# WIND PROFILE DERIVED FROM ANEMOMETRIC TOWER AND RAWINSOUNDINGS FOR THE DETERMINATION OF THE FLIGHT TRAJECTORY AT ALCÂNTARA SPACE CENTER

**Gilberto Fisch(1), Ricardo Costa Leão(1), Iria Fernandes Vendrame (2)**

(1) *Institute of Aeronautics and Space, Praça Marechal Eduardo Gomes, 50, CEP 12228-904, São José dos Campos, Brazil, Email: fisch.gilberto@gmail.com*

(2) *Institute of Aeronautical Technology*, Praça Marechal Eduardo Gomes, 50 *CEP 12228-904, São José dos Campos, Brazil, Email: hiria@ita.br*

## ABSTRACT

*The winds at lower (inside the surface layer ranging from the surface up to 120-150 m) and upper atmosphere (up to 20 km) are very important to determine the flight trajectory of the rockets. At the Space Launching Centers they are usually measured by wind or anemometric tower (lower winds) and from rawinsoundings (upper winds). These two measurements are used to compute the ballistic winds without any attempt or technique to match the two profiles. This work has been done in order to propose a technique to adjust and match the two different vertical profiles of wind at the Brazilian Space Launching Center. The winds from the lower part is characterized by an anemometric tower while the upper air winds were determined from the rawinsounding system (Vaisala, Finland) using the Global Positioning System technique (GPS). These two wind profiles were matched together using an interpolation method (cubic spline) in order to avoid the abrupt changes in the average profile. This paper described the method used and applied for a simulation with a sounding rocket (VSB30) launched from Alcantara Space Center (ASC) during the 2005 dry season (period when the winds are stronger). The results showed that this new and adjusted wind profile has determined the impact point better than the usual method used (no adjustment). The impact point has moved 2.4 km with the proposed method although within the dispersion area (usually accepted as 40 km of radius). The apogee (higher by 0.3 km) and the slant range (reduced by 0.9 km) also changed due to the different initial conditions*

## 1. INTRODUCTION

The Alcântara Space Center is the Brazilian gate to the space. From this Center, it is launched the guided rocket as Satelite Vehicle Launcher (VLS) and unguided sounding rockets (like VSB30). Especially for the sounding rockets, the winds are very important to determine the flight trajectory and it is computed as a sum of the internal (characteristics of the rocket) and external (winds) forces involved [1].

The bottom part of the troposphere (up to 3000 m) can be divided in Surface Boundary Layer (SBL) from the surface up to 150 m where the windspeed increases vertically following a logarithmic profile and the wind direction is almost constant and the Atmospheric Boundary Layer (ABL), which is trapped by the thermal inversion around 1-2 km height. Usually the measurements inside SBL are made with anemometric towers (AT) while the ABL characteristics are made with direct (rawinsounding) and/or indirect remote sensors (SODAR and/or LIDAR). The reference [2] presented the main characteristics of the SBL and ABL as well as the advantages and disadvantages. Consequently, the windprofile can be derived from measurements made at an anemometric tower and by rawinsoundings can be different. The AT measures the wind using point measurement sensors and the RS indicates layer measurements from a vertical average layer (usually 50 m height interval). In the last decade, several scientific papers were published comparing wind profiles made using different techniques. The reference [3] analyzed wind profile derived from a 50 m height tower and SODAR data in US and Canadá: the results showed very low difference (lower than 0.5 m/s at SBL). Accordingly to [4] comparing winds up to 300 m obtained using anemometric tower and a SODAR data in Russia, there is a good agreement between the measurements (correlation coefficient around 0.9 for windspeed and direction) and standard deviation of 1.1 m/s and 17 degrees respectively.

The objective this work is to adjust 2 different profiles made by different techniques: a) the wind profile from surface up to 70 m height derived from an anemometric tower (AT) and b) wind profile from surface up to 500 m made by rawinsoundings (RS). The new (matched) profile is compared with the previous wind profiles and applied for a case study of a sounding rocket launching (VSB-30) at the Alcantara Space Center (ASC).

## 2. DATA SET AND METHODOLOGY

The ASC is located along the coast at the latitude 2° 19' S and the longitude 44° 22' W and 40 m above sea-level. The climate presents a precipitation regime divided in wet period (from January up to June) being March and April the peak of the rain (higher than 300 mm/month) and a dry period (from July up to

*Proc. '20th ESA Symposium on European Rocket and Balloon Programmes and Related Research'*
*Hyère, France, 22–26 May 2011 (ESA SP-700, October 2011)*

December) with precipitation lower than15 mm/month. The wind regime possesses a distinct behavior between the rainy and dry season. During the wet period the surface winds are weaker (typically around 4.0 – 5.0 m/s) than during the dry season (winds around 7.0 – 9.0 m/s). This is due to intensification of the sea breeze that presents its maximum influence during this time (particularly from September until November). The wind direction is from the NE at both periods.

Two observational data-sets have been analyzed: an anemometric tower and rawinsounding measurements (Fig. 1). A 70 m anemometric tower was instrumented with sensors (aerovane Wind Monitor 05103) from R.M Young (Traverse City, USA) at six levels: 6.0, 10.0, 16.3, 28.5, 43.0 and 70.0 m at the launch pad (SPL). The rawinsounding system used was from Vaisala Oy (Helsinki, Finland) MW11 using a sonde RS80-15G (with GPS capabilities). During the ascension phase, the GPS sensor sampled the balloon positions at 2 s and an average winds for 50 m height interval were processed as the averaged wind profile for the layer. The data-set used was obtained from an intensive field campaign from July 28 until Aug 1, 2005 at ASC.

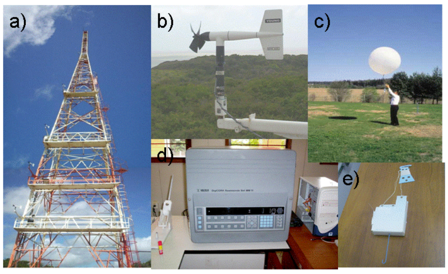


*Figure 1. Instruments used: AT (a), aerovane (b), balloon (c), RS system (d) and RS80-15G (d).*

Usually, the procedure used by the flight safety officer is to combine directly the wind profile measurements from the anemometric tower (up to 70 m) with the rawinsounding above (an example is shown at Fig. 2). The combination of the 2 curves is made using the method described by [5], attributing weight for the measurements: the AT receives more weigth up to 120 msl (which is the height of the AT and the surface altitude – 50 MSL) and RS dominates above this height. This technique may provoke a spurious and a sharp discontinuity at the overlap region.

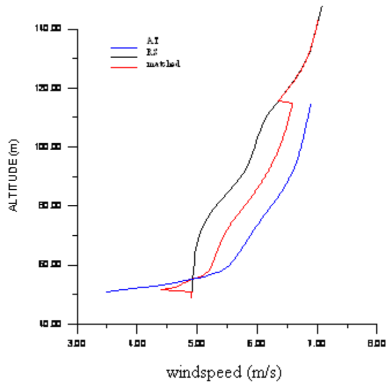


*Figure 2. Windprofile derived from anemometric tower (AT), rawinsoundings (RS) and matched.*

In order to derive a “smooth” profile, a cubic spline interpolation (using a 3 degree linear equation) was used with both wind profile measurements. The Fig. 3 presented the wind profiles obtained by the anemometric tower (AT), rawinsounding (RS) and the matched profile. For heights lower than 120 m of altitude, the AT presented values always higher than the values derived from the RS: at 70 m (equivalent of 120 msl), this difference is around 1.0 m/s.

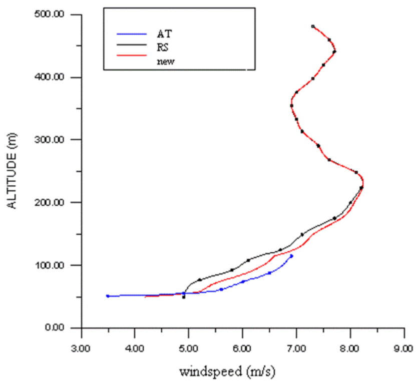


*Figure 3. Windprofile derived from anemometric tower (AT), rawinsoundings (RS) and matched.*

## 3. RESULTS

Initially, the wind measurements from the surface up to 70 m (the height of the tower) of AT and RS were computed and compared. Tab. 1 shows the statistical difference between them. The bias of the difference is maximum at the level 73 m (differences approximately -1.5 m/s). The wind direction rotated from a difference around -10° from the first 3 levels (up to 61 m) to a value + 25° for the upper levels. The root-mean square error (RMSE) presents the same pattern of the bias. The wind profile up to 500 m were computed with the actual and proposed method with the available data-set (anemometric tower and rawinsoundings) and the VSB-30 trajectories were computed. The apogee, the impact distance and the geographic coordinates of the impact point were determined for 4 trajectories and these results are shown at Tab. 2. A rocket sounding like VSB-30 usually carries a payload around 400 kg with an apogee about 250 km. With the winds computed with the method, the apogee is higher (1 km) and impact distance is far away (1-2 km). The Fig. 4 shows an example of using different wind profiles. The new trajectories are much closed among them, but they differ substantially from the nominal trajectory (which does not consider the influence of the wind).

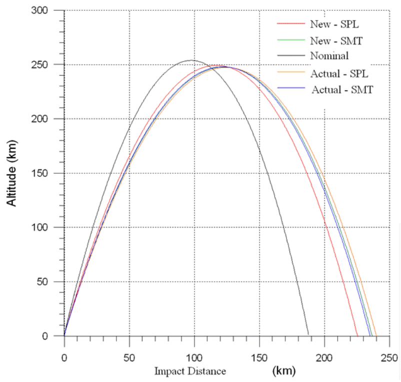


*Figure 4. Vertical projection of the trajectories for VSB30 simulated for Aug 1, 2005.*

At Fig. 5, there are different trajectories using the 2 methods as well as the rawinsoundings from SMT and SPL. Usually, for the operational launchings, the rawinsoundings are realesed from the Meteorology Sector (SMT). During this field campaign, simultaneous rawinsoundings were made between SMT and SPL. The distance between the 2 points is around 7 km (flat terrain). Previous study had showed that the wind differences between the soundings made at SMT and SPL are mainly below 1.000 m [6].

## 4. CONCLUDING REMARKS

The differences of the point of impact obtained for the trajectories using the actual or proposed method are very small (distance was 2.4 km) and within the permitted radius for the dispersion área (estimated to be around 40 km).

For launchings which is necessary to recover the payload, an error of 2 km can be crucial for the success or fail of the mission or launching. Specifically at Alcantara Space Center, the recovery area is at the water (in South Atlantic Ocean) and the helicopters have to fly around 30 min to reach the impact point dispersion circle. Also they have around 30 min of fuel availability to find and collect the payload before returning to the range center.

Finally, is should be mentioned that the Meteorology Sector at Alcantara Space Center is suffering a modernization with the installation of a windprofiler LAP-12000 (Vaisala Oy, Helsinki, Finland), which will measure the winds from 0.8 up to 14 km, with a installation of a mobile mini-sodar ASC 400 (ASC, Santa Clarita-CA, US) which measures the 3 D winds from the surface up to 200 m using the sonic anemometry and a 100 m new tower with 10 levels of windspeed and direction. The sensors will be the horizontal WS425 Ultrasonic Wind Sensor (Vaisala Oy, Helsinki, Finland). The reference [7] did a detail analysis of the comparisons between this new sensor and the traditional aerovane used at the anemometric tower.

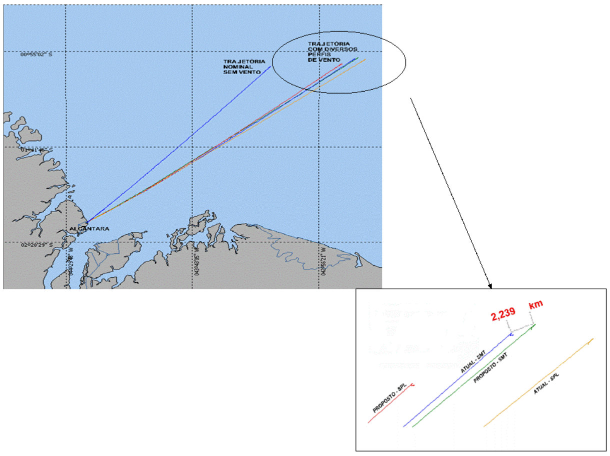


*Figure 5. Horizontal projection of the trajectories for VSB30 simulated for Aug 1, 2005.*

## 5. ACKNOWLEDGMENTS

The authors would like to thanks the financial support from the Brazilian Organizations: AEB – Brazilian Space Agency (contract number 559949/2010-3) and CNPq - National Council for Research (303720/2010-7). This work is part of the Master of Science Dissertation from Ricardo Costa Leão presented at CTA/ITA.

## 6. REFERENCES

1. Palmério, A.F. (2006). *Introdução a Engenharia de Foguetes*, ITA Mestrado Profissionalizante, São José dos Campos, Brazil, 142 p.
2. Fisch, G. (2010). Atmospheric Boundary Layer: concepts and measurements. In: *Air Pollution and Turbulence (Eds.* D. Moreira & M. Vilhena), CRC Press, US, pp 15-31.
3. Moore, K.E. & Bailey, B.H. (2008). Turbulence, shear and stability influences on lower boundary layer profiles. In: Proc. 18$^{th}$ Symposium on

Boundary Layers and Turbulence, Stockholm, Sweden (paper 74B).
4. Rusakov, Y.S. (2007). *Meteorol. Z.*, **16**(4), 349-356.
5. Görsdof, U., et al., (2002). *Theor. Appl. Climatol.*, **73**(1), 97-105.
6. Pires, L.B.M., Fisch. G. & Gielow, R. (2006). In: Proc. 5a Escola de Primavera de Transição e Turbulência, Associação Brasileira de Engenharia e Ciências Mecânicas (ACBM), Rio de Janeiro, Brasil (paper ETT-06-12).
7. Fisch, G. (2010). *J. Aerosp. Technol. Manag.*, **2**(1), 105-110.

**Table 1** –Statistical differences between wind data from rawinsoundings and anemometric tower.

| | BIAS | | | | RMSE. | | | |
|---|---|---|---|---|---|---|---|---|
| **altitude (m)** | **u (m/s)** | **v (m/s)** | **Direction (°)** | **Windspeed (m/s)** | **u (m/s)** | **v (m/s)** | **Direction (°)** | **Windspeed (m/s)** |
| **51** | 0.1 | -0.5 | -8.2 | 0.0 | 1.6 | 1.4 | 17.2 | 1.8 |
| **55** | 1.1 | -0.5 | -9.1 | -1.0 | 2.0 | 1.5 | 16.2 | 2.2 |
| **61** | 1.4 | -0.5 | -8.3 | -1.4 | 2.3 | 1.5 | 15.3 | 2.3 |
| **73** | 1.3 | 0.1 | -1.3 | -1.5 | 2.3 | 1.3 | 11.0 | 2.4 |
| **88** | -0.7 | 1.2 | 21.2 | -1.0 | 4.1 | 2.2 | 42.2 | 2.0 |
| **115** | -1.1 | 2.1 | 23.1 | -0.4 | 2.7 | 2.8 | 30.9 | 1.5 |

**Table 2** – Flight parameters of VSB-30 trajectories.

| **Sounding** | **Actual method** | | | | **Proposed method** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Apogee (km)** | **Impact distance (km)** | **Latitude (º) S** | **Longitude (°) W** | **Apogee (km)** | **Impact distance (km)** | **Latitude (º) S** | **Longitude (º) W** |
| 28/07/2005 (14:30 UTC) | 243.6 | 262.6 | -1.1210 | -42.328 | 242.5 | 269.0 | -1.0701 | -42.291 |
| 29/07/2005 (02:30 UTC) | 245.1 | 252.8 | -1.1023 | -42.441 | 245.4 | 251.2 | -1.1089 | -42.454 |
| 30/07/2005 (02:30 UTC) | 240.9 | 278.5 | -1.0831 | -42.184 | 240.7 | 279.8 | -1.0761 | -42.175 |
| 01/08/2005 (14:30 UTC) | 247.7 | 236.5 | -1.1895 | -42.560 | 248.0 | 234.6 | -1.1990 | -42.574 |