

# Full-scale Wind Tunnel Equipped with Single-belt Rolling Road System

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## ABSTRACT

Honda has begun operating a full-scale wind tunnel with a single-belt system. In order to simulate flow around a vehicle in actual motion, the wind tunnel is equipped with (1) a large-scale single-belt rolling road system, (2) a test section that can convert between open jet and adaptive wall systems, and (3) a model motion system that controls the attitude of a scale model. This paper gives an overview of the wind tunnel facility and gives an example of wind tunnel testing with and without an actual vehicle in place.

## 1. Introduction

With the growing demand for fuel economy felt in recent years, the role of aerodynamics has also increased. The demand for high-speed stability for the purpose of enhancing product market appeal and safety has grown as well, and the necessity for full-scale wind tunnels equipped with a rolling road system (RRS) has increased accordingly. Honda therefore formed plans for new construction of a full-scale wind tunnel with RRS, and began trial operation of the facility in April 2009.

The main features of this wind tunnel are the adoption of a single-belt RRS<sup>(1)-(3)</sup> and an adaptive wall system (AWS)<sup>(4), (5)</sup>. A single-belt RRS can recreate the flow under the floor of a vehicle in actual motion, thus enabling measurement of drag and lift that are closer to a vehicle in actual motion than in a conventional wind tunnel with a fixed ground plate. Wall interference is caused by the phenomenon of acceleration (blockage) in the flow around the vehicle that is due to the ratio between the area of the test section and the area of the vehicle. The AWS can minimize this wall interference to the equivalent of an open jet, and this enables testing at 288 kph<sup>(6)</sup>.

The present article presents an overview of this wind tunnel and an example of the testing performed.

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## 2. Overview of the Wind Tunnel

### 2.1. Wind Path Design

Figure 1 shows an outline drawing of the wind tunnel. The wind path is constructed of steel-reinforced concrete and allows conversion between an open jet test section that has a nozzle size of 24.1 m<sup>2</sup> (maximum wind speed of 200 kph) for aerodynamic and acoustic testing of actual vehicles and an AWS that has a nozzle

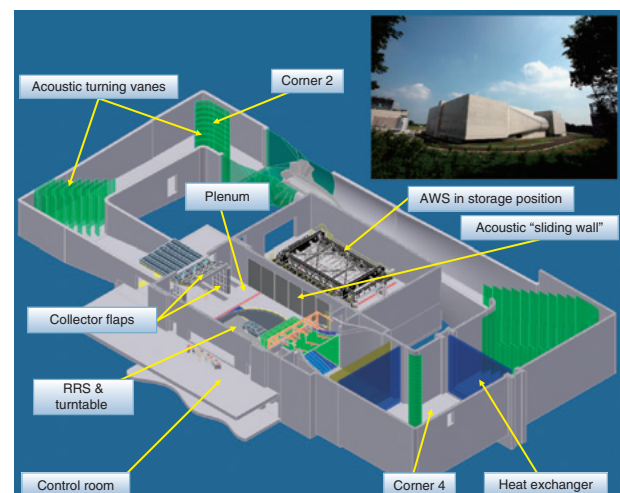


Fig. 1 Wind tunnel layout

size of  $17.1 \text{ m}^2$  (maximum wind speed of 288 kph) for aerodynamic testing of actual vehicles and scale models. This test section conversion is performed by placing the AWS assembly inside an open jet plenum and closing the movable plenum wall.

## 2.2. Open Jet Test Section and Plenum

Figure 2 shows a photograph of an actual vehicle emplaced in the open jet test section. The open jet test section is 14.5 m long. Collector flaps consisting of three flaps (a top flap and two side flaps) are installed at the end of the test section.

The primary boundary layer control system (PBLRS) is located 2 m upstream of the open jet nozzle outlet (1 m downstream of the AWS nozzle). It has a scoop height of 60 mm.

Acoustic tests with an open jet configuration are conducted by covering the scoop with a fairing with the PBLRS either in operation or stopped.

Distinctive features of the test section are the RRS manufactured by MTS Systems Corporation of the United States and the scales of various types installed in the RRS. Details will be provided below.

The test section is enclosed by a plenum that is 24 m long, 16 m wide, and 12.4 m high. The plenum walls are enclosed in acoustic material manufactured by the German firm FAIST GmbH. The wall opposite to the control room is movable and consists of a wall of acoustic material panels suspended from above. These panels are opened and closed when the AWS is moved between storage and the plenum.

## 2.3. AWS Test Section

Figure 3 shows a photograph of an actual vehicle emplaced in the AWS test section. The AWS provides for a maximum movement of 200 mm in the side walls and ceiling wall so as to reproduce in the wall geometry the flow lines around the vehicle when it is in motion. This is a device that can minimize the influence of blockage between the emplaced vehicle and the walls. The AWS test section is 17.5 m long and the cross-section area of the

inlet is  $17.1 \text{ m}^2$ . The initial position of the walls provides an enlarged shape, in consideration of the developed portion of the boundary layer, so that the cross-section area of the test section outlet is  $17.7 \text{ m}^2$ . The AWS is made up of the steel support pillars on the outside of the test section and clear acrylic panels in the side and ceiling walls. The side walls have 30 acrylic panels (15 on each side) that are 3 m high, 1 m wide, and 25.4 mm thick. The ceiling wall is made up of 15 acrylic panels that are 1 m long, 3.5 m wide, and 25.4 mm thick. In order to make the walls movable, the support pillars are mounted with 30 electromechanical actuators for the side walls and 30 for the ceiling.

Figure 4 shows an example of the effect of the AWS. The flat wall in the figure indicates the initial configuration of the AWS for comparison with the static pressure distribution along the central line of the vehicle when an actual vehicle is emplaced in the open jet and AWS. It is apparent that the static pressure distribution after operation of the AWS coincides with the distribution of the open jet. The static pressure distribution in the initial configuration before operation of the AWS is lower than the results after AWS operation and the open jet because the influence of blockage causes acceleration of the flow around the vehicle.



Fig. 3 AWS test section view from upstream



Fig. 2 Open jet test section view from upstream with collector in background

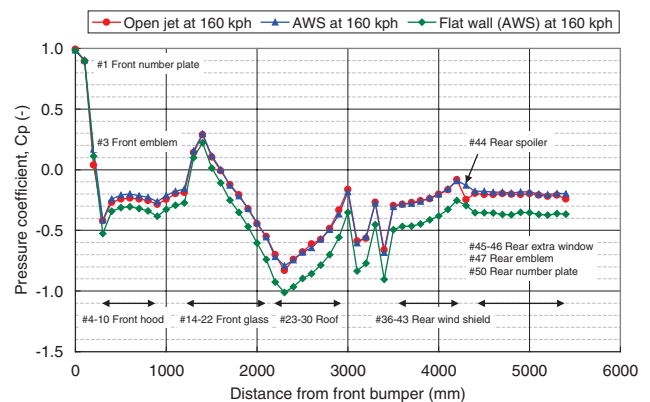


Fig. 4 Static pressure distributions along vehicle surface

## 2.4. Fan

The fan shown in Fig. 5 is manufactured by the United States firm FläktWoods. It is driven by a motor that provides maximum power of 3.6 MW (manufactured by TMEIC), and it generates a maximum flow volume of 1400 m<sup>3</sup>/s. The fan is 8 m in diameter and is made up of 24 rotor vanes made of carbon fiber-reinforced plastic and 35 stator vanes made of steel.

## 2.5. Heat Exchanger

The heat exchanger is located 9.8 m downstream from the outlet surface at corner 3. This heat exchanger consists of a combination of two rows of circular pipe and a horizontal fin. A mixture of 30% glycol in water is used as a cooling solvent.

## 2.6. Boundary Layer Control System and Single-belt Rolling Road

The boundary layer control system in the test section is made up of the scoop-shaped PBLRS described above and the secondary boundary layer control system (SBLRS), which uses a suction and tangential blowing system. The SBLRS has slots in the upstream roller portion of the RRS, and its width is the same as that of the belt at 3.2 m. The PBLRS uses a high-speed diffuser (HSD) for reinjection, and the SBLRS operates by tangential blowing from the upstream end of the belt immediately after suction.

Figure 6 shows the single-belt RRS. The present wind tunnel has a single belt that has horizontal force



Fig. 5 Main fan with 9 inlet guide vanes, 24 rotor blades and 35 stators

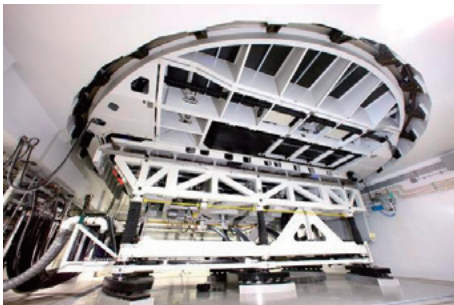


Fig. 6 Rolling Road System and turntable

measurement (HFM) mounted. This HFM is a system that is installed on structural members of the RRS; that conducts highly accurate measurement of the horizontal aerodynamic force exerted on the RRS, which floats using oil bearings; and that does so without measuring the resistance internal to the vehicle.

The stainless steel belt of the RRS is 3.2 m wide, 9 m long (the distance between rollers), and 1 mm thick. It operates at a maximum speed of 300 kph, and is operated so that the belt speed is synchronized with the wind speed in the wind tunnel. The RRS is synchronized with the turntable, which is 12.3 m in diameter, so as to enable testing with  $\pm 10^\circ$  yaw angles in order to simulate crosswinds.

The lift and downforce exerted on the vehicle can be measured independently in the four wheels by load cells installed under the stainless steel belt. There are load cells for use with actual vehicles and load cells for use with scale models. The load cells are placed in an eccentric system so that they can handle vehicles with different wheelbase and treads.

The following is one example of testing that involves the boundary layer control system and RRS.

Figure 7 shows a comparison of results from the main manufacturers for static pressure distribution in the X-axis direction along the central axis of the wind path. The graph was created on the basis of reference sources<sup>(2), (7), (8)</sup>. In the present wind tunnel, the static pressure gradient is held at even levels at the vehicle emplacement location.

Figure 8 shows a comparison of boundary layer distribution at the center of the belt for different boundary layer control conditions. It is apparent that the use of three stages of boundary layer control (PBLRS, SBLRS, and RRS) yields an even distribution.

Figures 9 and 10 show the total pressure distribution

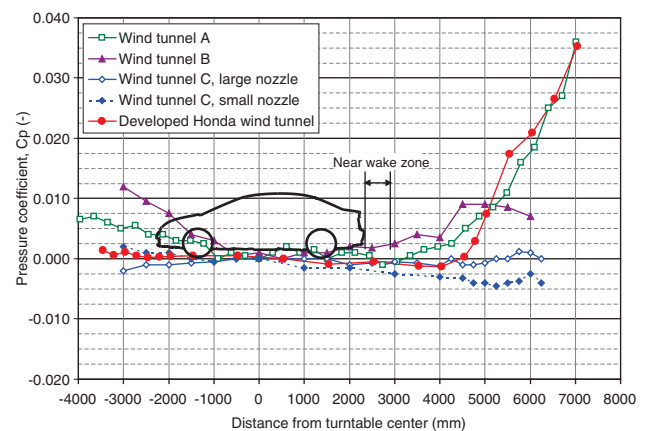


Fig. 7 Axial static pressure distributions along centerline of empty test section in selected wind tunnels (Outline of 4.5 m long test vehicle centered at  $x = 0$  is shown on open jet mode)

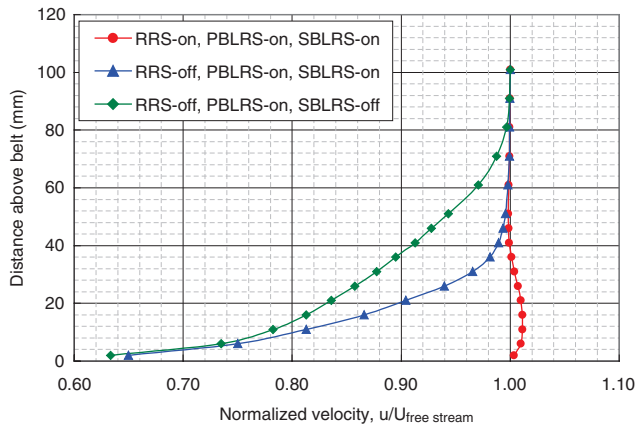


Fig. 8 Boundary layer velocity profiles at  $x = -2000$  mm at 200 kph for three boundary layer control conditions on open jet mode

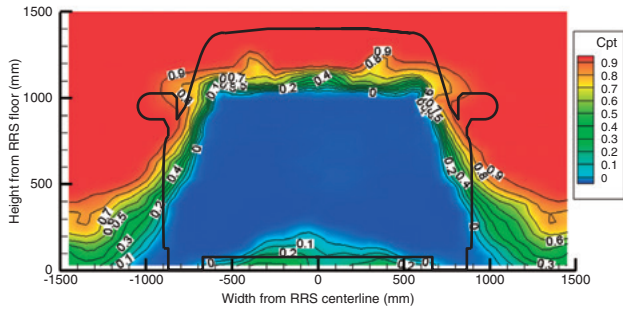


Fig. 9 Total pressure coefficients in cross-section at 10 mm behind vehicle with RRS-off at 100 kph on open jet mode

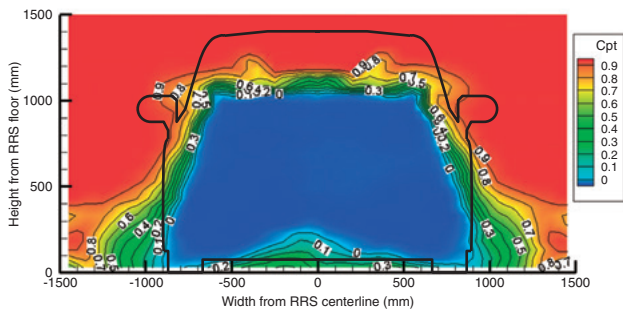


Fig. 10 Total pressure coefficients in cross-section at 10 mm behind vehicle with RRS-on at 100 kph on open jet mode

measurement results at the rear of an actual vehicle when the RRS is off and when it is on. It is apparent that the wake spreading out from the tires varies according to whether the RRS is operating or not.

### 2.7. Model Motion System

The model motion system called the hexapod, which is equipped with six electromechanical actuators, was also manufactured by MTS Systems Corporation of the United States. This system can operate scale models through

Table 1 Wind tunnel aerodynamic performance summary

| Test parameter                            |             | Open jet results                     | AWS results                          |
|-------------------------------------------|-------------|--------------------------------------|--------------------------------------|
| Total pressure uniformity                 |             | $\Delta Pt/q = 0.08\%$ ( $1\sigma$ ) | $\Delta Pt/q = 0.10\%$ ( $1\sigma$ ) |
| Static pressure uniformity                |             | $\Delta Ps/q = 0.33\%$ ( $1\sigma$ ) | $\Delta Ps/q = 0.19\%$ ( $1\sigma$ ) |
| Longitudinal turbulence intensity, $u'/U$ |             | 0.20% (at 200 kph)                   | 0.199% (at 288 kph)                  |
| Flow angularity                           |             | $\Delta\alpha = 0.09^\circ$          | $\Delta\alpha = 0.10^\circ$          |
|                                           |             | $\Delta\beta = 0.09^\circ$           | $\Delta\beta = 0.10^\circ$           |
| Boundary layer profile                    | $z = 2$ mm  | $ u-U /U = 0.82\%$                   | $ u-U /U = 0.15\%$                   |
|                                           | $z = 50$ mm | $ u-U /U = -0.42\%$                  | $ u-U /U = 0.18\%$                   |
| Sound pressure level                      | 100 kph     | 56.2 dBA                             |                                      |
|                                           | 180 kph     | 71.8 dBA                             |                                      |

movement in multiple degrees of freedom, including pitch, roll, and heave. The yaw motion system is placed inside the struts and its operation is synchronized with the turntable movement.

### 2.8. Airflow Measurement Results

The airflow measurement results are summarized in Table 1. The open jet and the AWS both show figures that are on a par with or that exceed performance at satisfactory levels for actual use.

## 3. Conclusion

The distinctive features of this wind tunnel were introduced and an example was given of aerodynamic testing with and without a vehicle.

As a device capable of simulating flow around a vehicle that is in actual motion, this wind tunnel can be considered a test device that is effective in reducing vehicle air resistance and enhancing driving stability.

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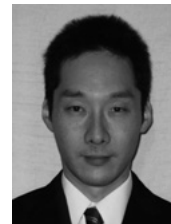
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