43 SURFACE LEVEL WIND GUSTS AND TURBULENCE IN THE ALCÂNTARA LAUNCH CENTER, BRAZIL

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1. INTRODUCTION

Brazilian rockets are launched from Alcântara Launch Center (ALC), whose location close to equator is privileged for launching of geosynchronous satellites. Turbulence and sudden change of wind velocity may affect straightforward the rockets' structure as well as its flight trajectory. The atmospheric boundary layer, the nearest atmospheric layer from the surface, is the one with higher time and space variability. Furthermore, the geographic and topographic features around make the ALC a special case from the micrometeorological point of view as it locates in the Atlantic Ocean sea cost nearby a cliff about 40-m high.

Surface winds and turbulence in the atmospheric boundary layer governs the forces experienced by rockets in the first few seconds of the flight. Also, when there is only a very small clearance between the rocket and the launch tower, winds can cause unaccepted tilts. Immediately before the launch, the rocket is taken from the tower shelter being exposed to the wind again (Kingwell et al., 1991). Thus, not only the rockets' launch but also the maintenance of rockets in the launch pad is of concern of the aerospace meteorology. Following Kingwell et al. (1991), the wind factors influencing the rocket launch are, among others, flight trajectory, vehicle controllability, structural loadings on vehicle and towers, rate of salt deposition (and therefore of corrosion) on launch structures, and human and environmental protection.

Ground wind studies has been carried out by NASA concerning a safety environment for both launch procedures and dispersion of toxic gases and particulate matter rising from fuel burning (Adelfang et al., 2008). Rocket fuels produce gases of varying degrees of toxicity. Generally, weather conditions such as entrainment of clear air and vertical mixing will keep concentrations of the combustion releases within the thresholds of toxicity. Note that turbulence can be critical in a go/no go decision: concomitantly to its desired effect on pollutants released during the fuel burning are the undesired effects on rocket's structure. In this connection, Moreira et al. (2011) has developed a multi-layer model to simulate rocket's fuel-burning releases. Such a characterization of wind behavior and turbulence within the surface boundary layer is very important to guarantee the safety during rocket launches from ALC.

With respect to the strength of the wind in the ALC, Fisch (1999) has studied the vertical profile of the wind in ALC and provided the first calculation of turbulence and gusts. Recently, a more detailed study of the turbulent properties of the wind in the area of the ALC has been addressed by Magnago et al (2010). Nonetheless, those studies had a still preliminary character e many questions are to be answered, for example, how is the wind profile nearby the launch pad and how does it change from ocean upstream passing by the cliff? What are the concerning characteristics of turbulence and gusts, time and spatial distribution, and time scales? Thus, the characterization of the surface boundary layer and, particularly, the internal boundary layer, is very important. To begin this attempt, we present data of wind turbulence and gusts collected for 10 days during the dry season in 2008 in ALC.

2. SITE, CAMPAIGN, AND DATA PROCESSING

Alcântara Launch Center coordinates are Lat. 02°19'10"; Lon. 44°22'05". In this latitude, wind trades interact with the sea breeze circulation, strengthening the easterly wind during the day. The launch pad located about 150 m from the sea cost and in mid way there is a cliff about 40-m high (Fig. 1).

Fig. 1. The 40-m high cliff upwind the Alcântara Launch Center.

The data presented here were collected during the *Murici II Campaign*, in September 2008 from 16 to 25 (DOYs 260 to 269), corresponding to the local dry season. Synoptic conditions were fair with clear sky and no precipitation during the whole campaign. In that experiment were dep-

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loyed, among other anemometers, 10 aerovanes (model 05103 from R.M. Young) displayed in a triangular mesh of masts 10-m high, and spaced 10-m from each other. Wind speed and wind direction were sampled at 0.5-Hz rate. Time-series of raw data were averaged over 10-minutes time interval and stored in a data-logger CR-7 Campbell Scientific Instrument. Fig. 2 shows the layout of the aerovane mast mesh. The background shows approximately the West view of the site so that the prevalent wind direction enters the page. Direct observations are speed as given by the rotation rate of the aerovane propeller after calibration applied, and wind direction, given by the aerovane potentiometer.

Fig. 2. Site studied and the mast mesh layout.

The zonal (u) and meridional (v) components of the wind velocity are computed from instantanes values of the observed speed and direction. They are averaged over 10 minutes. The vector mean wind speed is computed then from mean components. Tab. 1 gives a summary of the calculation procedures.

Aerovane direction in those formulas has been set with respect of magnetic North, so that a correction for magnetic declination has to be applied. The new vector mean wind direction speed and new vector mean wind speed are then written as

$$\begin{pmatrix} \bar{u}' \\ \bar{v}' \end{pmatrix} = \begin{pmatrix} -\cos\delta & -\sin\delta \\ \sin\delta & -\cos\delta \end{pmatrix} \begin{pmatrix} \bar{u} \\ \bar{v} \end{pmatrix} = -R_\delta \begin{pmatrix} \bar{u} \\ \bar{v} \end{pmatrix},$$

in which R_δ is identified with the counterclockwise Oz-rotation matrix. The magnetic declination, δ = 20°50'W (–20.833°), was obtained from NOAA National Geophysical Data Center calculator (http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp).

Despite of the wind components have changed because of the magnetic declination correction, the magnitude of the wind velocity is kept unchanged. The tanθ (ratio between the components) has an increment right in the argument. Therefore, it is enough sum δ to the old angle ($\theta' = \theta + \delta = \theta - 20.883°$). Besides, the correction for the magnetic declination, wind direction time-series showed a systematic differences among the aerovanes. This is mainly thought due to some aerovanes are a little misaligned. In fact, after subtracting the mean value of each aerovane and summing the overall averaged direction all aerovane direction becomes consistent with each other (Fig. 3). The 10-min mean amplitude of wind direction along the Murici II Campaign is high, reaching almost 80° by the Julian Day 266. Note that even after correction, a random variability of up to 10° can be still observed. It is observed that in the two latter days of the campaign (DOYs 267 and 268) the variability of wind direction has decreased.

Tab. 1. Averaging methods of the observations. All mean values were taken over a 10-min time interval.

$V_S = \frac{1}{N}\sum_n S_n$	Scalar mean wind speed (S_n, observed)
$\bar{u} = \frac{1}{N}\sum_n -S_n \sin\theta_n$	Zonal mean wind component
$\bar{v} = \frac{1}{N}\sum_n -S_n \cos\theta_n$	Meridional mean wind component
$\bar{\theta} = \tan^{-1}\frac{\bar{u}}{\bar{v}}$	Vector mean wind direction
$V_R = (\bar{u}^2 + \bar{v}^2)^{1/2}$	Vector mean wind speed
$I = \frac{\sigma_u}{S_n}$	Turbulence intensity
$G_n = \frac{S_{pn}}{V_S}$	Gust factor, S_{pn} is a 10-min peak velocity
$A_n = S_{pn} - V_S$	Gust amplitude

Maximum and minimum instantaneous speeds were taken from each 10-min intervals and were averaged hourly for each aerovane and then averaged over all ten aerovanes. Turbulence intensity (standard deviation over mean speed), gust factor (maximum speed over mean speed), and gust amplitude (maximum speed minus mean speed) were computed from the available dataset. Since the aerovane sampling rate is 0.5 Hz, the time interval between two consecutive readings is 2 s and thus the gust we consider here has automatically a time width of 2 s. It seems that there is not a standard in defining the duration of the gust. Usually the gust duration is set as a function of instrumentation/data availability or specific objectives; 2 or 3 seconds wind peak in a time-interval of 10 min is often used.

3. RESULTS AND DISCUSSION

3.1 Wind features

Scalar and vector mean speed (not shown) are very close throughout the time-series and the maximum mean difference for the diurnal cycle is not greater than about 2%. Such wind persistence is already a known fact for a much larger area covering the ALC site. Hereafter, e will then refer only to the *vector* mean wind speed. Fig. 3 shows 10-min time-series for the magnitude of the vector mean velocity for each aerovane as well as for the aerovane ensemble average. It is not clear what causes such variability. A misalignment of aerovanes would generate systematic differences between each couple of aerovanes. We investigate those differences finding that they are either negative or positive throughout the time-series, i.e., the time-series crosses each other.

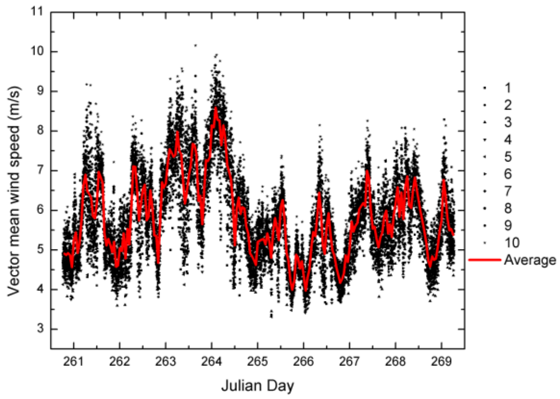

Fig. 3. 10-min averaged time series for the whole Murici II Campaign. Red line is the ensemble averaged, and black symbols individual aerovane values.

Therefore a misalignment does not seem to be the answer. Furthermore, this large scattering is also observed in the scalar wind speed and suggests a scale length of few meters, since the dataloggers were all synchronized.

A time- and frequency-domain analysis would be helpful to investigate this variability, but because the raw data is not available these will be postponed until the future in another observational campaign. The autocorrelation and cross-correlation, spectrum and cross-spectrum of the 10-min time-series (not presented herein) show only a diurnal cycle and another cycle of about 4-5 days, due to a large-scale system or still due to limited length of the series. However, surface data pressure supports the idea of a large scale forcing. Some higher frequency features with a time scale of 8 to 12 h are also observed and can associated to the double-peak diurnal cycle of surface pressure.

In the Fig. 4 is presented the vector mean wind speed, maximum wind, minimum wind, and direction averaged over all days and over all aerovanes. We apply offsets of –3 m/s and +3 m/s to the maximum and minimum speed, respectively, in order to enhance the diurnal cycle on the graphic. The diurnal cycle of wind direction averaged over all aerovanes is strongly marked varying from 25 to 55 degrees, that is, on the central half of the first quadrant. Its peak value occurs at about 1000 LST.

Mean speed presents values ranging from 5.0 to 6.5 m/s. Minimum and maximum speed are about 3.0 and 9.0 m/s, respectively. These numbers show that wind is rather strong in the ALC site. A possible scenario would be that in which the main contribution comes from the Trades whereas the variation along the diurnal cycle is due to the mesoscale regime of the land-sea breeze circulation, which strengths the wind during the daytime and weakens it during nighttime. Nonetheless, this is still an open issue and other factors might be acting. The point is that the peak value of the diurnal cycle, for both speed and direction, seems to occur too early (0800 LST) so that the sea-breeze circulation would be just starting to act.

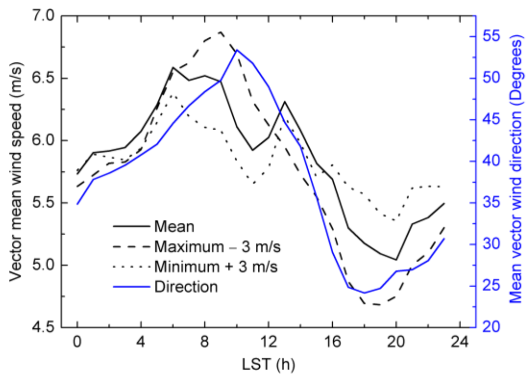

Fig. 4. Diurnal cycle of mean, maximum, and minimum wind speed (black lines) and wind direction (blue line).

To complete the statistical characterization of the wind, histograms for the mean wind speed and the wind direction for the whole time series after averaging for the ensemble of all ten aerovanes were drawn (Figs. 5 and 6). Accordingly, the wind average and standard deviation are 5.8 m/s and 1.0 m/s, respectively. For direction, average and standard deviation are 36.6^o and 12.4^o, respectively. Gaussian distributions based on those values have also been plotted in Figs 5 and 6. As it can be seen, both wind speed and wind direction are not symmetrically distributed about the mean value; wind speed tends to be below the mean value (skewness = 0.50) and wind direction tends to be above the mean value (skewness = –0.43).

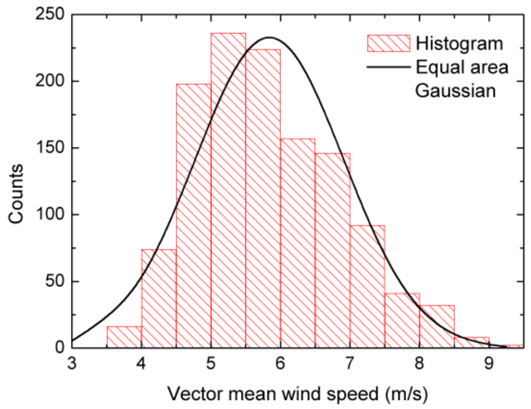

Fig. 5 Distribution of the vector mean wind speed with its correspondent normalized gaussian curve.

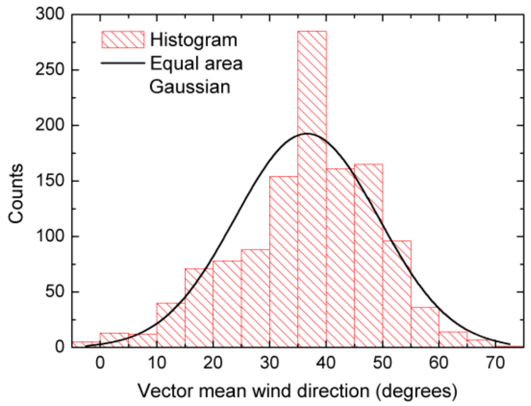

Fig. 6. Distribution o the vector mean wind direction and its normalized gaussian curve.

3.2 Gust and turbulence features

There are very few studies of the impact of wind on the rocket and launch tower in the Brazilian space program. Wind engineering has devoted most time to other kind of structure such as transmission line towers. Even if the results for transmission line were extended to other vertical structures like a rocket or a launch tower, the particular features found in the ALC would likely fall out the code criteria. Gusts can affect rocket structure due to stresses caused either because the strength or the frequency of the gusts (Hrinda, 2009). A particular concern is about the structure natural frequency which may not withstand to a resonance process.

Time-series show that the gusts and turbulence are intensified between 0500 and 1000 LST, likely due to the interaction between the sea breeze and the Trades (Fig. 7). Turbulence intensity, gust factor, and gust amplitude are strongly correlated to each other: their peak values take place at about 1000 LST. Turbulence intensity values are between 0.13 and 0.27. Turbulence intensity should be associated with the wind shear. Gust factor and gust amplitude are between 1.3 and 1.8 m/s, and 2.2 and 4.3 m/s, respectively.

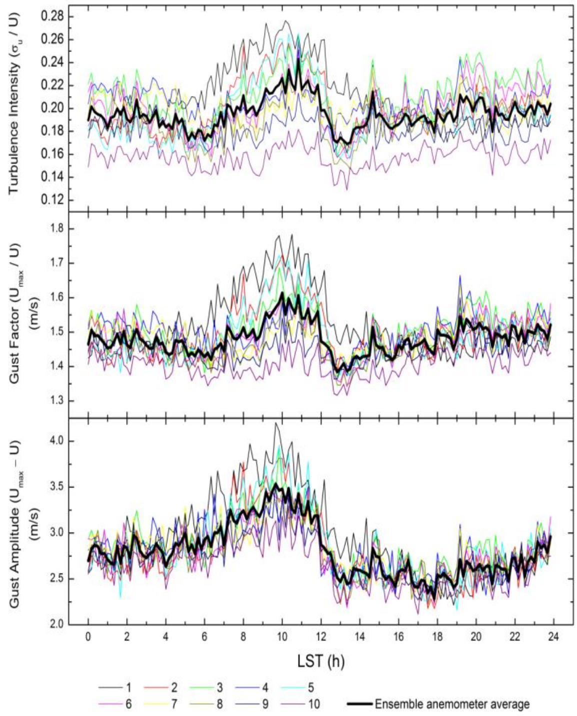

Fig. 7. Diurnal cycle of turbulence and gust properties.

One important issue found in the Brazilian space program is that there still are an appreciable lack of laboratory and field data to characterize not only the flow regime in the ALC, but also to better understand how the such flow regime can affect launches as well as the rocket and launch tower structures themselves. Furthermore, the lack of acceptance criteria for wind conditions makes more difficult the use of existing data. As Adelfang et al. (2008) point out "*there is not a clear-cut precedent from building codes to follow in recommending design risk for a given desired lifetime of structure.*"

4. CONCLUDING REMARKS

We present data of winds and atmospheric turbulence collected for the ALC during a 10-day field experiment in the dry season in 2008. Aerovanes were mounted in 10-m high masts displayed in a triangular fashion. ALC represents a special case from the micrometeorological point of view, as it locates in the Atlantic Ocean seaboard nearby a cliff about 40-m high. Wind speed, wind direction, turbulence intensity, gust factor, and gust amplitude all present a marked diurnal cycle. The mean, minimum, and maximum speeds are about 6.0, 3.0 and 9.0 m/s, respectively. Mean wind direction is about 40^{o}. The gust factor found for ALC is rather low when compared with literature. The latter aspect will also to be tackled in future. Finally, the characterization of wind behavior and turbulence within the surface boundary layer is very important to guarantee the safety during rocket launchings from ALC.

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