greater than 0.1 s^{-1}; and 4) significant number of occurrences of wind speed shears greater than 0.1 s^{-1} below 30 m during low ($0<5\ ms^{-1}$) sustained speed questions the generally accepted belief that low wind speeds and subsequent light shears present little or no hazards to aviation safety.

This study certainly lends support to the ideas that short-term wind measurement accuracy is vital in wind shear detection and that the need for information on low-level shear is most important over the lowest 150 m of the Earth's atmosphere—may be even more important over the lowest 60 m.

Acknowledgments

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Application of Unsteady Airfoil Theory to Rotary Wings

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A PREVIOUS Note[1] pointed out that unsteady airfoil theory is being used incorrectly in almost all major helicopter loads analyses and also in some aeroelastic stability analyses. The difficulty lies in relating the variables used in unsteady airfoil theory to the variables used in describing the motion of a rotary wing. Reference 1 presented an attempt to identify correctly the relationship between the two sets of variables and to apply the resulting theory to an articulated

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