Upgrade of the Ontario Tech ACE Climatic Wind Tunnel to a Climatic and Aerodynamic Wind Tunnel

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Abstract: The ACE climatic wind tunnel at the Ontario Technical University was recently upgraded. The test capabilities were expanded with the addition of a full belt rolling road module, which is interchangeable with the dynamometer within the test section turntable. This transforms the ACE climatic wind tunnel into the ACE Climatic and Aerodynamic wind tunnel with the unique ability to perform climatic and aerodynamic testing within the same airstream. In addition to new rolling road, further upgrades were completed to enhance the simulation quality for both climatic and aerodynamic testing.

1 Introduction

Ontario Tech University ACE is a core research facility and a solutions provider in Canada designed to serve both industry and academia. ACE nurtures Canada's entrepreneurial spirit by introducing students to the commercial applications of research, supports research and development collaborations between the academic and industry community and serves industry to advance and bring new products to market.

Ontario Tech University took the opportunity to further diversify the multi-sector client base and grow industry/academic partnerships in Canada and internationally through the expansion of aerodynamic capabilities within the ACE climatic wind tunnel. The result is a flexible and market responsive innovation centre that provides thermal, aerodynamic, and aero-acoustic capabilities and address new and emerging global aerodynamic standards in the mobility sector.

“The automotive industry is moving towards lower CO_2 emissions and higher efficiency. Especially for higher driving speeds this can be achieved by minimizing aerodynamic drag.”[1] “To improve the aerodynamic efficiency of a vehicle it is essential to have reliable ground simulation in the wind tunnel.”[1] The result of the ACE Enhancement Project is a climatic and aerodynamic test facility that provides excellent underbody simulation to provide test capabilities to achieve high fidelity tests that replicate real-world driving conditions, as either an aerodynamic or climatic platform.

Prior to any improvements, the ACE Climatic Wind Tunnel (CWT), was a multifunctional wind tunnel with unique features. Upon completion of the ACE Enhancement Project, the facility was upgraded to not only improve aerodynamic and acoustic performance but to add improved underbody simulation capabilities with a new rolling road system in a readily reconfigurable “plug and play” exchange of a full-scale dynamometer with a full-scale single belt rolling road. The new ACE Climatic and Aerodynamic Wind Tunnel (CAWT) is now capable of providing climatic, aerodynamic, and acoustic simulation and testing, all within the same wind tunnel, all within the same wind stream.

The paper will detail the transformation and improvements to the ACE CWT, which include:

- Improved air flow quality, realised through the introduction of a new honeycomb flow straightener, a new Helmholtz resonator and a stand-alone collector.
- Improved acoustics, realised with new acoustic panels added to the test section walls.
- Improved under-body flow simulation, realised with a new rolling road system (RRS) and enhanced boundary layer treatment.
- Aerodynamic force measurement via a new custom force balance system for aerodynamic testing of full-scale vehicles in conjunction with the rolling road system.

2 Background

The ACE CWT is a large climatic wind tunnel, designed by Aiolos Engineering Corp., that began operation in early 2012 [2]. It is a steel construction with a closed-circuit overhead return, incorporating an open-jet style test section. The nozzle has a variable nozzle area, with flexible sidewalls and a roof that can be lifted, in tall mode, to accommodate class 8 trucks and buses. In normal mode, the nozzle range is from 7 m^2 to 13 m^2; in tall mode it is 20 m^2. The airline drawing of the ACE CWT is given in Figure 1.

The key features of the ACE CWT, prior to the present improvements, were:

- An adjustable nozzle, with flexible sidewalls to achieve 3 standard nozzle sizes: 7 m^2, 9.3 m^2 and 13 m^2.
- Wind speeds in excess of 250 km/h (7 m^2 nozzle).
- Good flow quality for thermodynamic and aerodynamic testing.
- Temperature range from -40 °C to +60 °C and a general humidity range from 5% to 95% RH.
- Low background noise level, 64 dB(A) at 50 km/h.
- A primary boundary layer scoop, for reasonable underbody simulation.
- A 750 kW (combined) chassis dynamometer mounted in a turntable to allow for climatic testing at yaw (cross-wind). See Figure 2.
- Solar simulation system (up to 1100 W/m^2 intensity) with sunrise/sunset simulation.
- Blowing rain and blowing and falling snow simulations.
- Hydrogen and electric vehicle compatibility.

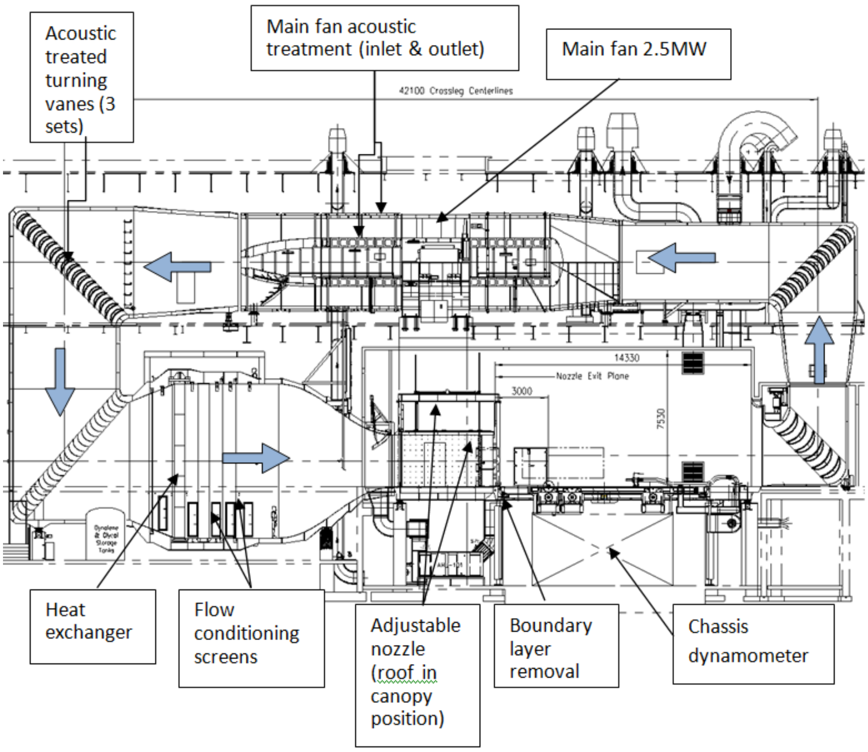

Figure 1: ACE CWT Airline drawing

The ACE CWT was designed and constructed with the present upgrade in mind. The original design included the following provisions:

- A cavity and support for the installation of a honeycomb flow straightener.
- A dedicated area at the front of the turntable for a distributed suction type secondary boundary layer system.
- Provisions for acoustic panels to be installed over the insulated panels.
- A turntable with a removable dynamometer, to allow for the replacement with other devices, such as a rolling road system.

Figure 2: Climatic (snow) Testing at Yaw

3 Upgrades

The ACE CWT was purpose built with the intention of having an interchangeable dynamometer and rolling road system. The impetus for the ACE Enhancement project was the availability of a “used” MTS rolling road system. ACE was able to purchase an MTS full belt rolling road that was originally built for an Old Dominion University wind tunnel but was never installed. Upon purchase of the rolling road, the hardware was transported to Oshawa and MTS was employed to reconfigure the system for installation within the ACE wind tunnel.

There have been several wind tunnels that have both a force balance/turntable for aerodynamic testing and a dynamometer for thermal testing [3,4]. In those facilities, the dynamometer is located downstream of the turntable, within a more unstable region of the jet flow. In the newly upgraded ACE CAWT, the dynamometer and rolling road/force balance are interchangeable within the turntable and thus the flow field is the same regardless of a thermal or aerodynamic configuration.

Along with the implementation of the new rolling road module, ACE took the opportunity to further upgrade the CWT. Enhancements were made to compliment the RRS with new boundary layer treatment, improve the flow quality and the acoustic performance of the wind tunnel. ACE took full advantage of the provisions built into the facility for future upgrades and included elements that were not originally envisioned. Aiolos Engineering was employed as a collaborative partner in the overall Enhancement Project.

Rather than shutting down the CWT for an extended period, the various upgrades were staged over a 2-year period, corresponding to regularly scheduled maintenance stoppages. This allowed for less disruption for the various clients and users of the facility.

Descriptions of the primary upgrades are given in the following sub-sections.

3.1 Honeycomb

The honeycomb was the first upgrade element to be installed. The honeycomb was fabricated in 35 boxes that were installed 5 wide x 7 high. The cell size of the honeycomb is 38 mm and the length is 600 mm, for an L/D of 15.8. The new flow conditioning arrangement of the CAWT is a honeycomb and 2 fine mesh flow conditioning screens.

3.2 Collector

The size and shape (angle of the sidewalls and ceiling to the test section centreline) were configured as part of the model wind tunnel study – see Section 4. However, the collector was constructed with the ability to adjust the wall and ceiling angles, during commissioning to account for any differences to the model scale testing. In addition, the collector has trailing edge flaps that were used to fine tune the axial gradient, something that has proven beneficial in the past [5].

The stand-alone collector is removeable to allow for the continued testing of large trucks and busses. It can be removed or installed within the test section in less than 4 hours. Photographs of the new collector and a model scale collector are given in Figure 3.

Figure 3: The new stand-alone collector (left) and a model scale version, rotated 90 degrees (right)

3.3 Boundary layer treatment

The original CWT was equipped with a boundary layer scoop located just downstream of the nozzle exit plane. While this provided adequate boundary layer control for most climatic testing, it, alone, is not sufficient for aerodynamic testing with a rolling road. To compliment the scoop, distributed suction was added along the leading edge of the turntable and on the leading edge of the rolling road insert. To reduce the distributed suctions influence on the static pressure field, every effort was made to minimise the amount of solid floor between the primary scoop and the leading edge of the rolling road.

The distributed suction on the turntable uses a high-loss perforated plate, which provides uniform suction without influence of the static pressure field of the vehicle. Since the leading edge of the rolling road module is closer to the vehicle, the pressure loss needs to be even greater and as such a sintered metal filter plate is employed. The final boundary layer control device is a tangential blowing slot, just upstream of the leading edge of the belt.

3.4 Rolling Road System

The Rolling Road System is an MTS single belt rolling road solution. Its effective measurements are 7 m long and 2.4 m wide using a 0.8 mm thick stainless-steel belt. The system has a yaw capability of ±30° and a top speed of 80 m/s. An integrated lift system allows the road to be raised into position level with the turntable while imbedded sole plates in the basement floor ensure the device remains level while in operation. The frame assembly rests on an independent rotation base aligned with the centre of rotation of the main turntable. This allows for the systems angular control to be passive relying on the turntable to set angular position without the need to synchronize two control methods. A photograph of the new rolling road configuration is given in Figure 4.

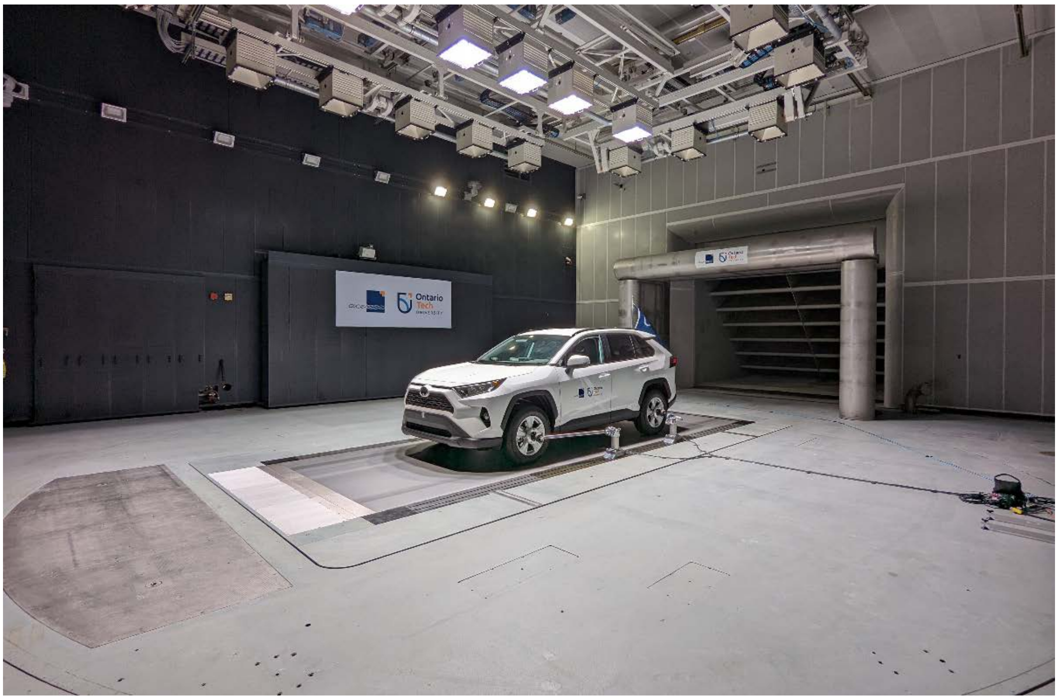

Figure 4: The new rolling road configuration inside the ACE CAWT test section

3.5 Force Balance System

Under each high pressure contact patch air bearing consists three uniaxial load cells to measure vertical forces on the vehicle. The system works on the principle that as pressure is applied to float the belt, and vehicle, the resulting force can be measured. Taring the static wind off force required to "hold" the belt/vehicle up results in the measurement of only the lift forces when wind is applied. Combined the three load cells give a maximum calibrated load range up to 8 kN per corner. The vehicle is restrained using a three-post hub mounted restraint system. The restraints, including an integrated ride height system, were designed and provided as part of a collaborative partnership with Multimatic Inc. This serves two purposes as it restrains the vehicle while also incorporating force measurement for lateral and longitudinal forces. Force measurement is attained through the use of inline 5 kN uniaxial load cells mounted on each tie rod between each tower and wheel hub. Coupled with two absolute rotary encoders (Yaw & Pitch) the force vector can be decoupled into cartesian force components resolving for X|Y|Z forces placed on each restraint. By combing this with the through-the-belt measurement, a full six degrees of freedom can be resolved.

3.6 Acoustic Wall Treatment

The original design of the wind tunnel allowed for 200 mm thick flat panel absorbers. Compact absorber panels were supplied by TAB Ingenieure GmbH of Germany. The treated walls include the ceiling, the back wall and the side walls from just upstream of the nozzle exit plane to the back wall.

The addition of the acoustic panels compliments the originally installed acoustic treatment. The CWT was designed and constructed with acoustic treatment on either side of the fan and with three acoustically treated turning vane sets: corner 1, corner 2 and corner 3.

4 Model Wind Tunnel Testing

Open jet wind tunnels are prone to low frequency pressure fluctuations that can inhibit high fidelity testing at specific velocities or even limit the top speed of a facility. These fluctuations are a result of the excitation of wind tunnel resonant modes through the vortex shedding at the nozzle exit plane. A significant source is an edge-tone feedback mechanism between the nozzle and collector [6].

Over the last 20 plus years, there have been many solutions to control or limit static pressure fluctuations. These include:

- Disruption of the coherent generation of vortex shedding at the nozzle [7]
- Collector design strategies [8,9]

- Active noise control [10]
- Selective attenuation using passive devices [11,12,13]

To control any pressure fluctuations in the ACE CAWT, the authors chose to utilise a stand-alone collector and add in a new Helmholtz resonator, in much the same manner as in [5]. The originally constructed CWT has been equipped with a small resonator with limited effectiveness. This resonator was included in the model wind tunnel.

The first task in the model wind tunnel programme was to configure a collector to provide a good axial static pressure gradient. The size of the collector was limited by the existing design – it had to fit between the turntable and the bell-mouth entrance to corner 1. A variety of collectors were examined with various side wall and ceiling angles. In addition, the sensitivity of the trailing edge flaps was examined.

The second task was to configure the new Helmholtz resonator. This began with an examination of the pressure pulsation within the full-scale wind tunnel. Figure 5 shows the frequency/wind speed dependence of the pulsations. In this diagram, the significant peaks are plotted, along with the excitation modes (natural vortex shedding and edge-tone feedback) and wind tunnel natural frequencies. It clearly shows resonate modes locking in near the excitation modes, with the most intense peaks closest to the crossing locations. The goal of the model wind tunnel testing was to configure a new Helmholtz resonator to attenuate the intensity of the large peaks, while taking into account the attenuation influence of the collector.

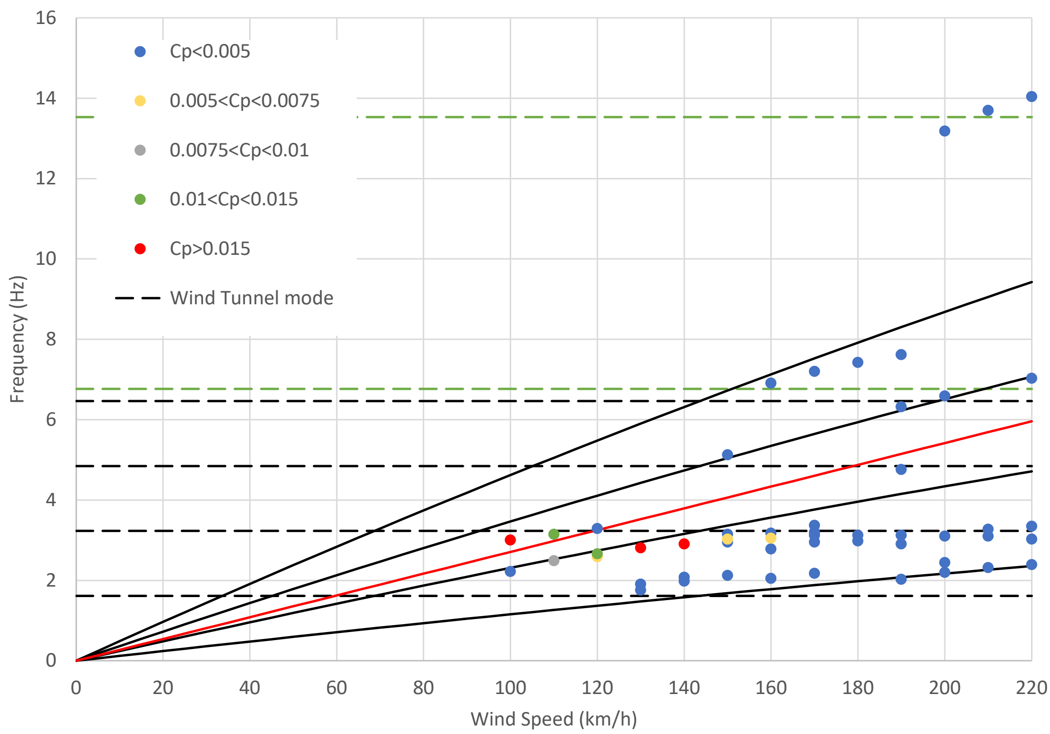

Figure 5: Pressure Pulsation Frequencies in the CWT prior to modifications

Again, the size and location of the resonator were limited by the existing design, predominately the infrastructure around the wind tunnel. In total, 2 suitable locations were tested, with various configurations at each location (volume, neck size and opening). In the end, a large Helmholtz resonator was positioned at cross-leg 1, close to the 2nd corner.

5 Summary of Commissioning Measurements

The results of the Enhancement Project can be summarised as: an improvement to the axial static pressure gradient and low frequency fluctuations, an improvement to the overall flow quality, new aerodynamic test capabilities with the new rolling road and force balance arrangement and an improved acoustic performance.

The axial static pressure gradient was measured at various wind speeds and conditions – in general, the centreline gradient is less than $dCp/dx = 0.0025\ m^{-1}$ within the vicinity of the test vehicle. The static pressure fluctuations are summarised in Figure 6 for various configurations, including before and after modifications. Of note, there is good agreement between model and full-scale, and the post modification maximum Cp_{rms} (0 to 20 Hz) is less than 1% over the entire wind speed range.

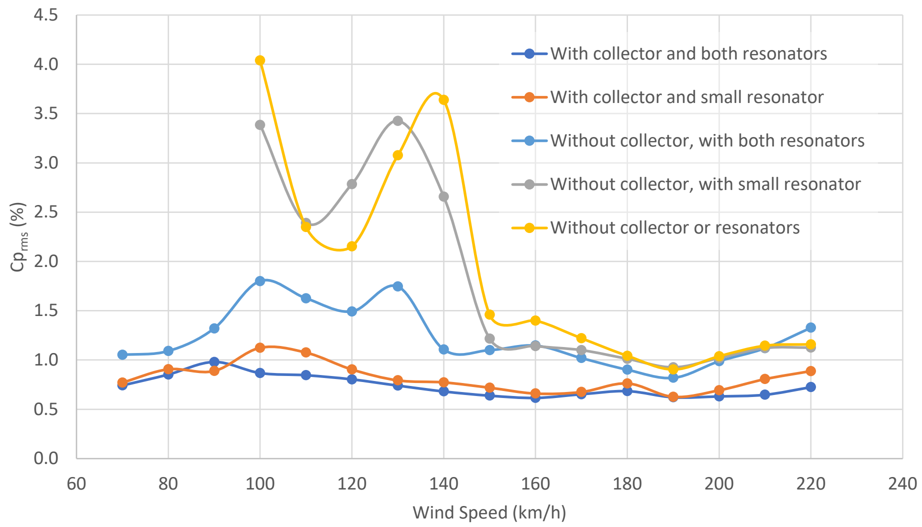

Figure 6: Measured overall static pressure fluctuations (0 to 20 Hz)

The flow quality (uniformity) was measured pre and post modification. The results are summarised in Table 1. The reported data was from measurements made 1.5 m downstream of the nozzle exit plane and over a width of +/- 1.35 m from the centreline to a height of 2.12 m. The result of adding in the honeycomb was a significant improvement in each of the flow uniformity parameters.

Table 1: Flow Uniformity results (post and pre modification)

Parameter	After Upgrade	Before Upgrade
Average Pitch Angle	0.34°	0.71°
Standard deviation of Pitch Angle	0.22°	0.72°
Average Yaw Angle	0.00°	0.13°
Standard deviation of Pitch Angle	0.23°	0.59°
Standard deviation of Velocity	0.35%	0.50%
Mean Turbulence level	0.15%	0.25%

The boundary layer systems were calibrated with the new rolling road module and the resulting profiles are within 1% of free-stream down to approximately 1 mm above the moving belt. The resulting profiles for various speeds are shown in Figure 7.

Figure 8 shows the acoustic performance of the CAWT for various conditions, include the pre-modification measurement. The measurements were made out-of-flow, beside the turntable on the control room side. The results show that in general the noise level within the test section was reduced by approximately 5 dB throughout the wind speed range. The results also show that the boundary layer systems have an impact on the noise level at lower speeds, but the collector does not. It also showed a very slight reduction when acoustic shutters are installed over the test section windows.

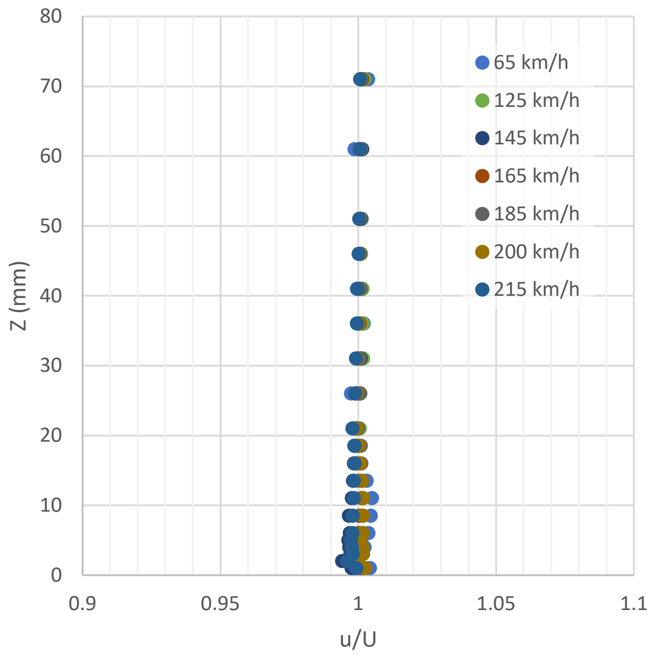

Figure 7: Boundary layer profiles above the rolling road

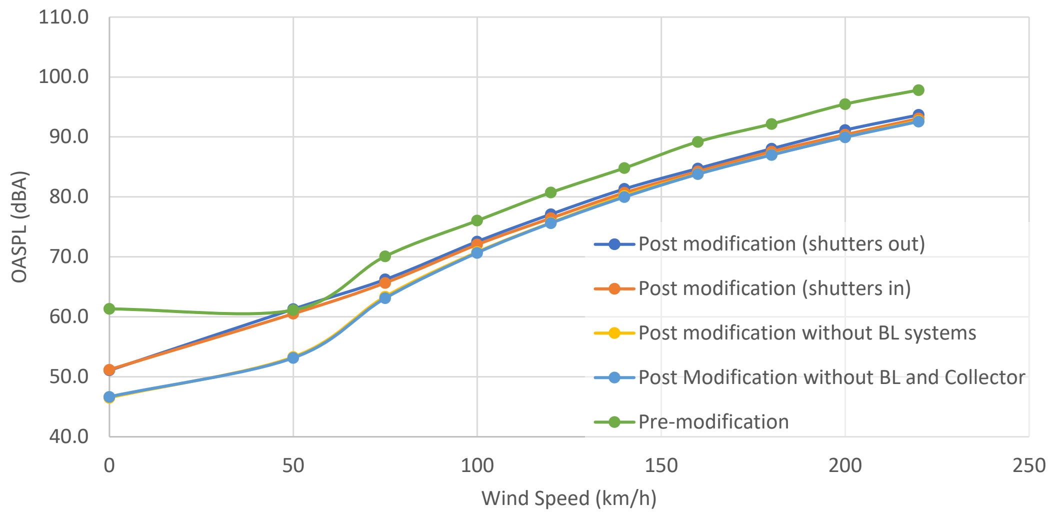

Figure 8: Acoustic performance measured out-of-flow

6 Conclusions

The ACE Enhancement project was a success: the addition of the new full belt rolling road expands the unique test capabilities of the ACE CAWT and the overall flow simulation was improved, for both aerodynamic and climatic testing.

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