On the Influence of Shoreline Buildings on Sailing Conditions

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ABSTRACT

The northwest coast of Aruba is called Palm Beach, and the buildings along this tourist portion of the coast are the tallest on the island. The winds in Aruba are strong and dominantly driven from the east. These winds travel over the open, small, portion of the north of the island (see Figure 1) and hit the highrise buildings along the western coast. Tourism is very important to the Aruban Government and, since sailing and windsurfing form a large portion of that tourist industry, the impact of the "Highrise Section" (as the area is known) buildings on the sailing conditions to their west needed to be assessed. A study was performed to understand the impact of a proposed new building at the north end of the highrise section of Palm Beach, both with and without the new building present. The results [1] were used to explain the impact of these coastal buildings on the sailing conditions offshore to various interested government members, lobby groups and private tourism enterprises. Since these circumstances are not uncommon, what was learnt here may be applied to other seaside locations with an offshore-sailing tourist industry.

EXPERIMENTAL APPROACH

The Palm Beach Highrise Section (Figure 2) was modeled at a scale of 1:300 with and without the proposed new hotel in place. The approach flow from the east, across the island, was modeled as a suburban condition (n = 0.23), due to the lowrise homes and foliage over that fetch.

Figure 1: The highrise buildings (about 8 to 12 storeys) are on the northwest coast of Aruba at Palm Beach. This area is known locally as the "Highrise Section", shown in Figure 2.

The Weibull analysis of the wind record from the Queen Beatrix International Airport (1979 to 1998) in Aruba is shown in Figure 3. The substantial statistical dominance of easterly winds and their strength are readily apparent. Additionally, calm conditions are actually quite rare. These conditions have already had a profound impact on the architectural design of the resort properties. Almost all have a general plan form which is U shaped. The base of the U is at the eastern end of the property and often contains the foyer entry. As such, a sheltered condition exists within the cavity formed by the three segments of these hotels and condominiums. The pools and other long-term activity areas are in this central, protected area. It is quite clear from these local wind statistics that sailing in general, and windsurfing or kitesurfing in particular, is a natural vacation activity in Aruba. As a consequence both the sailing concession operators and the Aruban Government were concerned when anecdotal reports suggested a deterioration of the offshore sailing condition as the Palm Beach area became more built up.

Figure 2: The randomly spaced taller buildings in Aruba are along the northwest Palm Beach coast. Sailing off the beach appears influenced by their presence to a distance of about 300 m offshore.

A wind-tunnel study was performed for the three easterly wind azimuths (60, 90 and 120 degrees) to assess the impact of a new building, and by extension, the general conditions generated by the existing buildings in the Highrise Section of Aruba's northwest coast. Data were collected with and without the new development on the turntable. Figure 5 shows the case of the proposed hotel in place. A five-hole probe was used to measure vertical profiles of the flow on a 100-m grid shown in Figure 5. This instrument yielded a useful variety of vertical profile data (U, V, W, u', v', w', uv, uw, vw, pitch and yaw). The five-hole probe is shown in Figures 4 and 7, while Figure 6 shows the coordinate system that governs its use. The device and its data-reduction algorithms have been shown to have a combined error of less than 1 percent in velocity magnitude and 0.5 degrees in flow angularity for the velocities being measured in this work. Additionally, the probe has a directional cone of acceptance, relative to the approach direction, of about 70 degrees in pitch and yaw. A selection of these profile data is presented here, along with some general conclusions that may help with the designing of other seaside resorts.

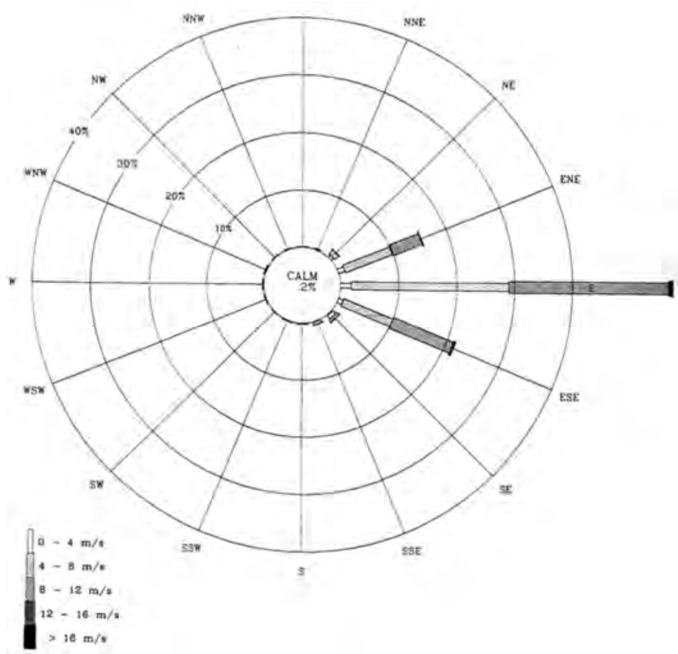

Figure 3: The Weibull wind rose for Aruba from the Queen Beatrix International Airport (#789820) generated from 10-metre data taken from 1979 to 1998.

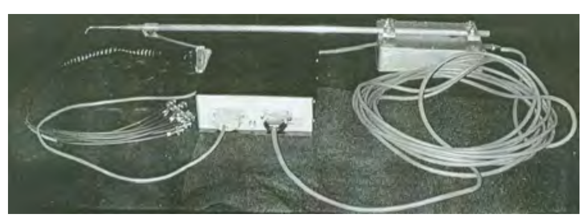

Figure 4: The five-hole probe (Aeroprobe Corporation) used to collect velocity profile data.

Some qualitative full-scale calibration at the site was also performed with the help of Dr. Mark Powell (a world-class windsurfer) and a GPS positioning device on a day of strong easterly winds [2]. His experience, and those expressed by the commercial windsurfing operators on the island, both served to yield an improved level of confidence in the results generated. Additionally, when the results were presented to the interested parties in Aruba the windsurfing and kitesurfing communities agreed that the results presented were consistent with their own personal experience sailing off the Palm Beach shore. It is actually quite rare in wind engineering to have the results of a model study confirmed by full-scale experience – even if from expert observations that are anecdotal in nature.

The goal of the study was to give the responsible authorities in Aruba more than just data on one project. If the impact of taller buildings on sailing conditions could be generally understood it could provide a guide on future height limits or whether some no-build national park coastal areas should be maintained or expanded. There was a political desire to obtain some idea of the actual impact of these unevenly-spaced and diverse architectural designs on the sailing conditions in general.

Figure 5: The suburban easterly flow approaching the resort buildings. These buildings are about 30 metres tall in full scale and they locally reduce the mean windspeed at sail height and add gustiness to the ambient conditions close to shore.

PROCEDURE

Fortunately there were only three principal strong wind azimuths that needed to be investigated. To cover the directional range shown in Figure 3 only approach azimuths of 60, 90 and 120 degrees were investigated with the five-hole probe on the traverse (Figure 7). The wind rarely blows for any other azimuth range in Aruba, and so the scope of wind directions of interest was conveniently reduced. The flow-centred coordinate system used by the five-hole probe during data reduction is shown in Figure 6. The suburban approach flow is defined in Figure 8 where the mean velocity, power-law exponent is n = 0.23

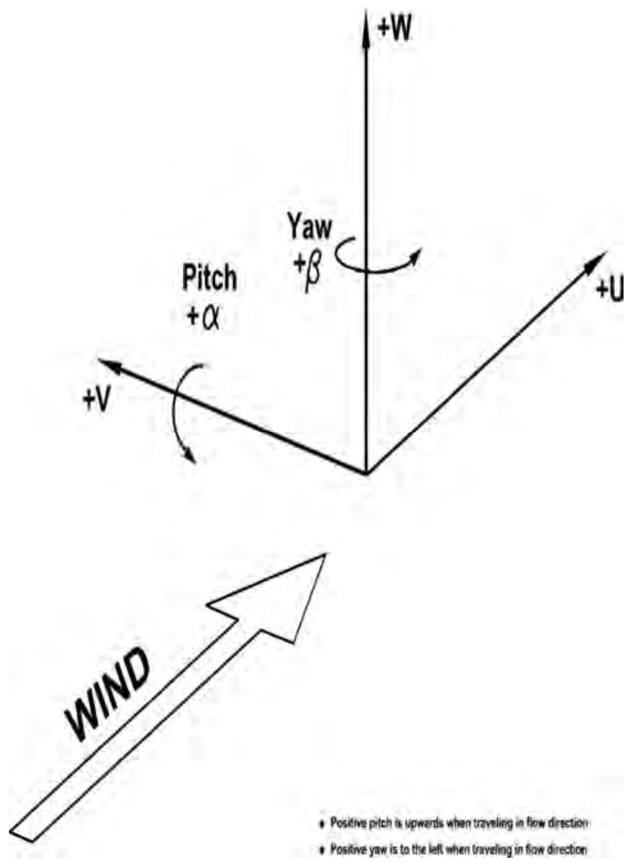

Figure 6: Flow-oriented coordinate scheme used in the five-hole probe data reduction.

and the turbulence profile is in reasonable agreement with ESDU [3].

RESULTS

The profile data were compared between the two physical configurations in order to assess the impact of buildings on the sailing conditions. The measured velocities were non-dimensionalized by a reference value measured at 500 mm (150 m in full scale). The lower probe elevations (1.5, 3 and 5 metres in full scale) were chosen to represent the rider, sail centre and sail tip for common windsurfing rigs. Higher elevations (20 to 30 metres) could be used to assess the impact on a kitesurfing wing – a relatively new sport. The data presented here are for the 60-degree azimuth case, but they are indicative of all three approach azimuths. The copious amounts of data were reduced to a variety of contour plots of flow parameters at elevations of interest. For example, Figures 9 and 10 show contours of the mean velocity ratio (U_{3m}/U_{150m}) at the typical mid-sail height of 3 m with and without a beachside development in place, respectively. The velocity deficit close to shore is readily apparent in this presentation. However, more understanding is gleaned from the profiles of the data at two locations (defined as sites 12 and 16 in Figure 9) that illustrate the range of ambient conditions. The profiles in Figure 11 and 12 show a case close to the shore (site 16) and one farther offshore (site 12), respectively. At site 12 the presence of the shoreline structures is effectively negligible, while close to the shore, at site 16, there is a lot to be understood. The mean longitudinal velocity is substantially reduced, but the turbulence is increased in all three components within this wind “shadow”. Close to the shore is where the beginners to the sport are learning and the additional turbulence may not be desirable.

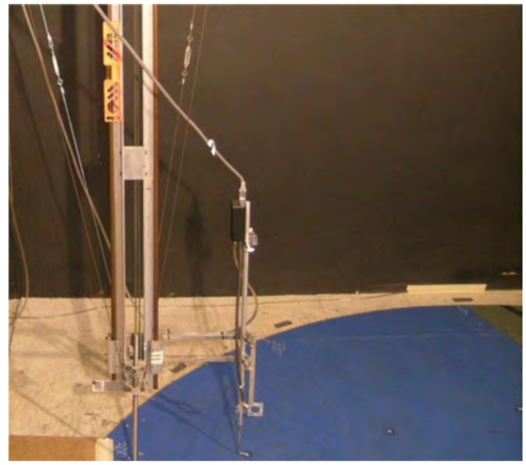

Figure 7: A traverse was used to move the five-hole probe vertically at each on the 25 grid locations (100 metre spacing) to generate windspeed profiles offshore from the subject building.

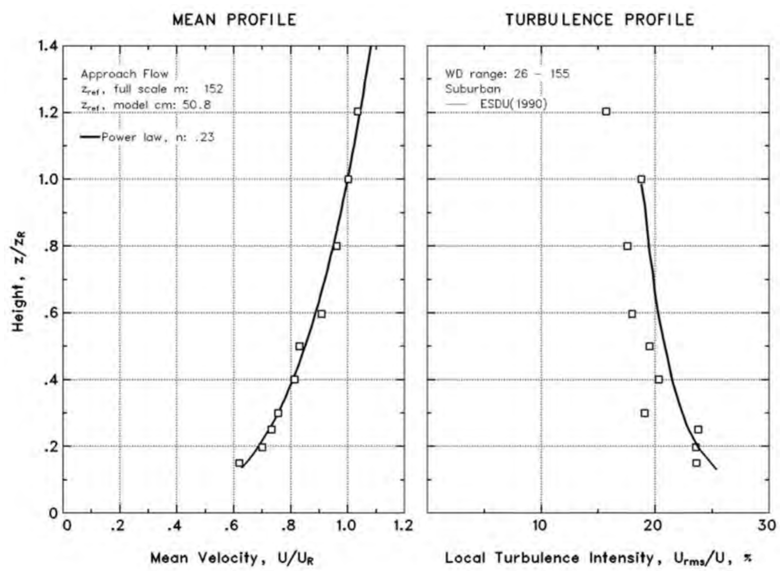

Figure 8: The flow characteristics generated upwind of the turntable by the roughness elements, trip and spires in Figure 5.

In order to explain this to the sailing community and the legislators who may, or may not, have wished to take action, three general regions were defined:

- Noticeable Impact – higher surface-level turbulence and substantial velocity deficit when a building is present.

- Marginal Impact – slightly increased surface-level turbulence with little mean velocity change when a building is present.

- No Impact – the mean velocity and turbulence intensity profiles are unchanged when the building is present.

These notions were combined with all three wind azimuth data sets to produce the summary image shown in Figure 13. The raw data are presented in detail here for the 60-degree case, due to space limitations, in Figures 9 to 12. However, the 90 and 120 degree data are not dissimilar.

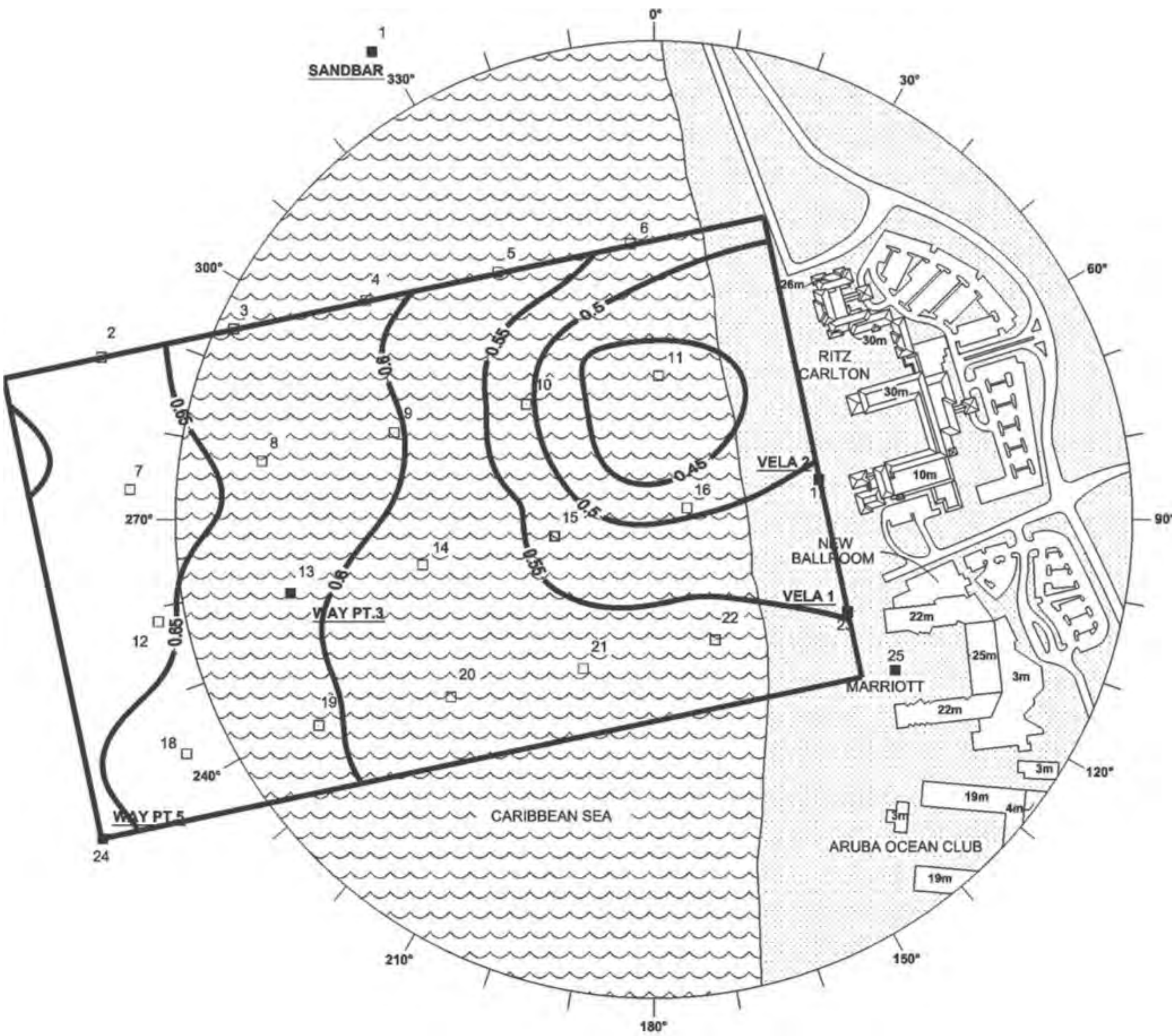

Figure 9: Contours of the mean velocity ratio (U_{3m}/U_{150m}) at mid-sail height for 60-degree wind case with a 30 metre building upwind. Note the velocity deficit downwind of the hotel.

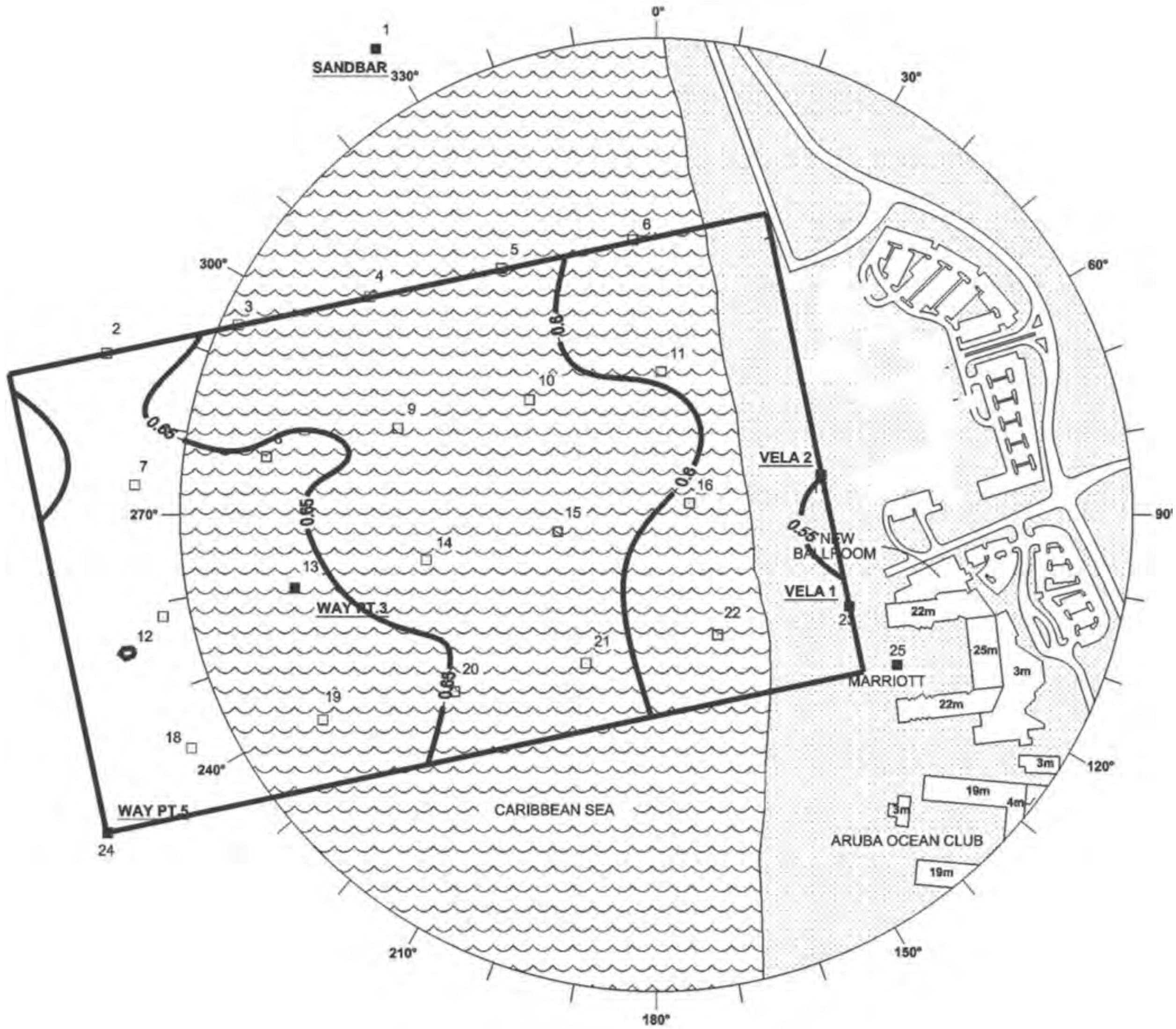

Figure 10: Contours of the mean velocity ratio (U_{3m}/U_{150m}) at mid-sail height for 60-degree wind case with no building upwind. Note the faster, surface, mean windspeeds as the flow transitions from a suburban to open-water, boundary-layer profile.

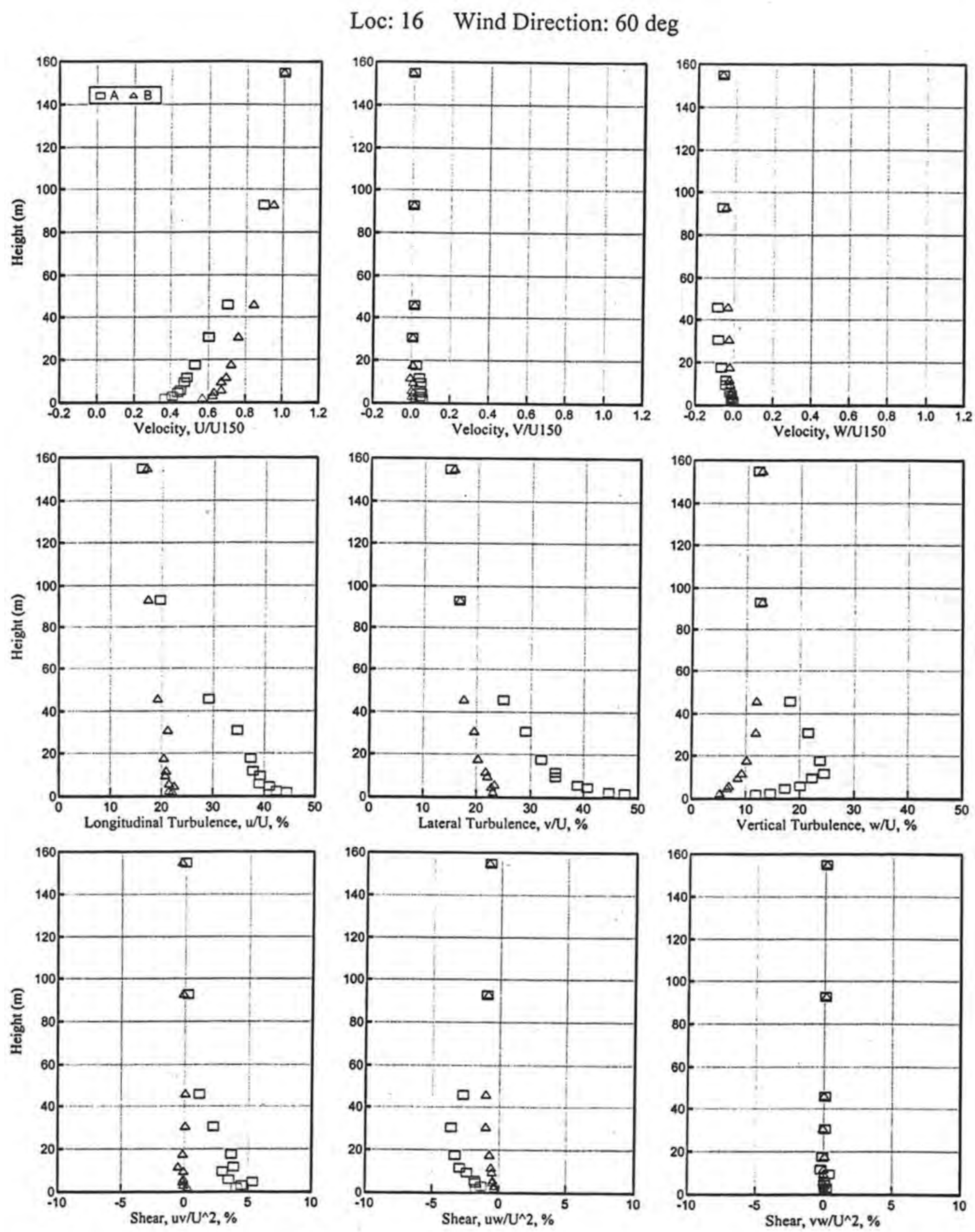

Figure 11: Profiles of selected flow properties at site 16 (close to the shore - see Figure 9). The with-building case is shown by an open square [A] and the vacant shoreline is the open triangle data [B]. Note the impact on the mean longitudinal velocity and all the turbulence intensity profiles.

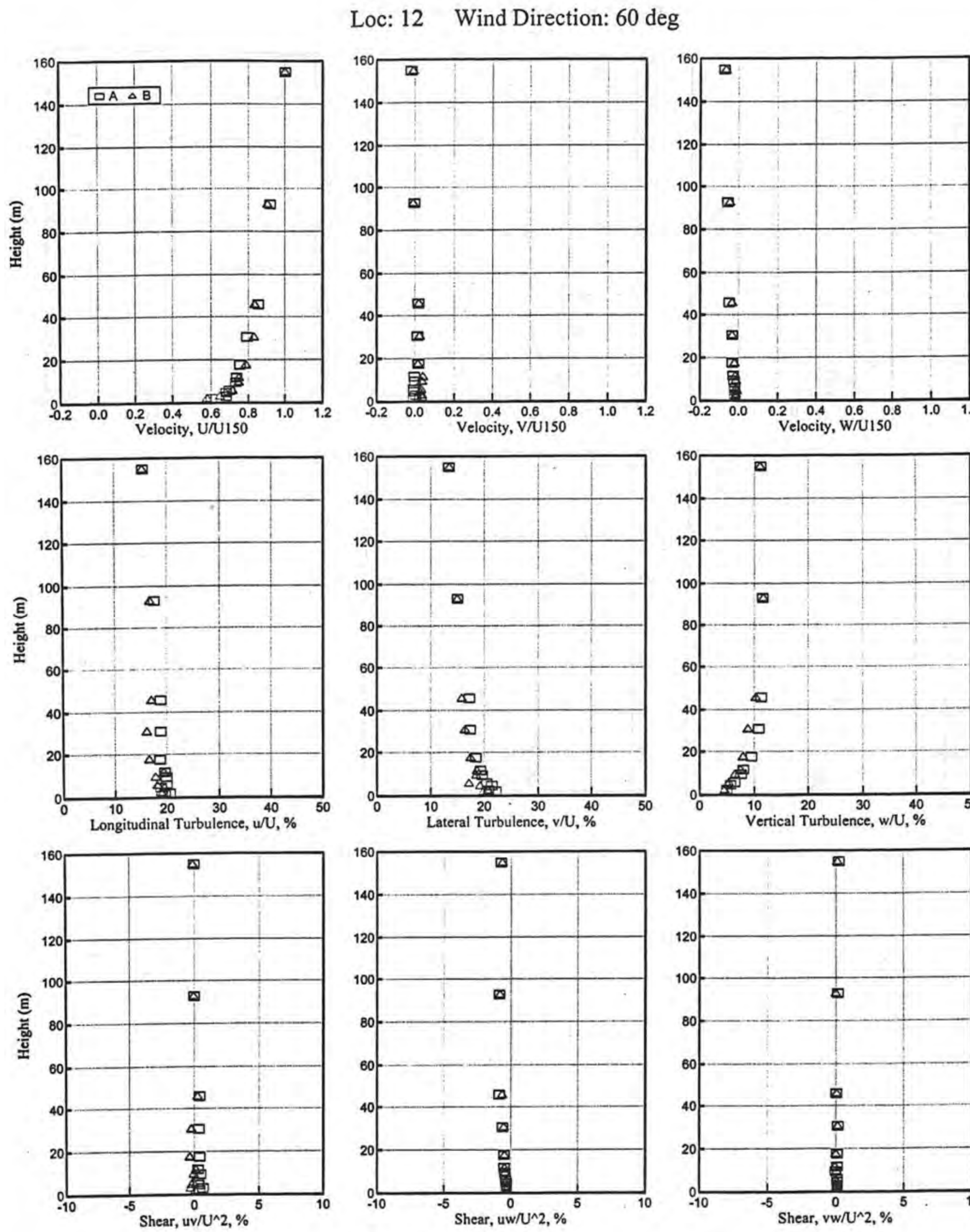

Figure 12: Profiles of selected flow properties at site 12 (far from the shore - see Figure 9). The with-building case is shown by an open square [A] and the vacant shoreline is the open triangle data [B]. The lack of variation in the two data sets is indicative of the extent of the influence of shoreline structures with a height of about 30 metres.

CONCLUSIONS

The massive amounts of data collected were distilled down to useful conclusions for the interested parties in Aruba. In essence, the first 300 m offshore would see some reduced mean windspeed and added turbulence. Beyond about 500 metres there appeared to be no impact on the sailing conditions. Full-scale observations also suggested that the main impact to sailing was closer than 300 metres, and that the "Marginal Impact" region was not of great consequence. Due to the building height trends (or limitations) in this "Highrise Section" of Aruba all the shoreline buildings are approximately the same height (see Figure 2).

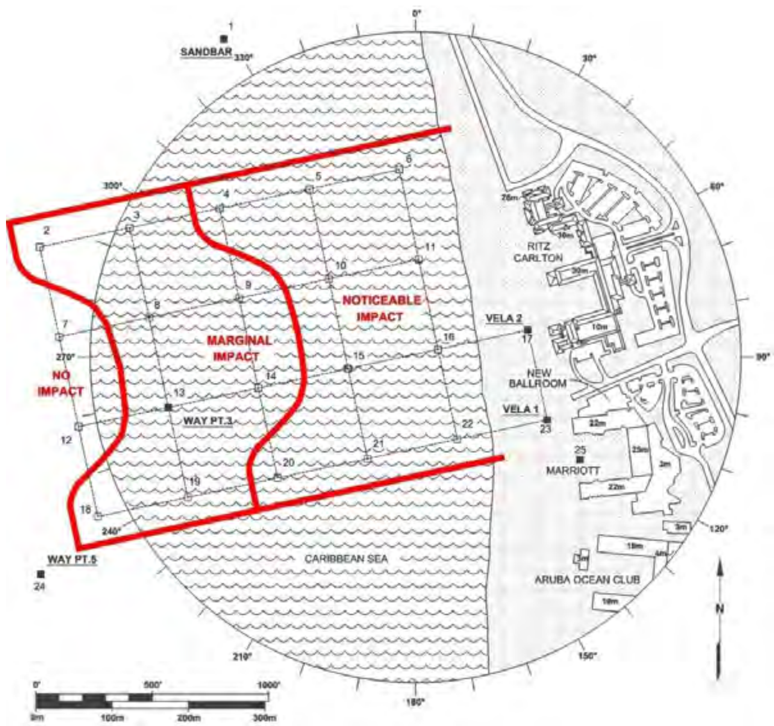

Figure 13: Summary of the regions that effect ambient sailing conditions offshore.

Experienced windsurfers would quickly leave this area and be unaffected farther out to sea. Unfortunately, learners tend to stay closer to shore and their ambient conditions will be diminished somewhat, when compared to the no-building case. The author presented these facts to the Aruban Parliament and other local lobby groups in late 2005. The upshot was that development will not be permitted any further north along the Palm Beach coast so that "clean" winds can be maintained on part of the northwestern tip of the island.

An interesting observation is that the 300-m of disturbed air corresponds to about 10 typical building heights – very similar to what one may see for a re-attachment length behind a modestly porous shelterbelt fence or, perhaps, a series of solid "fences" (ie buildings) along the beach. This strip of coastal buildings appears to act, in a general sense, like a long, large shelterbelt. Interviews with experienced Aruban windsurfers confirmed the "noticeable impact" distance of about 300 m and the "clean air" condition beyond about 500 m; a rare and important real-world confirmation. This observation may be a useful tool for other shoreline locations where there is a concern about the ambient wind conditions downwind of an array of similar-height buildings along a coast. It could be said that, in general, the influence on sailing conditions extends about 10 building heights downwind over the ocean.

ACKNOWLEDGEMENT

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