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WIND TUNNEL INVESTIGATION OF THE WIND FLOW PATTERNS IN THE CENTRO LANÇAMENTO DE ALCÂNTARA (CLA)

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Abstract. *The purpose of the present study is a wind tunnel investigation of the airflow patterns in the Centro de Lançamento de Alcântara (CLA), from where most of the Brazilian rockets are launched. The CLA presents several desirable aspects due, mainly, to its geographical location, 2°17'S 44°23'W, very close to the Equator Line. However, it is observed in this region the occurrence of a geographic formation known as coastal cliff, around 40m height, which can modify the characteristics of the atmospheric boundary layer, and that under certain conditions may affect the launching of space vehicles. The focus of this study is the airflow pattern behind the building called Integration Mobile Tower (IMT), where the rockets are assembled. The IMT is located around 200m from the border, and once a vehicle is integrated, the IMT moves back, and the vehicle stays there for few minutes before launching. In the present work the flow features behind the IMT is investigated before and after the displacement of the building. In the second case, after the IMT displacement, the experiments were carried out considering the presence of the VLS, the Brazilian Satellites Launching Vehicle (VLS). In the wind tunnel experiments, a model in scale 1:120 of the CLA region was used and the velocity flow field around the IMT was characterized by Particle Image Velocimetry (PIV). In the experimental tests, the influence of the coastal cliff slope angles, as a way of taking into account its irregular structure, and of the wind incidence, angle was investigated. From the results obtained it seems that both, the wind angle of incidence and cliff irregular structure play a role in the flow features in CLA.*

Keywords: *Centro de Lançamento de Alcântara, Atmospheric Boundary Layer, Wind Incidence Angle, Wind Tunnel*

1. INTRODUCTION

The *Centro de Lançamento de Alcântara* (CLA) is the launching base from where most of the Brazilian rockets are launched, and it has a great importance for the Brazilian Space Program. CLA has some advantages in comparison to others launch centers around the world due its privileged location, 2° 17' S latitude and 44° 23' W longitude, at northeast of the country, state of *Maranhão*, close to the equator, a privilege shared just with the Guiana Space Centre. In addition, a stable climate, allows the researchers reliability in scheduling the launching operations. Despite of favorable aspects, CLA presents in its topology the occurrence of a coastal cliff of about 40m high at the edge of the sea land, which can modify the atmospheric boundary layer characteristics, and consequently affect the safety during launching operations once the rockets launch pad and the Integration Mobile Tower (IMT), the building where the space vehicles are assembled, are located around 150 – 200 m from the sea border, respectively. Another important physical feature occurrence at CLA is the formation of an Internal Boundary Layer (IBL) as a consequence of the surface roughness change from ocean surface to the continental terrain (Pires, 2009), which makes essential the study of the meteorological conditions and wind flow pattern in the CLA region.

The functionality of launching a space vehicle is very simple and occurs in three steps, on step one, rockets are assembled at *Torre Móvel de Lançamento* (IMT), when this part is concluded, the next step is to move back the IMT, around 55m and then the final step is blast-off the vehicle. The concern of studying this situation is when the rockets are waiting to leave and its first seconds in air. Thus meteorological studies are necessary for the comprehension of the whole situation, to predict problems and improve the security of those space operations. The *Instituto de Aeronáutica a Espaço* (IAE), has been performing several research investigation in this field in the last years. These studies have been conducted based on field measurement (Fisch, 1999; Roballo and Fisch, 2008, Marciotto *et al.*, 2012), on numerical simulations (Pires *et al*. 2011) and also on wind tunnel tests experiments (Roballo e Fisch, 2008 e Pires *et al.*, 2009,

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Avelar *et al*. 2010, and Avelar *et al.,* 2012). These experiments were undertaken at TA-2 Wind Tunnel, from the IAE Aerodynamics Division (ALA), which is a valuable tool for aeronautical experiments. Therefore, for being an aeronautic facility, its short test section yields a short boundary layer, and for this reason the first challenge of the experiments was to generate there a thicker boundary layer, representative of the Atmospheric Boundary Layer (ABL) at CLA. This task was conducted using passive methods described in the literature (Loredo-Souza, 2004). The procedures used for the ABL formation in the TA-2 are described in details by Avelar *et al*. (2012). The present work gives continuation to a previous study (Avelar *et al*., 2013) which investigated, through a series of wind tunnel experiments, the impact of the predominant wind incidence angles, 0º, 45º and 35º, from Northeast, in the wind flow pattern around the IMT. The variation of the wind incidence angle was investigated together with the different slopes with the purpose of accounting for the irregular structure of the cliff. The PIV mean velocity and vorticity contours obtained indicate that the flow possesses complex features in the CLA launching system neighborhood. The formation of strong recirculation regions behind the IMT for the wind incidence angle of 35º and 45º was observed. The results obtained indicate that the parameters investigated play a significant role in the flow features in the CLA base since the dimensions of the recirculation bubble, in case of flow separation, as well as the vorticity intensity at the cliff edge, and over and behind the IMT it can be quite different depending on these parameters.

In the present work it was looked with attention the flow pattern behind the TMI after the assembling of the rockets and its displacement of 55m backward. The results were obtained from the same campaign reported by Avelar et al. (2013). The experiments were carried out for wind tunnel velocity values of 10m/s, 20m/s and 30 m/s. A VLS, Brazilian model, also in scale 1:120 was positioned at the previous TMI location and measurements for the critical configuration of coastal cliff slope of 55° and wind incidence angle of 45° were carried out in planes parallel and perpendicular to the wind tunnel bottom wall. Recirculation regions were identified behind the IMT for several conditions.

2. DESCRIPTIONS OF THE EXPERIMENTS

The experiments were performed in the TA-2 wind tunnel, a subsonic facility reaching the velocity of 120 m/s through its test section 2.10 high and 3.00 width. As described before, TA-2 is an aeronautic tunnel, with a short boundary layer thickness, and for this reason, it was necessary to increase the boundary layer thickness for the purposes of the present study, in an attempt to simulate an atmospheric boundary layer. With this aim, a combination of spires, a barrier and bottom wall surface roughness (Avelar *et al*., 2012) was used based on descriptions from literature (Loredo-Souza, 2004).

The CLA wind tunnel model was built in scale 1:120, and it was assembled over a mobile wooden platform, allowing the variation of the slope angle, β, which for this work the values of 90º, 70º and 55º were considered, and also the variation of the wind incidence angle, α, for which it was considered the values of 0º, 45º and 35º, as represented in Fig. 1. For each configuration of α and β, the velocity values of 8m/s, 20m/s and 30m/s were also considered, with and without the presence of VLS rocket model, resulting in a set 288 trials.

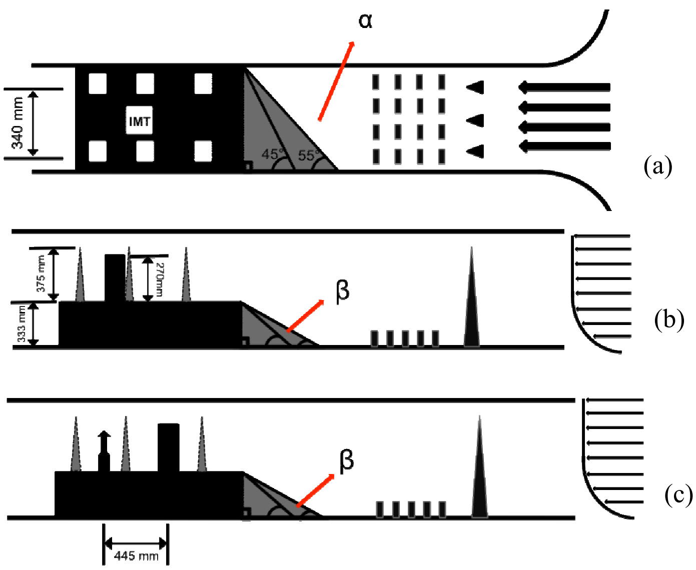

Figure 1. Schematic representation of wind incidence angle (a), coastal cliff slope without the VLS model and (b) with VLS model(c).

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In Fig. 2, it is represented the CLA model over the wooden platform representing the coastal cliff with a slope angle of 45º and 35º of wind incidence.

(a)

(b)

Figure 2. The CLA model installed in TA-2 test section - (c) General view – (b) View of region of TMI.

2.1 PIV measurements

The mean flow velocity fields were measured using a Dantec Dynamics two-dimensional PIV system, Fig.3. The system is a double-cavity pulsed laser, Nd:Yag, 15 Hz, with an output power of 200 mJ per pulse at the wave length of 532 nm (New Wave Research, Inc.) and two HiSense 4M CCD camera, built by Hamamatsu Photonics, Inc. with acquisition rate of 11 Hz, spatial resolution of 2048 × 2048 pixels, and 7.4 µm pixel pitch. A Nikon f# 2.8 lenses with 105 mm of focal length was used.

Two configurations for the PIV set up were considered. Initially the laser sheet was shot from the wind tunnel top wall, which was replaced by a glass window. In the second set up the laser sheet was parallel to the wind tunnel bottom wall with the purpose of getting insights about the airflow patterns in a plane parallel to streamwise flow direction. In both cases the measurements were conducted in the middle of the test section. Two hundred images pairs were acquired in each experiment (Avelar *et al*., 2013).

Figure 3. PIV experiment – laser shot from the top.

The flow was seeded with theatrical fog (polyethylene glycol water-solution) generated by a Rosco Fog Generator placed inside the wind tunnel diffuser. The images were processed using the adaptive correlation option of the commercial software Dynamic Studio, developed by Dantec Dynamics. A 32×32-pixel interrogation window with 50% overlap and moving average validation was used. The model was painted in flat black to minimize laser reflections.

3. RESULTS AND DISCUSSION

Figures 5 to 8 show vorticity fields and velocity vectors obtained from PIV measurements with cliff slope angle, β, of 90^{o} and wind incidence angles, α, of 45º and 35º, for wind speed of 20 m/s, with and without the VLS model. The flow patterns in the VLS region are compared for the velocity values of 8m/s, 20m/s and 30m/s.

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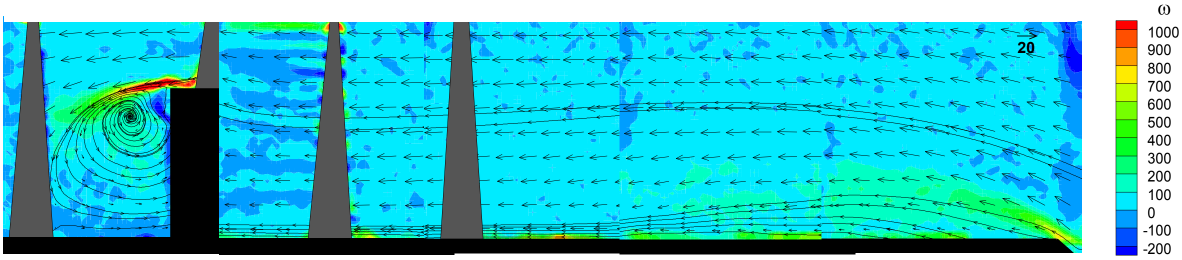

Figure 5. Velocity vectors and vorticity contours - $U_\infty = 20$ m/s - $\beta = 90^o$, $\alpha = 45°$.

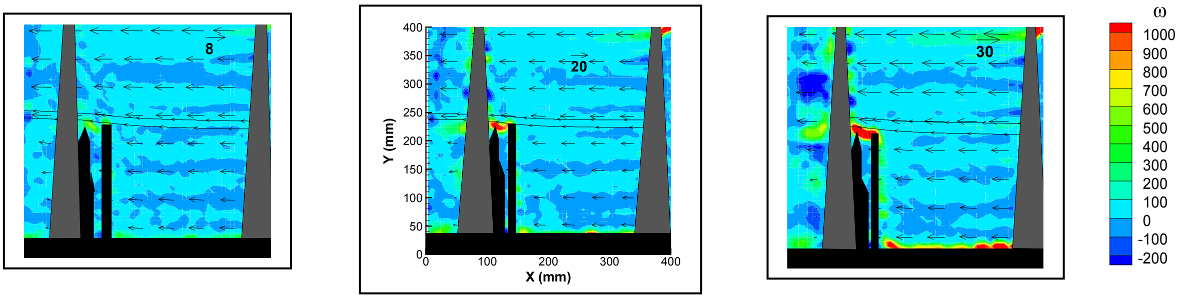

Figure 6. Velocity vectors and vorticity contours in the VLS neighborhood - $U_\infty = 20$ m/s - $\beta = 90^o$, $\alpha = 45°$.

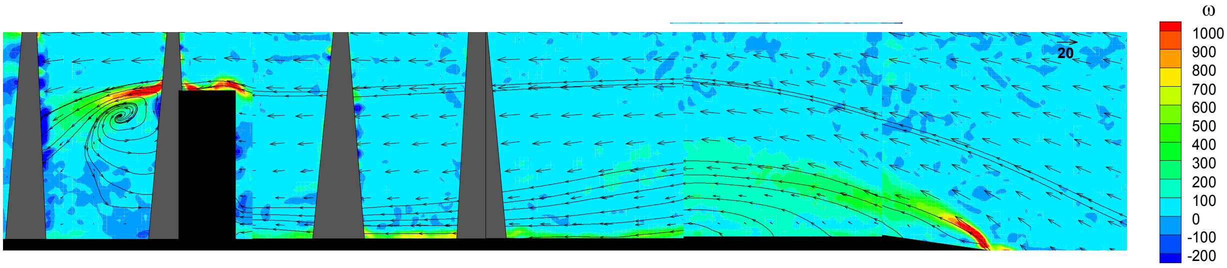

Figure 7. Velocity vectors and vorticity contours - $U_\infty = 20$ m/s - $\beta = 90^o$, $\alpha = 35^o$.

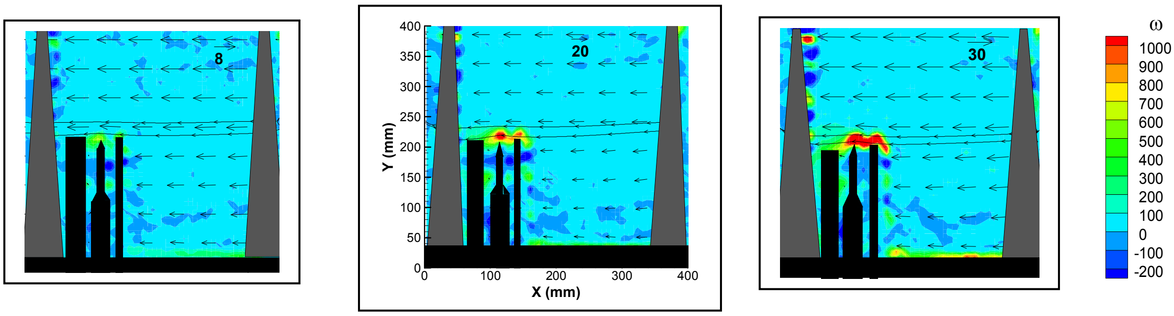

Figure 8. Velocity vectors and vorticity contours in the VLS neighborhood - $U_\infty = 8$ m/s, 20 m/s e 30 m/s - $\beta = 90^o$, $\alpha = 35^o$.

Figures 9 to 14 present results obtained when the coastal cliff angle, *β,* of 45º were simulated for the wind incidence angles, *α,* of 45º and 35º. Comparisons of flow patterns obtained for the velocity values of 8m/s, 20m/s and 30 m/s in the VLS neighborhood are presented as well.

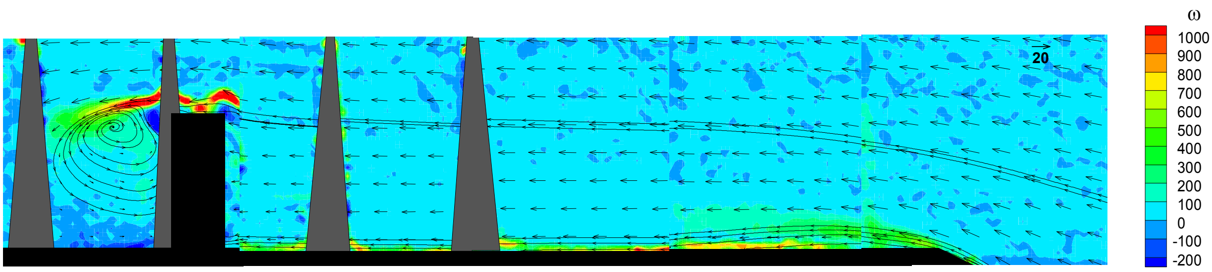

Figure 9. Velocity vectors and vorticity contours - $U_\infty = 20$ m/s - $\beta = 45^o$, $\alpha = 35^o$.

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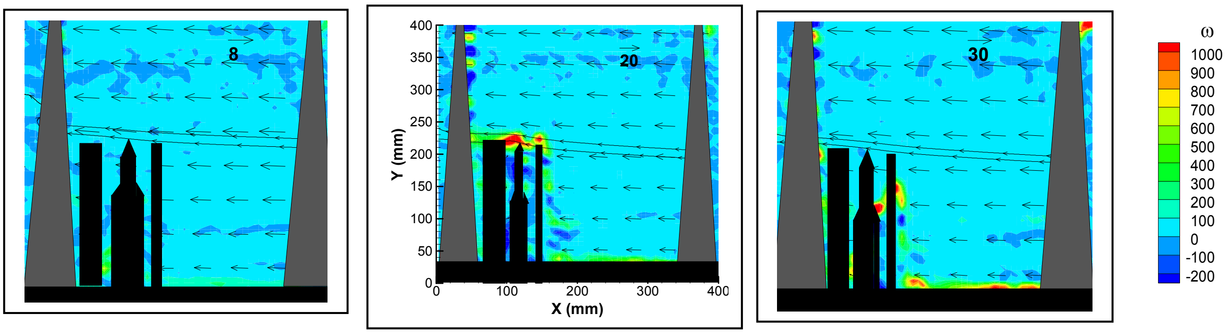


Figure 10. Velocity vectors and vorticity contours in the VLS neighborhood - $U_\infty = 8$ m/s, 20 m/s e 30 m/s - $\beta = 45^o$, $\alpha = 35^o$.

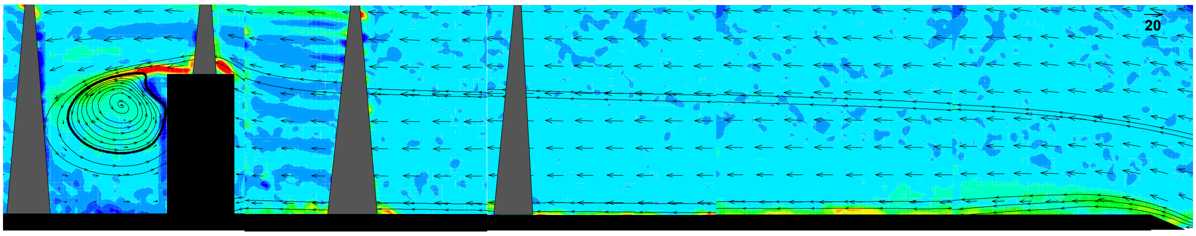


Figure 11. Velocity vectors and vorticity contours - $U_\infty = 20$ m/s - $\beta = 45^o$, $\alpha = 45^o$.

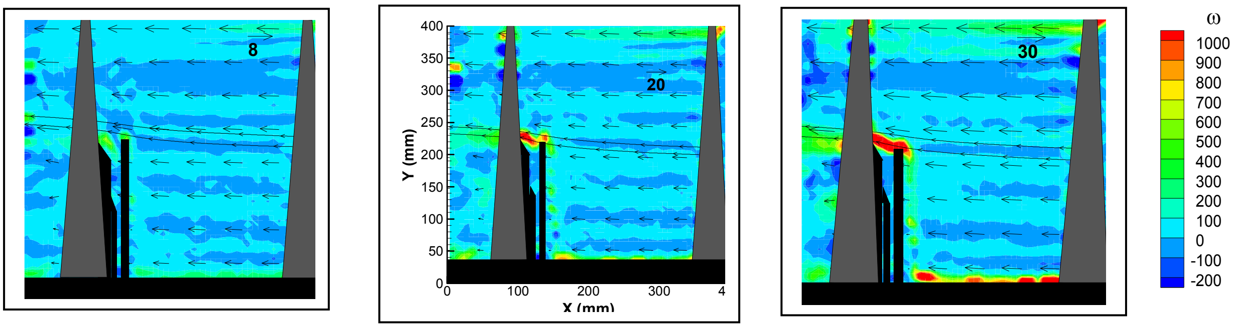
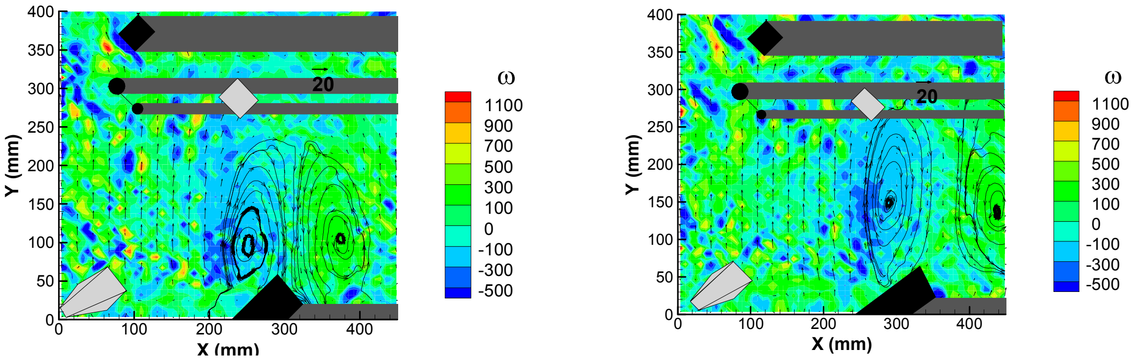


Figure 12. Velocity vectors and vorticity contours VLS - PIV velocity vector and vorticity contours for $U_\infty = 8$ m/s, 20 m/s e 30 m/s - $\beta = 45^o$, $\alpha = 45^o$.

The results presented in Fig. 5 to Fig. 12 seem to indicate that the configurations where $\beta = 45^o$ and $\alpha = 35^o$ or $\alpha = 45^o$ are the most critical. In this case, strong recirculation regions observed behind the IMT, when the VLS model is still not present. It seems that no recirculation regions are occurs in the neighborhood of VLS. These observations can be confirmed from Fig. 13, where results from PIV measurements in a plane parallel to wind tunnel floor, 220 mm above it are presented. Pairs of counter rotating vortexes appear behind the IMT for these configurations, but not behind the VLS.



(a) U = 20m/s - $\beta = 45^o$, $\alpha = 35^o$

(b) U = 20m/s - $\beta = 45^o$, $\alpha = 45^o$

Figure 13. Pair of counter rotating vortexes behind the IMT - horizontal plane, 220 mm from the wind tunnel floor.

It is important to emphasize that the lightning rod towers, represented in gray in the flow field images, seem to have significant role on the airflow at CLA in the IMT neighborhood, at least in the central plane.

Although it was not added in the present paper many results of velocity flow patterns for the different wind tunnel velocity values, it was shown by Avelar *et al*. (2013) that slight variation in Reynolds number does have considerable influence in the CLA flow pattern.

4. CONCLUSIONS

From the wind tunnel investigation described in the present study and from the results obtained it seems the wind incidence angles as well as the coastal cliff irregular structure, represented by varying the slope angle have significant influence in the flow patterns in CLA. Strong recirculation regions were noted behind the IMT for wind incidence angles of 35º and 45º, and cliff slope angle of 45º. Nevertheless, It was observed that none significant recirculation upon the VLS were found. It is important to emphasize that the lightning rod towers had not significant role on the airflow at CLA region, especially upon the VLS.

It was found also that the steeper the cliff slope, the stronger is the flow separation at the cliff edge, and weaker is the vortexes formed behind the IMT. This observation is particularly true for zero wind incidence angle. For this incidence angle, and cliff slope angle of 90^o and 70^o, no recirculation regions were observed behind the IMT. However, for wind incidences of 45^o or 35^o, vortexes appear behind the IMT for every value of slope considered.

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