

The Honda R&D Americas Scale Model Wind Tunnel

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ABSTRACT

This paper describes the new Honda R&D Americas Scale Model Wind Tunnel (SWT). To help address Honda's ongoing need to improve fuel economy, reduce the driving force of a vehicle, and decrease product development time, the wind tunnel was developed and implemented to achieve high accuracy aerodynamic predictions for product development and a significantly improved capability for vehicle aerodynamics research. The SWT can accommodate model scales up to 50%. The $\frac{3}{4}$ -open jet test section has a top speed of 250 km/h, a 5-belt moving ground plane with a long center belt for proper wake simulation, a test section designed specifically for very low static pressure gradient, three separate dynamic pressure measurement systems for state-of-the-art blockage corrections, and an overhead traverse for specialized measurement activities. This paper describes the decision process that led to the SWT, key commissioning results, and performance validation results with models installed. In addition, the paper describes a concurrent program within Honda to design and build scaled vehicle models that have spinning wheels, realistic engine cooling and underbody flows, and excellent geometric accuracy.

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INTRODUCTION

Honda has long been at the leading edge in developing low emission engines that bring good fuel economy to customers. Vehicle development programs are routinely under regulatory or competitive pressure to achieve difficult design targets for fuel economy, while engineers and designers must also balance styling, cabin room, adequate engine cooling flow, wind noise, safe handling characteristics, and so on. Recent changes in U.S. fuel economy regulations have also accelerated the need for innovative solutions.

To address the growing need to improve vehicle aerodynamic performance, Honda initially considered increasing the use of Honda-owned wind tunnel facilities or of contracted facilities in North America. However, as product development responsibilities of the North American engineering (and aerodynamics) staff continue to grow, these options would have posed logistical challenges. A wind tunnel at the North American R&D Center was envisioned to

complement Honda's existing global strategy. Some of the goals for this facility were to (1) streamline the development process and increase development efficiency by allowing exterior designers, design engineers and aerodynamic engineers to work together at a central location, (2) impact the product as early as possible in the development process, and (3) increase aerodynamic research capability. To meet these goals it was decided to build a scale model wind tunnel and develop a large-scale model with sufficient detailed geometry to increase prediction accuracy for total vehicle aerodynamics early in development. State-of-the-art aerodynamic simulation and moving ground simulation were also considered necessary components to ensure that the scale model performance predictions early in the development process would compare well with full-scale wind tunnel and on-road measurements of the prototypes that are eventually built.

The new Scale Model Wind Tunnel (SWT) is located at Honda R&D Americas, Inc. (HRA-O), in Raymond, Ohio, which has been in operation since 1984 and is near several of

Honda's original U.S. manufacturing plants in that part of the state. HRA-O works closely with the styling studios at the American Honda Headquarters in Torrance, California as well as with Honda Automotive R&D Center, in Tochigi Prefecture, Japan, to develop products for various markets around the world.

Approval to proceed with the SWT project was given in June 2008. Jacobs Technology was responsible for the aerodynamic design and construction of the wind tunnel and Horiba Europe GmbH was responsible for the design and construction of the balance and rolling road system. The first production test was completed in August 2010. This paper gives an overview of the SWT design, commissioning, and calibration, and describes the techniques used to develop scale models tested in the wind tunnel.

SWT DESIGN FEATURES

The SWT is a 3/4 open-jet, closed return wind tunnel enclosed in a dedicated building that was added to the HRA-O campus. This section describes the salient features of the design.

AIRLINE

The SWT airline is shown in [Fig. 1](#). While airline details are always different, the overall philosophy employed in the design of the airline components is the same as in other efforts [1,2,3,4,5]. Fundamentally, the approach is to minimize the circuit footprint (capital cost) while taking extreme care not to create flow separations and other instabilities throughout the circuit, which can then be only partially cleaned up in the flow conditioning section at the cost of increased fan power and circuit length.

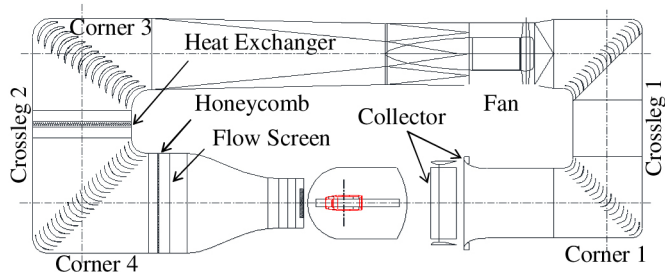


Figure 1. Plan view of the SWT airline

The top speed of the SWT is 250 km/h, driven by a 3.35 m diameter fan with 19 blades and a 670 kW variable frequency drive. Of particular note is that the wind tunnel does not have a plenum enclosing the test section. This was omitted to simplify model installation and integration of the traverse into the test section and to provide unhindered visual access. The control room is near the test section on the outfield side, but in a separate enclosed room. As shown in [Fig. 2](#), the test section is elevated about 1 m above the main floor of the enclosing building so that the model is at eye level from the perspective of a person sitting in the control room. Beyond the test section, the remaining floor area of the

building is recessed so that corners 3 and 4 rest on this recessed floor, while the fan and corners 1 and 2 are elevated on concrete piers.



Figure 2. View into the SWT test section from the control room

Corners 1, 2, and 4 consist of plate steel circular-arc turning vanes with leading and trailing edge extensions. Corner 3 is an expanding corner (the outlet area is about 40% greater than the inlet area), so double circular arc airfoil vanes are used to control the diffusion as the flow turns. The tube and fin heat exchanger is located downstream of Corner 3 in the second crossleg. Flow through the circuit is maintained at 20° C by regulating the temperature of secondary coolant through the heat exchanger tubes. The secondary fluid is chilled water that is supplied by the facility chiller plant, so the SWT does not require a standalone chiller system.

While keeping the crossleg length to a minimum, the diffusing third corner also provides a long settling length into the contraction, as the cross-sectional area does not change from the outlet of Corner 3 all the way through the settling chamber. Therefore, a properly-designed diffusing corner is in keeping with the philosophy of maintaining a clean circuit flow and minimizing the need for flow conditioning elements. The settling chamber consists of a honeycomb flow straightener and a single turbulence reduction screen. The contraction ratio to the start of the constant-area nozzle section is 5.4. The primary suction scoop of the boundary layer control system is inside the nozzle, so accounting for this, the net contraction ratio is 5.5 at the nozzle exit plane, whose cross-sectional area is 4.15 m².

TEST SECTION

[Figure 3](#) shows views of the test section looking upstream and downstream. The test section length is 6.7 m from the nozzle exit plane to the inlet plane of the collector airfoils. The model center of rotation is 2.1 m downstream of the nozzle exit plane. The collector design is similar to an existing system [3], which was developed with the aid of extensive scale model and computational simulations [6]. The suction side of the airfoil shape faces inward, working to reduce the pressure as the flow approaches it, even while it must finally increase as the collector area is larger than the

jet's potential core. The result is a significant improvement in axial static pressure gradient over the rear half of the usable test section. The distance of the airfoils from the inlet to the first diffuser is adjustable, as is the angle of attack.



Figure 3. SWT Test Section

Boundary Layer Control System

As shown in Fig. 4, the boundary layer control system consists of a primary suction scoop inside the nozzle and a secondary pair of tangential slots just upstream of the turn table. The first of these provides suction and the second provides blowing. The primary suction scoop removes the boundary layer build-up through the contraction and nozzle.



Figure 4. Primary suction scoop and secondary suction and blowing slots

Boundary layer suction is very effective at removing a boundary layer, but it also distorts the pressure field far above it, which degrades the axial static pressure gradient. The effect is normally worse with distributed porous suction compared to slot suction because the former represents a sink that disturbs the pressure field over a much larger region to achieve the same boundary layer performance. The present approach, combining a small amount of slot suction to remove the boundary layer build-up downstream of the primary slot, followed immediately by blowing, has been shown in recent designs [3,4] to provide a flat static pressure gradient over the front portion of the test section. A computational simulation was used to size the suction and blowing fans in the system, predict the boundary layer behavior downstream at the model location, and check the pressure field above the floor. As shown in Fig. 5, the static pressure field is undisturbed downstream of the blowing slot.

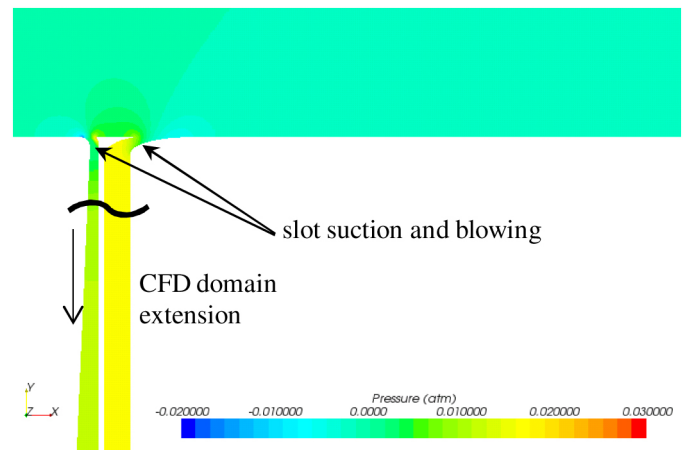


Figure 5. Static pressure field in the vicinity of the secondary suction and blowing slots

Balance and Moving Ground Plane

The 5-belt rolling road and 6-component external platform balance system was provided by Horiba Europe GmbH and integrated into a double-radius turn table capable of ± 15 deg yaw. The double-radius turn table (Fig. 6) allows the secondary boundary system equipment (fans, valves, ductwork, etc.) to remain stationary upstream of the turn table rather than being integrated into (and rotating with) a much larger conventional turn table [3,4,5]. Either approach is usually workable, but the double-radius turn table is a good solution for small test sections because space is at a premium and not all of the auxiliary equipment scales down with the size of the test section. The only drawback to this approach is that covering plates are necessary at each side (± 90 deg) of the turn table, which means a discontinuity in the floor elevation exists at these locations; however, as shown in Fig. 3, these are well outside of the flow.

Center belt widths of either 400 mm or 280 mm are available. Their overall length is 4.7 m, of which 3 m extends downstream of the center of rotation to ensure good wake

simulation for any model size. The belts are made of a polymer material that is durable, inexpensive, easy to maintain, and easy to replace. In operation, the center belt is held against the running surface by individual suction chambers that sense the differential pressure between the belt surface and the chamber and adjust the suction rate accordingly. The wheel spinner units are mounted on an X-Y adjustment table on the balance measuring platform. The track and wheelbase adjustment for the wheel spinners is accomplished remotely by a hand-held pendant. The adjustment ranges on these can accommodate models scales between 25% and 50%. The model attaches to the balance through four rocker panel restraints and the four wheel contact points.

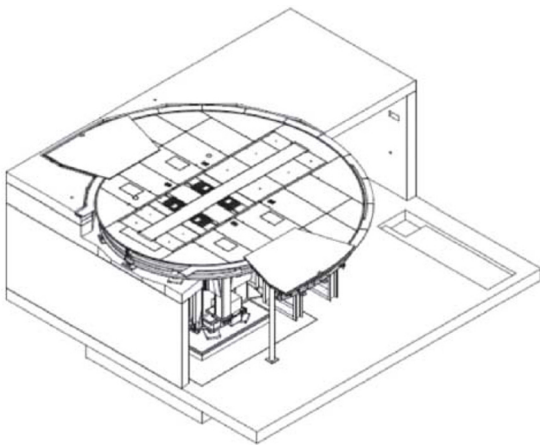


Figure 6. 5-belt moving ground plane system integrated into the double-radius turn table

The main measuring ranges are 900 N, -1100/+450 N, and ± 900 N-m for drag, lift, and pitching moment, respectively. The corresponding combined accuracy and repeatability requirements were ± 0.31 N, ± 0.41 N, and ± 0.32 N-m, respectively, which were shown after the on-site calibration to be met with considerable margin. Load cell data from the balance are acquired through high-accuracy digital voltmeters. The amplified load cell signals are sampled at a very high rate (2^{18} samples/s/channel) to avoid the temperature-dependent drift in analog filtering circuitry. The high-speed data are then decimated to the user-requested sampling rate after applying a digital low-pass filter with a cut-off frequency appropriate to the sampling rate. The user can also specify a moving-average window to apply to the data for further smoothing.

Overhead Traverse

An overhead gantry-style traverse provides coverage over 5 m in the axial direction and 1.3 m in the vertical direction. The traverse was provided by Raagaard ApS. Traverse systems are normally suspended from the ceiling of the enclosing plenum structure. In this case, however, a lattice construction was used (Fig. 7), with the traverse resting on four columns located in the four corners of the elevated test

section. The columns are visible in Fig. 3. In the absence of a plenum, this approach allowed a conventional and less expensive design for the building enclosing the SWT. Although used extensively during commissioning, the main purpose of the traverse is to provide for probe surveys (Fig. 8). The traverse has a natural frequency of 22 Hz with a positioning accuracy and repeatability of ± 0.3 mm and ± 0.02 mm, respectively, and deflection under maximum wind load of less than 0.2 mm.

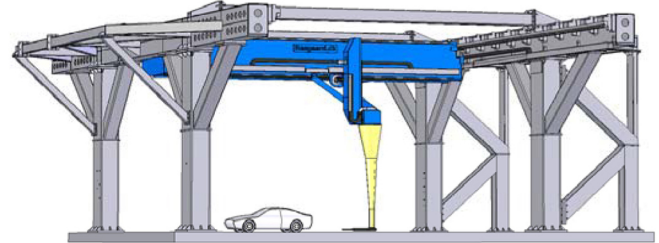


Figure 7. SWT Traverse System

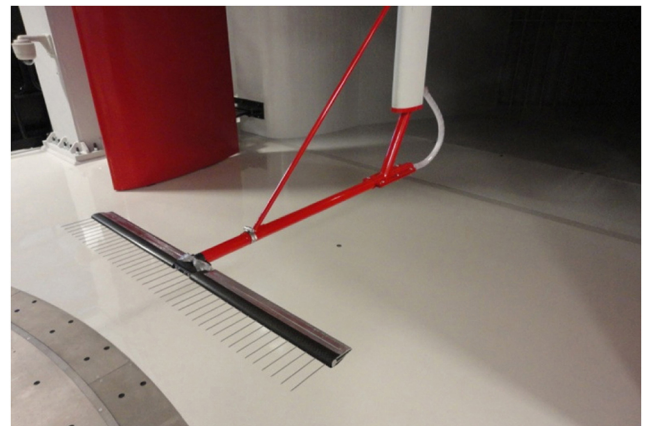


Figure 8. Total pressure survey rake

VEHICLE MODEL DEVELOPMENT CONCEPT

The ability to do aerodynamic work as early as possible in the development phase of new vehicles is very important. The SWT was commissioned as a key development tool allowing Honda to drive its design process towards aerodynamically sensible shapes and proportions from the earliest phases of a new car project. The SWT was built to accommodate models from 25% to 50% scale. A 40% scale was chosen to improve both geometric and Reynolds number accuracy relative to smaller scales. This scale is also a good compromise between cost, weight, and other logistics-related concerns (e.g., shipping, handling, etc.).

Because the models are intended for repeated use as development tools, they need to be accurate, durable, reliable, modular in construction, quickly updatable, easy to handle, and preferably low in cost. Honda's Design Studio Fabrication group based in Torrance, CA was tasked with the

designing and constructing the SWT models. An overview of the design process is provided in the following sections.

DESIGN

The Large Scale Model (LSM) is built on a rolling chassis architecture that includes a fully functional front and rear suspension assembly with spinning wheels, fully detailed engine room and underbody, and a highly accurate upper body. This section focuses on the main building blocks of the model: rolling chassis, suspension assembly, wheel unit construction, floor and underbody components, upper body, and engine bay.

Rolling Chassis

The rolling chassis is a frame-like structure made of aluminum square stock. This simple spine structure is modular; a parametric CAD model of the structure was created to be easily and quickly updatable from one project to the next. [Figure 9](#) shows an example of the rolling chassis. This aluminum structure receives and locates the front and rear sub frame components onto which the suspension linkage is secured, the floor piece representing the sheet metal underbody of the vehicle, as well as the upper body components.

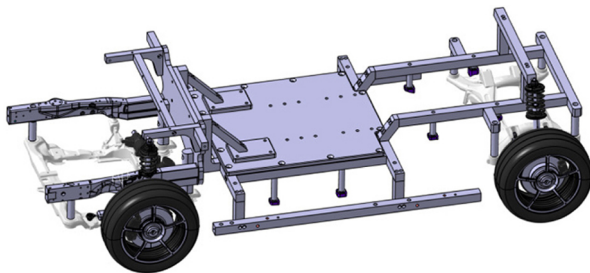


Figure 9. LSM Rolling chassis

The sub frame components of the spine hold most of the mounts for the suspension linkage. The front sub frame also receives the engine assembly. To fulfill these roles adequately, be easily manufactured, and to stay faithful to the full size mass production geometry of these components, rapid prototyping has proven to be the best process.

Suspension and Wheels

Wheel Construction

The wheel unit consists of a simple 5-spoke machined aluminum billet wheel bonded to a carbon fiber tire. The billet wheel is designed to receive rapid prototyped cosmetic covers to allow for testing of multiple wheel designs. To guarantee optimum wheel assembly balance both radially and axially, a specific machining and bonding process was carefully developed and tested. This process allows the final wheel unit diameter to be within established tolerances and prevent any transient “bouncing” during the moving belt speed ramp up. It also guarantees wheel stability at test speeds up to 250 km/h (around 5000 RPM).

Suspension Construction

The suspension geometry has to be modified from mass production to achieve 0 degree of toe and close to 0 degree camber gain for proper operation on the wind tunnel moving ground plane. Suspension components are built out of a combination of aluminum billet parts and various rapid-prototyped components depending on the mechanical properties desired for the part. All the linkage and components holding the wheel assembly to the chassis are made out of high grade aluminum to avoid catastrophic failure. They are either connected directly to the aluminum spine or to the rapid-prototyped sub frames.

The degrees of freedom of each pickup point are generally modified to achieve the desired kinematics without over-constraining the model. The model suspension parts use rod ends or spherical bearings to connect to the chassis, each allowing for 3 degrees of freedom in rotation.

Floor and Underbody

The floor of the vehicle is a CNC (computer numerical control) milled part that accurately represents the sheet metal surfaces of the full size vehicle underbody panels. The model underbody includes all the elements large enough to affect the airflow. These components include the exhaust system, fuel tank, heat shields, and miscellaneous covers. All the underbody components are bolted to the floor using threaded inserts. The floor's hardness is thus a factor. [Figure 10](#) shows the level of detail of the underbody of a LSM.

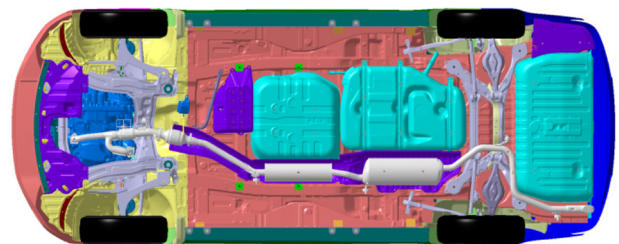


Figure 10. 40% model underbody

Upper Body

The upper body of the model is the element that sees the most changes during the development of the vehicle. As feasibility progresses towards a mass production solution, the outer shapes of the vehicle evolve greatly. The upper body is constructed in sections to facilitate updates to quickly reflect the latest design iteration. Areas of high aerodynamic sensitivity are built as independent pieces that can be swapped individually. In the early stages of the development, the high sensitivity areas are covered with a layer of clay to allow modelers to update the surfaces quickly and keep up with the styling changes. This also gives the aerodynamicists the option of trying different alternatives. As the design matures and the character lines and surfaces solidify, the clay parts are gradually replaced by hard parts.