Table 1 Effect of low Reynolds number turbulence amplification on surface-heating and mass-loss rates for the 335-kg probe at a time of 49.13 s

Condition	$-\int_0^s \bar{q}_w^c \mathrm{d}\bar{A}$, MW		$\int_0^s \bar{q}_w^{R-} \mathrm{d}\bar{A}$, MW		$\int_0^s (\bar{\rho}\bar{v})_w \mathrm{d}\bar{A}$, kg/s		Mass-loss ratio	
(i) Standard model as of May 1982 with coupled spallation; employs standard two-layer eddy-viscosity model of Cebeci with $k_2 = 0.0168$ (without low Reynolds number turbulence amplification)	9.00[a]	15.00[b]	115.00[a]	212.00[b]	4.00[a]	7.70[b]	1.00[a]	1.00[b]
(ii) With low Reynolds number turbulence amplification: $k_2 = \ell^2 \left(\left\| \frac{\partial u}{\partial n} \right\| \right)_{\mathrm{mp}} / U_e \delta_k$; $(\ell/\delta)_{\max} = 0.085$; $\delta^+ \geq 2000$	9.00[a]	16.50[b]	88.10[a]	148.50[b]	3.00[a]	5.13[b]	0.75[a]	0.067[b]
(iii) Same as (ii) except $(\ell/\delta)_{\max} = 0.17$; $\delta^+ = 105$	8.50[a]	14.61[b]	119.20[a]	222.26[b]	4.31[a]	8.00[b]	1.08[a]	1.04[b]
(iv) Same as (ii) except $(\ell/\delta)_{\max} = 0.255$; $\delta^+ = 85$	6.65[a]	11.40[b]	155.35[a]	303.40[b]	5.88[a]	11.75[b]	1.47[a]	1.53[b]

[a] Results are integrated to an s value of 2.06; end of probe forebody is at $s = 2.84$. [b] Results are integrated to an s value of 2.86; end of probe forebody is at $s = 2.84$.

Table 2 Effect of the variation in turbulent Lewis number on surface-heating and mass-loss rates for the 335-kg probe at a time of 49.13 s[a]

Le_T	$-\int_0^s \bar{q}_w^c \mathrm{d}\bar{A}$, MW		$\int_0^s \bar{q}_w^R \mathrm{d}\bar{A}$, MW		$\int_0^s (\bar{\rho}\bar{v})_w \mathrm{d}\bar{A}$, kg/s		Mass-loss ratio	
1.0	9.00[b]	15.00[c]	115.00[b]	212.00[c]	4.00[b]	7.70[c]	1.00[b]	1.00[c]
1.2	8.00[b]	13.90[c]	121.50[b]	222.80[c]	4.40[b]	8.00[c]	1.10[b]	1.04[c]
0.8	7.90[b]	14.11[c]	112.00[b]	206.50[c]	3.85[b]	7.50[c]	0.96[b]	0.97[c]

[a] Employs standard two-layer eddy-viscosity model of Cebeci. [b] Results are integrated to an s value of 2.06. [c] Results are integrated to an s value of 2.86, end of probe forebody is at $s = 2.84$.

these physical events in absence of any measurements may be more appropriate for the Galileo probe design.

Acknowledgments

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Procedure for Generating Ground Wind Environments for Shuttle Liftoff Studies

George H. Fichtl* and Clark Brown†
NASA Marshall Space Flight Center, Huntsville, Alabama

Background

THIS Note provides a procedure for generating ground wind environments for Monte Carlo Shuttle liftoff and related studies. The procedure is based on a random selection of peak wind speeds at the 18.3 m level from which the mean wind profile and turbulence intensities are derived.[1] Random selection of mean wind direction is also used. The simulation of longitudinal and lateral turbulence components are obtained from a turbulence simulation tape as described in Refs.

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*Chief, Fluid Dynamics Branch, Atmospheric Sciences Division. Associate Fellow AIAA.

†Aerospace Engineer, Environmental Applications Branch, Atmospheric Sciences Division.

2 and 3 and are superimposed on the mean wind profile to simulate a time-varying horizontal wind profile along the vertical.

Peak Wind Speed, 18.3 m Level

The 18.3 m level peak wind speed $u_{18.3}$ is obtained by random selection based on the distribution function

$$P(u_{18.3}) = \exp\{-\exp[-\alpha(u_{18.3} - \mu)]\} \quad (1)$$

where $P(u_{18.3})$ is the probability that the 18.3 m level hourly peak wind speed is less than or equal to $u_{18.3}$ and α and μ are functions of time of day and time of year. Figure 1 provides plots of this function and the values of α and μ recommended for the Kennedy Space Center (KSC) in Florida.

Peak Wind Speed Profile

The peak wind speed $u(z)$ at height z in meters above the natural grade is given by[1]

$$u(z) = u_{18.3}\left(\frac{z}{18.3}\right)^{cu_{18.3}^{-3/4}} \quad (2)$$

The quantity c is a normally distributed random variable with mean value 0.52 $m^{3/4} \cdot s^{-3/4}$ and standard deviation 0.36 $m^{3/4} \cdot s^{-3/4}$. The peak wind profile is obtained by random selection of the parameter c and application of Eq. (2) with the randomly selected value of $u_{18.3}$.

Mean Wind Speed Profile

The mean wind speed $\bar{u}(z)$ at height z in meters above the natural grade is obtained by applying a gust factor to the peak wind profile, so that

$$\bar{u}(z) = \left[1 + \frac{1}{g_0}\left(\frac{18.3}{z}\right)^p\right]^{-1} u(z) \quad (3)$$

where the quantity in square brackets is the gust factor.[1] The nondimensional parameters g_0 and p are functions of $u_{18.3}$ and are given in Ref. 1.

Mean Wind Direction

The direction θ from which the mean wind blows, measured clockwise with respect to true north, is obtained by random selection from the conditional distributions (with respect to the 18.3 m level peak wind speed) given in Table 1 that are consistent with the time periods used for random selection of the peak wind speed.

Turbulence Parameters

The profiles of turbulence standard deviation σ and integral scale of turbulence L for the simulation of turbulent flow at KSC are given by

$$\sigma_1(z) = 0.217u_{18.3}(z/18.3)^{0.075}$$
$$\sigma_2(z) = 0.166u_{18.3}(z/18.3)^{0.171} \quad (4)$$

and

$$L_1(z) = 31.5(z/18.3)^{0.65}$$
$$L_2(z) = 18.4(z/18.3)^{0.83} \quad (5)$$

where L and z are in meters and σ and $u_{18.3}$ are in meters per second.[1,2,4] The subscripts *1* and *2* denote longitudinal and lateral components of turbulence, respectively.

Turbulence Simulation

Turbulence simulations have been developed for the Space Shuttle program for the entry flight phase[2,3,5] and are stored on computer tapes. The turbulence velocity components (u_i, $i=1,2$) and time t are scaled with σ and $1.339\ L/V$, respectively, so that the simulated time histories can be represented as

$$u_i/\sigma_i = f_i(t_i V/1.339L_i), \qquad i=1,2 \quad (6)$$

where V is the true air speed. The turbulence simulation consists of six tapes, each tape being applicable to a specific turbulence velocity component or gust gradient. In turn, each tape has six bands corresponding to various altitude regions during Shuttle entry from 150 km altitude to the surface of the Earth. The tapes are designed so that the Nyquist frequency of the associated dimensional time histories is nearly constant with altitude. There are six different altitude bands to accommodate the range of variation of V, L, and σ during

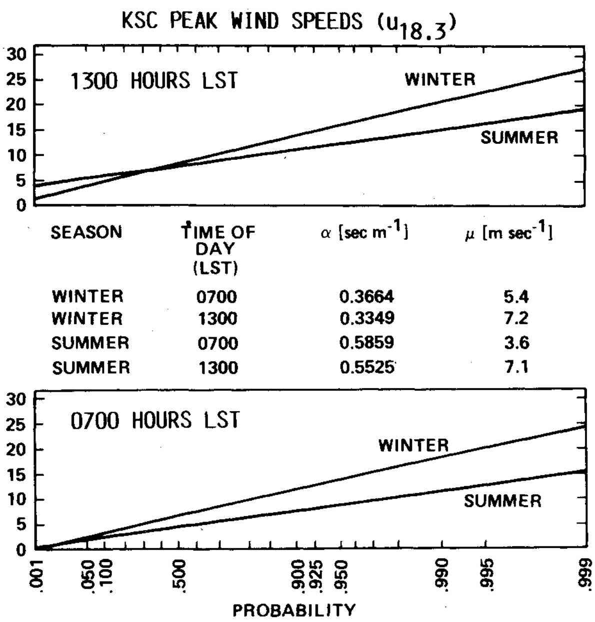

Fig. 1 Distributions of 18.3 m level peak wind speed for KSC.

Table 1 Conditional distributions of mean wind direction at the 18.3 m level for KSC

PROBABILITY X 100	WIND DIRECTION, θ (DEGREES)							
	0700 EST				1300 EST			
	S^a $u_{18.3} \leq 8$ m sec^{-1}; W^a $u_{18.3} \leq 10$ m sec^{-1}		S^a $u_{18.3} > 8$ m sec^{-1}; W^a $u_{18.3} > 10$ m sec^{-1}		S^a $u_{18.3} \leq 8$ m sec^{-1}; W^a $u_{18.3} \leq 10$ m sec^{-1}		S^a $u_{18.3} > 8$ m sec^{-1}; W^a $u_{18.3} > 10$ m sec^{-1}	
	S^a	W^a	S^a	W^a	S^a	W^a	S^a	W^a
$0 < 100P \leq 4$	330	157	292	157	305	022	315	022
$4 < 100P \leq 8$	292	180	270	202	260	022	292	067
$8 < 100P \leq 12$	270	180	247	202	225	022	270	112
12 16	270	202	225	225	202	045	247	135
16 20	247	225	225	225	180	067	247	135
20 24	247	247	202	270	157	067	247	157
24 28	247	247	202	270	157	90	225	157
28 32	225	270	180	292	157	112	202	157
32 36	225	292	180	292	135	135	202	180
36 40	225	292	157	315	135	135	180	180
40 44	202	315	157	315	135	157	157	202
44 48	202	315	135	315	135	157	157	225
48 52	180	315	135	315	135	180	135	247
52 56	180	315	112	315	112	180	135	270
56 60	180	315	112	315	112	202	135	292
60 64	180	337	112	315	112	225	135	292
64 68	180	337	112	315	112	247	135	315
68 72	157	337	112	315	112	270	112	315
72 76	157	337	090	337	090	292	112	337
76 80	135	360	090	337	090	315	112	337
80 84	135	022	090	337	090	337	090	337
84 88	112	022	067	360	067	337	067	337
88 92	090	090	067	360	067	360	045	360
92 96	067	112	067	360	045	360	360	360
96 100	010	135	045	360	022	360	360	360

^{a} S = SUMMER, W = WINTER

Shuttle entry. Each history consists of 8500 discrete signals per altitude band, with a nondimensional time interval T between signals being equal to a specific number (a function of the desired Nyquist frequency). The simulation tapes can be applied to Shuttle liftoff studies by setting $V=\bar{u}(z)$ (frozen eddy hypothesis) at the altitude level where the turbulence is to be applied using the values of $\sigma(z)$ and $L(z)$ specified above. However, the dimensional Nyquist frequency from band to band on a given tape will vary significantly because presently for a given simulation V and L are fixed instead of varying from band to band as would occur during Shuttle entry. Thus, the bands on each of the simulation tapes correspond to various Nyquist frequencies in the application of the tapes to Shuttle liftoff studies. Simulation tapes 1 and 2 correspond to the longitudinal and lateral components. In turn, the recommended band 4 will provide a Nyquist frequency of approximately 1 Hz. The other bands are characterized by Nyquist frequencies at least one order of magnitude greater or less than 1 Hz. Those bands with Nyquist frequency less than 1 Hz have insufficient frequency response for the problem at hand. Those bands with Nyquist frequency greater than 1 Hz correspond to wavelengths of turbulence on the order of 1 m, which in turn were removed from the spectra used to simulate the turbulence by not permitting in the simulation turbulence wavelengths comparable to or less than the mean aerodynamic chord and one-half wingspan of the Shuttle Orbiter.

The dimensional time intervals that correspond to the appropriate value of $T=59.18$ are given by

$$\Delta t_i = 79.24 L_i(z)/\bar{u}(z), \qquad i=1,2 \tag{7}$$

Note the Δt's are not necessarily equal and are functions of z. The procedure for simulating the turbulence time histories consists of the following:

1) Go to random starting points on band 4 of turbulence simulation tapes 1 and 2.

2) Read successive sequences of values of u_i/σ_i, $i=1,2$.

3) Multiply nondimensional values u_i/σ_i by specified values of $\sigma_i(z)$ to obtain the dimensional turbulence components u_i, $i=1,2$.

4) Calculate the dimensional time interval with Eq. (7).

5) Let the initial values of u_i, $i=1,2$ occur simultaneously and interpolate the successive values to a common interval as described in Ref. 5.

This procedure will provide turbulence components as functions of time for level z above natural grade, i.e., $u_i(t,z)$, $i=1,2$.

Horizontal Wind Field Simulation

Let x_1 and x_2 denote a right-hand coordinate system in which x_1 is parallel to the mean wind as shown in Fig. 2. In this coordinate system the total simulated horizontal wind field at level z is given by

$$v_1(t,z)=\bar{u}(z)+u_1(t,z) \qquad v_2(t,z)=u_2(t,z) \tag{8}$$

Once this wind field is specified, the Shuttle can be flown through it on a computer run as follows:

1) Select discrete altitudes $z=30, 40\ldots150$ m.

2) Calculate $u(z)$ at selected altitudes.

3) Generate time histories of u_i, $i=1,2$ at specified altitudes. It is recommended that the starting points on the tapes be obtained by random selection for each level and for each run.

4) Calculate v_i, $i=1,2$ as specified by Eq. (8).

5) Select location on the Space Shuttle to apply wind field.

6) Calculate trajectory $Z(t)$ of selected location on the Shuttle to apply wind. This could be a "zero-order" trajectory, i.e., one without turbulence.

7) Evaluate wind field components at $Z(t)$, i.e., $v_i[t,Z(t)]$, $i=1,2$.

8) Calculate resulting aerodynamic forces and response of the Shuttle to wind field.

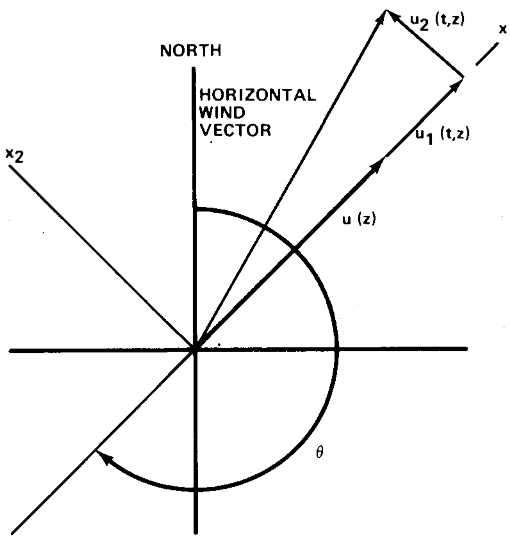

Fig. 2 Addition of turbulence components to mean wind to obtain horizontal wind at height z above natural grade as a function of time.

Conclusions

Statistical analysis of each season/hour separately will permit consistent interpretation of results. Indiscriminate combination of all seasons and all hours as specified herein would lead to statistical engineering quantities that would be difficult, if not impossible, to interpret. This arises from the fact that the peak wind distributions and wind direction distributions given herein do not come from the same statistical populations. To obtain combined statistical results from each population requires knowledge about the fraction of time each population occurs at KSC.

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