

Aerodynamic Development of 2013 Model Year Accord and Accord Hybrid

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ABSTRACT

Improvement of the $C_D A$, which is an index of aerodynamic performance, is one factor in improving fuel economy. Honda has achieved a 1.3% enhancement in the $C_D A$ of the LX grade of the 2013 model Accord relative to the previous model, and an 8.3% enhancement in the $C_D A$ of the Accord Hybrid relative to the EX grade of the previous model Accord.

Based on an analysis of the phenomenon of the flow field around the car body, parameter studies were conducted using the previous model Accord before beginning aerodynamic development. Aerodynamic features contributing to the reduction of air resistance were applied to the package design before development was begun.

During aerodynamic development, aerodynamic performance of the exterior styling was enhanced through wind tunnel testing using 25%-scale detailed models, conducted jointly with the Styling Design Office.

The aerodynamic performance of the under-floor aerodynamic devices was optimized using CFD, a wind tunnel with rolling road, and other such tools in addition to the detailed model.

1. Introduction

Reducing a vehicle's running resistance can contribute to improvement of fuel economy and reduction of gas emissions. This is important in terms of having less negative impact on the global environment.

In the Accord, even though the reduction in running resistance in a single vehicle may be extremely small, with approximately two million vehicles sold in one model cycle, it plays a much greater role in reducing the impact on the global environment.

Running resistance includes air resistance, rolling resistance, grade resistance, and acceleration resistance. Since air resistance increases in proportion to the square of the speed, it accounts for approximately 75 to 80% of the running resistance of a 2013 model year Accord (the new Accord) at 100 km/h. There is, therefore, a need to reduce running resistance through aerodynamic performance, by paying attention to the details of geometry and reducing the $C_D A$, which is the product of the vehicle body's coefficient of drag (CD value) and the frontal projected area A (in m^2).

On the other hand, there are the areas and the volume taken up by passenger space, cargo space, collision safety performance, and other such factors of necessity in terms of the vehicle's product appeal. There is therefore a limit to how much the area A can be reduced in connection with making the vehicle more compact, since the styling of the exterior is

given priority in terms of product appeal^{(1),(2)}. There are also limited areas where aerodynamic features for lower C_D can be applied to the vehicle exterior that encloses those spaces.

It can be effective, therefore, to use Computational Fluid Dynamics (CFD) to analyze the flow field around the vehicle during full model changes and isolate the features of improved aerodynamic performance. Based on the results from this approach, Honda is carrying out repeated wind tunnel tests jointly with exterior styling sections and applying aerodynamic features in styling design.

This paper will introduce elements that have significant impact on aerodynamic performance according to the results from analysis of the flow field phenomenon in prior studies. The paper will also describe methods used to improve the aerodynamic performance of the new Accord.

2. Aerodynamic Development Goals

Figure 1 shows a $C_D A$ distribution graph that expresses aerodynamic performance in the three-box sedan category. These distribution values were all obtained from CD values measured in Honda's full-scale wind tunnel.

Prior studies were conducted to find a method to achieve improvement of the $C_D A$ by 7% over the previous model Accord, which is already at the top level of aerodynamic performance.

At the development stage, the styling concept of

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“exhilarating, advanced, and high quality” provided a basis for pursuing a balance between the horizontally oriented three-box proportions and aerodynamic performance. On that basis, achieving fuel consumption performance was set as the objective through developing a highly efficient aerodynamic package in terms of cost, weight, and various other such factors.

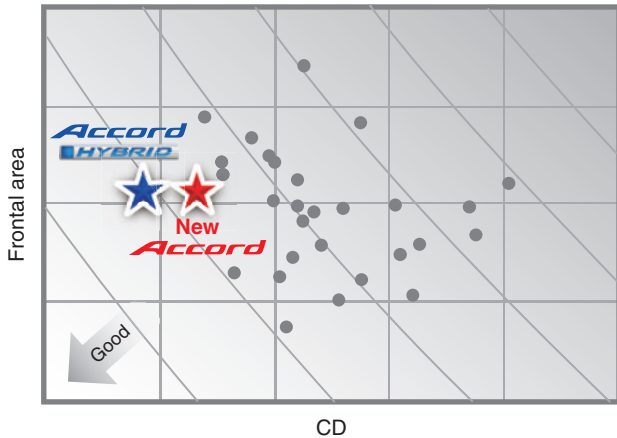


Fig. 1 CD-A distribution of 3box sedan category

3. Exterior Aerodynamic Analysis

Phenomenon analyses and parameter studies were conducted to explore directions for geometry that would achieve the aerodynamic objectives of the new Accord by using a 25% scale clay model of the previous model. Vehicle development proceeded on the basis of a package design together with the vehicle concept that determines the fundamental frame, including the total length, total width, and total height, as well as the placement of passengers, the volume of the cargo compartment, and other such factors. We therefore began with and analyzed those areas that have a significant impact on the aerodynamics, that cannot be readily changed after the package design has been decided, and that affect the overall form of the vehicle. The parameter study of 16 items included the area around the A pillar, narrowing of the sides (tapering in toward the rear), the trunk height, and mirror placement, for which a total of 500 or more variation measurements were carried out.

As a result, a proposal was made to the vehicle package designers before exterior styling development began regarding quantitative changes with regard to the area around the A pillar, the narrowing of the sides (tapering in from the cabin toward the rear), and the relationship between the roof and the trunk end that could achieve the aerodynamic objectives while balancing each of them with other functions.

3.1. Area Around A Pillar

At the A pillar, a vortex with its axis in the direction of flow (longitudinal vortex) ordinarily generates resistance when the flow wraps around from the front windshield to

the cabin side surfaces. That longitudinal vortex, like the vortex A shown in Fig. 2, continues as far as the wake of the vehicle, and it promotes the decrease in pressure at the trunk end. This causes an increase in the wrap-around flow from the side surfaces of the vehicle and an increase in longitudinal vortex drag caused by Vortex B. In order to improve aerodynamic performance, therefore, it is important to weaken the longitudinal vortex as much as possible that is generated at the A pillar.

Basically, the longitudinal vortex generated at the A pillar can be weakened by smoothing the flow from the front windshield to the side glass (Fig. 3). Methods that are effective for this purpose include increasing the angle between the front windshield and the side glass at the A pillar in order to reduce the amount of deflection from wrap-around flow, increasing the pillar width in order to reduce the curvature change of the wrap-around flow, and reducing the height of the drip molding in order to lessen the difference in level in the path of the flow.

However, these elements will affect various functionalities, such as visibility, drip treatment, wind noise,

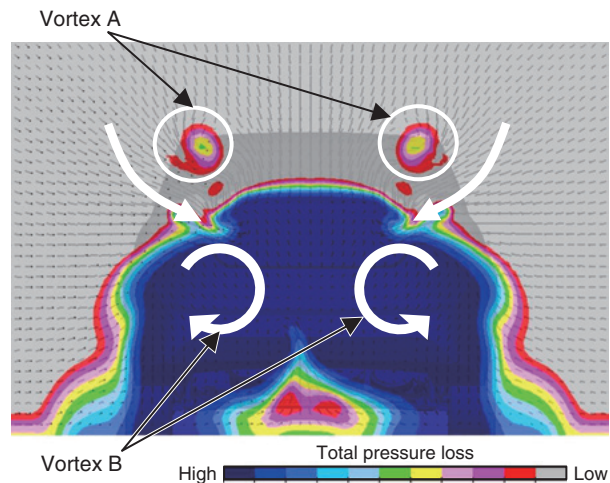


Fig. 2 A-pillar vortex on total pressure loss distribution

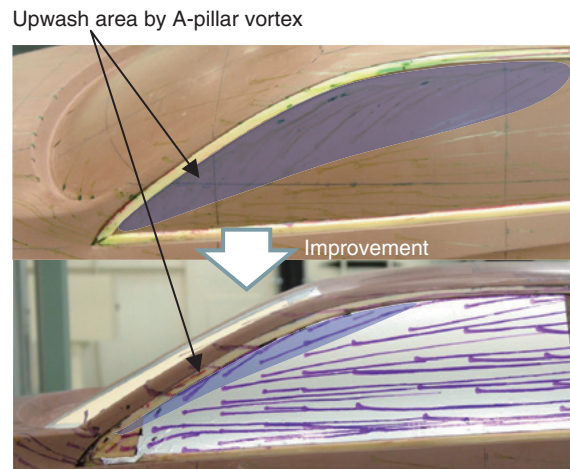


Fig. 3 Vortex improvement around A-pillar

and collision safety. At the stage of the prior studies, a 1.6% increase in aerodynamic performance was proposed by changes in geometry within a range that would effectuate those functionalities. These changes included increasing the angle between the front windshield and the side glass by moving the A pillar inward, and also virtually reducing the height of the drip molding by increasing the curvature of the leading edge of the A pillar molding.

3.2. Narrowing of the Side Panels (Tapering in from the Cabin Toward the Rear)

In order to keep the flow from separating from the vehicle until it reaches the tail of the vehicle, the rear side surfaces of the vehicle can be drawn inward and the total pressure loss that occurs behind the vehicle can be reduced. This can improve aerodynamic performance. This narrowing can also reduce the separation vortex that occurs at the C pillar as well as the longitudinal vortex drag that is generated when the flow from the upper surface of the trunk joins that from the side surfaces of the vehicle.

In the case of the side panels, however, statutory requirements limit exposure of the tires to 30 degrees on the front sides and 50 degrees on the rear sides, both measured from the tire center⁽³⁾, as shown in Fig. 4. Consequently, the wheel arches are the outermost side of the vehicle in almost all vehicle types, and narrowing toward the rear portion of the side panels is limited to the relatively short distance rearward of the wheel arches.

At the stage of the prior studies, the outermost sides were located in the vicinity of the front door, near the middle of the vehicle, and the side panels were narrowed smoothly toward the rear. A geometry with improved aerodynamic performance was also proposed drawing the rear 50-degree portion of the wheel arch inward by making the rear tread narrower.

With regard to the cabin, the B pillar was to be kept in the same position for interior space while the curvature of the side glass would be increased to make it continuous with the A pillar, which was to be moved inward, as described above. The C pillar was also to be moved inward to form a barrel shape, which is advantageous for aerodynamic performance. With these proposals, the geometry would yield a 1.9% increase in aerodynamic performance.

3.3. Relationship Between the Roof and the Trunk End

When the pressure drops caused by downwash to the rearward of the trunk that is deflected downward from the

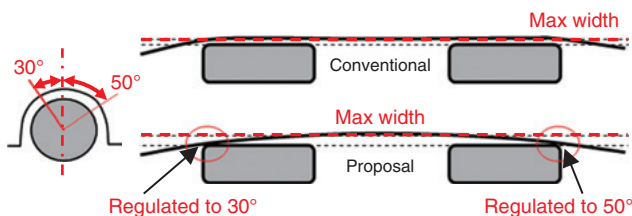


Fig. 4 Proposal of barrel shape to hide wheels

rear edge of the roof, the drag is increased by strengthened longitudinal vortex in the wake of the vehicle (Fig. 5). Effective methods for pressure recovery and suppressing the longitudinal vortex include extending the upper trunk surface toward the rear and raising it higher (Fig. 6). However, when the pressure on the upper surface of the trunk is extremely high relative to the side surfaces of the vehicle, reverse-phase vortices are generated at the trailing edges of the trunk sides. Since this can contribute to increased longitudinal vortex drag, there are threshold values for the magnitude of the geometry changes.

Meanwhile, the height of the trunk affects rear visibility, and extending the trunk to the rear affects the rear bumper stroke in the event of a collision. There are limits, therefore, to the amount of change. Since the height of the rear edge of the roof affects the angle of the flow toward the trunk, the height and location of the trailing edge of the trunk were optimized for reduction of drag by the height and shape of the rear edge of the roof.

With the trunk at a height that does not impact rear visibility, aerodynamic performance would be increased by extending the trailing edge of the trunk to the limit for the rear bumper stroke. This can be combined with optimization of the lowered height of the rear edge of the roof. With these proposals, the geometry would yield a 2.4% increase in aerodynamic performance.

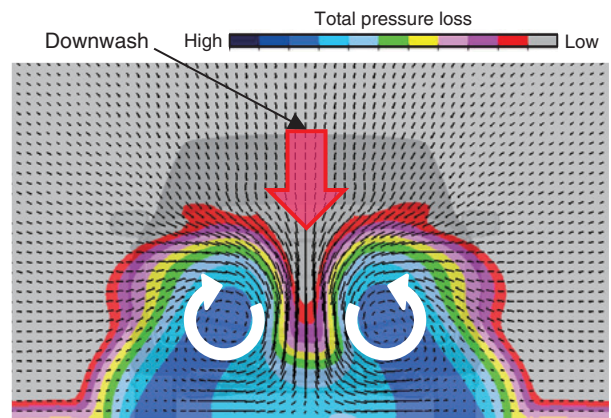


Fig. 5 Example of vortex caused by strong downwash at trunk end

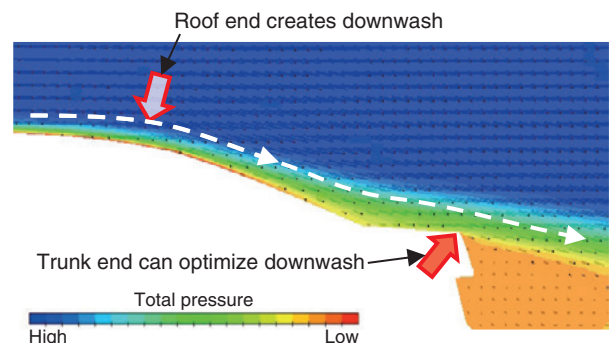


Fig. 6 Relationship between roof end and trunk end

4. Exterior Aerodynamic Design

During development that began with the fundamental frame proposed in prior studies, wind tunnel testing using 25% scale clay models was conducted jointly with the Styling Design Office to achieve a balance between styling and aerodynamic performance.

In Wind tunnel testing, a clay model applying the new Accord styling was used. A thorough, detailed review was conducted again on the basis of results obtained in prior studies, and the styling was enhanced while also increasing aerodynamic performance (Fig. 7).

Where the A pillar had been moved inward, that change was maintained while the pillar was moved forward to enhance the styling. The resulting slight reduction in visibility was recovered by making the A pillar thinner. Although making the A thinner pillar reduces aerodynamic performance slightly, and a thoroughgoing review of section curvature profile and a reduction in the drip molding level difference weakened the A pillar vortex (Fig. 8).

With regard to the cabin sides, the B pillar was moved outward to enhance passenger space in the cabin. When this was done, the curvature of the glass was also increased,

achieving a more barrel-shaped body without moving the A pillar outward.

With regard to narrowing toward the rear of the side panels, the area around the rear wheel arch was expanded outward without making the rear tread narrower to achieve a balance between styling and handling stability performance. However, in order to maintain the narrowing from the middle of the vehicle, the area around the rear edge of the front door was made the outermost point on the sides. A continuous narrowing from the cabin side surfaces was also extended to the trunk sides, making the vehicle more barrel-shaped than the previous model (Fig. 9).

The rear edge of the roof was configured to be even lower than on the previous model, with the trailing edge of the trunk at the same height as the previous model. Considering that the wheelbase has become 25 mm shorter, this has yielded the effect of extending the trailing edge position of the trunk rearward relative to the rear edge of the roof. Since the height of the trailing edge of the trunk is close to the limit in terms of visibility, the top surface of the trunk was given a ducktail shape to adjust the departure angle to optimize pressure recovery. The trailing edge of the trunk was also configured higher for the entire width, and this has been useful not only in reducing drag but also in enhancing rear lift (Fig. 10).

The above refinements yielded better flow from the cabin to the trunk and along the side panels. Figure 11 shows the results from visualization of these effects.

After the overall geometry and dimensions were decided, the wind tunnel model was shifted from clay models to a detailed model (Fig. 12) with an engine compartment. Further optimization was then explored.

The detailed model has an open front grille for cooling, and the exhaust from the engine compartment is simulated. This, when combined with the effect of the under-floor

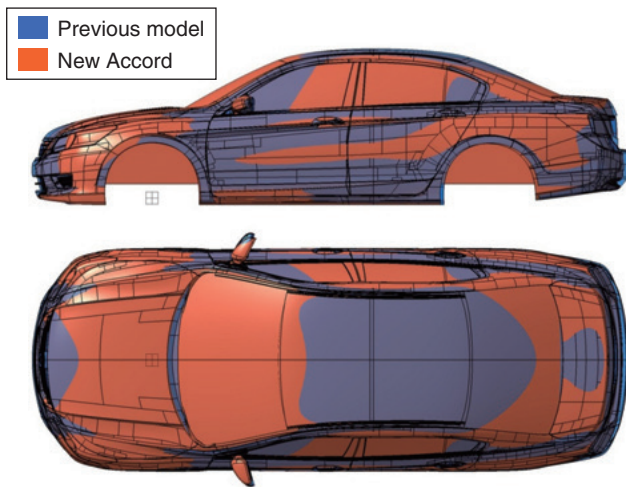


Fig. 7 Side and top view comparison between new Accord and previous model

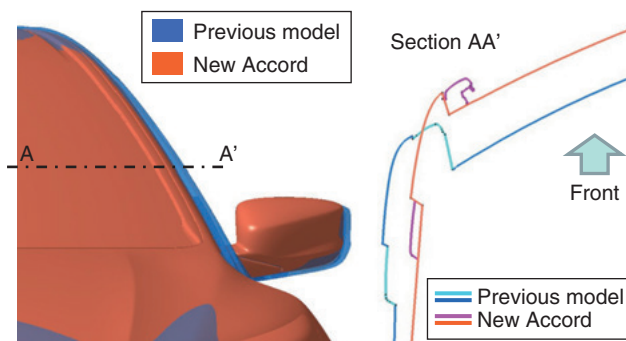


Fig. 8 A-pillar moved inboard

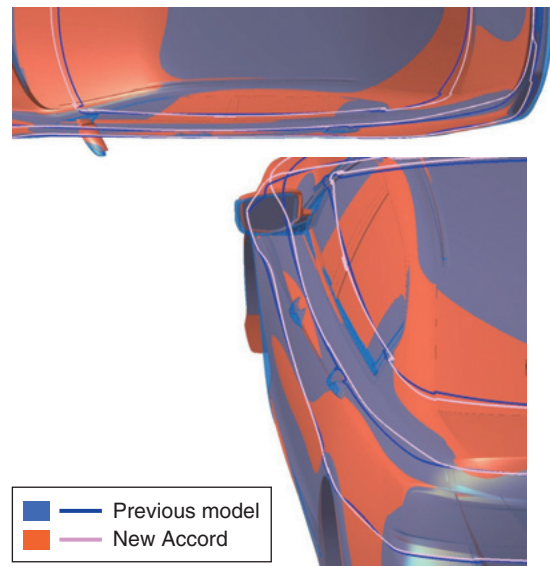


Fig. 9 Barrel-shaped cabin and body side panel

devices, enables aerodynamic optimization of the exterior. It was particularly useful that the shape of the lower edge of the front bumper, which has an important relationship with the chin spoiler, the trunk height, which is affected by the flow from under the floor, and other such areas could be optimized under circumstances closer to an actual vehicle.

With regard to the exterior, as well, the front bumper corner geometry was optimized so that flow would wrap around to the side panels without separation. With the

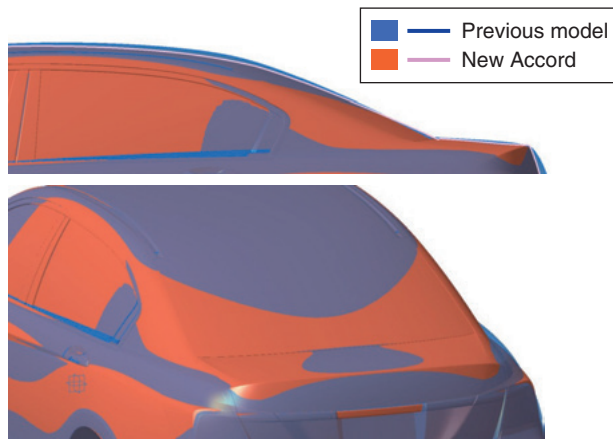


Fig. 10 Roof end and trunk height comparison

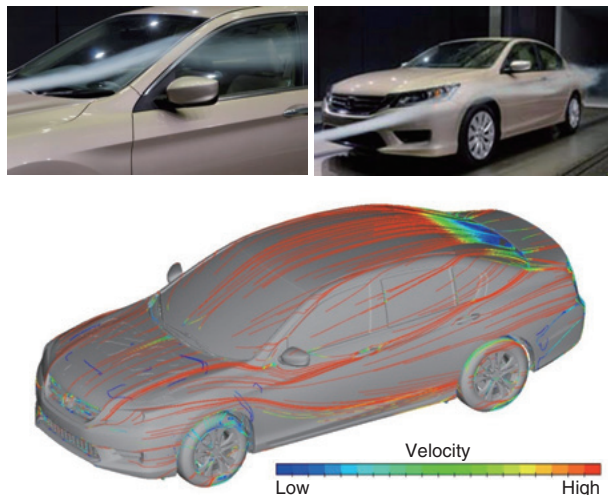


Fig. 11 Flow visualization of barrel-shaped body

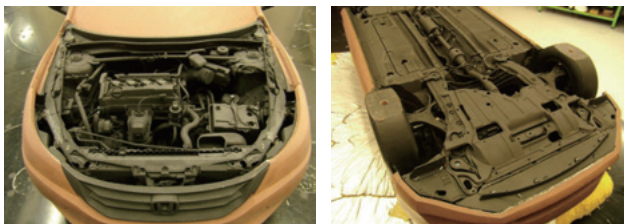


Fig. 12 25% scale model with engine room and under covers for wind tunnel test

vehicle rear made narrower as an extension of the barrel shape, the rear bumper corners were also optimized by such means as adding an edge shape that stabilizes the point of separation so that the flow would not be turned back onto the rear surface of the vehicle.

Optimization of the exterior aerodynamic design extended to fine details and involved measurements in wind tunnel made a total of more than 1,000 times.

5. Analysis of Under-Floor Devices

The reduction in drag by means of under-floor devices naturally involves smoothing the under-floor flow. It is also achieved, however, by reducing longitudinal vortex drag.

The flow that has passed through the under-floor could change the structure of longitudinal vortex by reducing downwash behind the vehicle.

In the prior studies, the task of confirming the CD level that could be achieved by current design methods began with installation of maximum size under-covers together with floor devices using CFD to examine the result.

The flow field could then be analyzed on the basis of those results. Attention was focused on areas that could contribute to enhancement of the under-floor flow, and the range and shape of an effective under cover were considered.

Given the results from analysis of the effect of each device, it was found that reducing the pressure in the area between the rear tires could reduce the total pressure loss region and reduce the longitudinal vortex drag behind the vehicle.

Lowering the pressure in the area between the rear tires improves the flow field inside the rear tires by means of the influence from inward deflection. As a result, total pressure loss area behind the rear tires is reduced (Fig. 13).

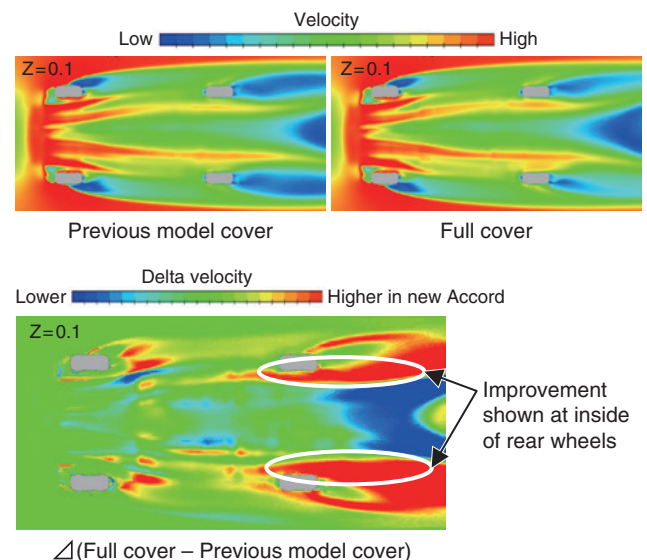


Fig. 13 Velocity distributions and delta velocity between full cover and previous model cover

There is a large vortex (Vortex A in Fig. 14) behind the vehicle caused by downwash at the middle of the vehicle. Reducing the total pressure loss region to the rear of the rear tires strengthens Vortex B, which is in the same phase with Vortex A and located behind the rear tires. This Vortex B weakens Vortex A in the area behind the rear bumper corners, and so causes the rear surface pressure on the vehicle to be recovered. Weakening the downwash from Vortex A also increases the angle of the upwash from the under-floor at the middle behind the vehicle. This reduces the longitudinal vortex behind the vehicle.

For the design policy of the under-floor devices, it was decided to achieve that flow field in the new Accord to lower the pressure in the area in front of the rear tires.

Increasing the velocity in the area between the rear tires was considered an effective means of lowering the pressure in that area. The tank located in the middle and to the front of the rear tires has basically a flat bottom surface. However, the tank cannot be located so that its bottom surface is at the minimum height above ground because of the difference in the above-ground height configuration of the bottom surface from covers made of resin.

A bridge is therefore added between the tank bands. This increased the clip bases so the under-cover could be extended. This measure produced a flat surface at the minimum height above ground between the rear tires. This can increase the velocity under the flat surface to achieve lower pressure (Fig. 15).

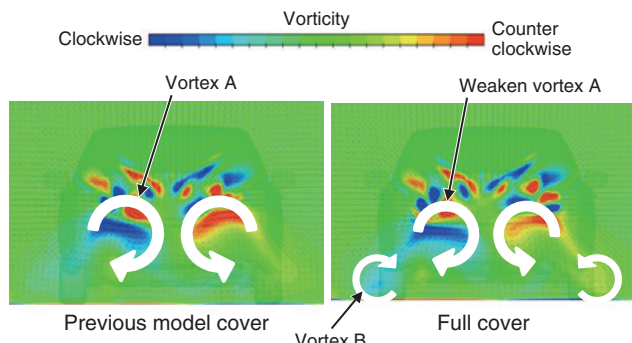


Fig. 14 Vorticity distributions between full cover and previous model cover

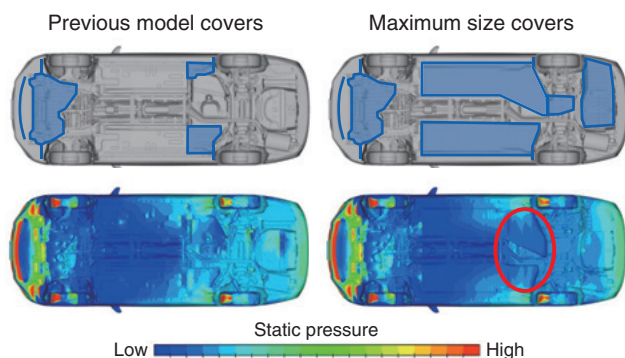


Fig. 15 Static pressure distributions

6. Design of Aerodynamic Devices

6.1. Under-Floor Devices

The geometry of the under-floor devices was optimized using the detailed model, with the prior studies conducted with CFD as a basis.

Upholding the design policy of reducing the pressure in the area in front of the rear tires, and taking a device studied using the largest area under current design methods as the basis, a geometry that takes attachment points and strength into account was applied. Making the cover size more efficient, optimizing the shape of the leading edges of the floor under-cover and rear under-cover, and other such tasks were carried out under conditions more closely resembling an actual vehicle by using a detailed model that simulates the engine compartment exhaust. The geometry based on those results was applied to the prototype vehicle, and the prototype vehicle was used in turn to make detailed improvement with regard to the enlargement of area and the synergistic effects from the cover.

In development of the new Accord, there were improvements in fuel economy performance due to enhancements of engine performance compared to the initial plan at the start of development. The judgment on whether or not to adopt under-floor devices was made taking cost and weight into consideration along with the fuel economy objective.

In the LX grade vehicle, the floor under-cover incorporating design policy was enlarged and it very efficiently improved the aerodynamic performance in comparison with the previous model. The improvement achieved in this way allowed the engine under-cover, which needed to be aluminum for its heat resistance, to be made smaller than in the previous model. This also allowed engine compartment cooling and heat resistance performance to be enhanced while avoiding the adoption of aluminum.

In order to achieve still greater fuel economy performance in the Accord Hybrid, the devices from prior studies were largely adopted. Aerodynamic performance was increased 2.5% (Fig. 16).

6.2. Ducting in Cooling Opening

Air needs to be drawn in through the front grille in order to cool the engine compartment. However, engine compartment airflow resistance (cooling drag) increases approximately in proportion to that flow rate.

In order to improve aerodynamic performance, therefore, it is important to reduce the flow volume taken in from the front grille to the necessary minimum. One effective means of reducing the necessary flow rate to the minimum is to direct the incoming flow where it will be used efficiently for cooling, without flowing to areas other than the radiator and other such places where cooling is needed. In the case of the new Accord, this involves installing air guide plates all around the radiator for ducting (Fig. 17). By optimizing the

ducting and the grille opening, cooling drag was reduced 13% relative to the previous model.

6.3. Front-edge Shape of Exhaust System

The exhaust system is exposed under the floor so that there is a vertical wall at the front edge of every enlarged portion. Aerodynamic features were applied to reduce the resulting drag by even the slightest amount (Fig. 18).

There is a protective barrier to prevent contact in front of the pre-chamber. This was therefore given a semispherical shape that flares out toward the rear.

Laser welding was used on the forward edge of the

muffler in order to eliminate the crimped portion. At the same time, the front surface was made to bulge out and the muffler was shaped so that the flow could be deflected smoothly under it. This increased aerodynamic performance 0.6%.

7. Development Using Wind Tunnel with Rolling Road

Toward the end of development of the new Accord, a new wind tunnel with a single-belt rolling road was put into operation⁽⁴⁾ with the capability to simulate flow under conditions closer to actual vehicle operation.

For the aluminum wheels to be used in the Accord Hybrid, development of aerodynamic wheels was carried out using the results of research being pursued during that same period. This took into consideration tire rotation on the rolling road, and the result was improved aerodynamic performance under vehicle operating conditions (Fig. 19).

The final stage of prototype testing in development of the new Accord was also tested in the wind tunnel with rolling road. The size and placement of the front strakes was optimized, and the effectiveness of each under-floor device was confirmed in the wind tunnel with rolling road. The selection of under-floor devices was made under operating conditions.

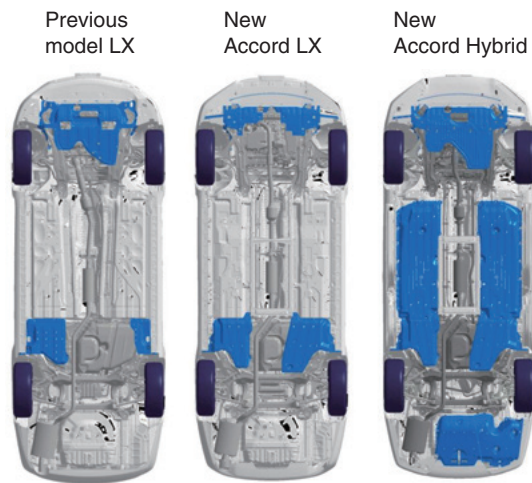


Fig. 16 Under cover variations

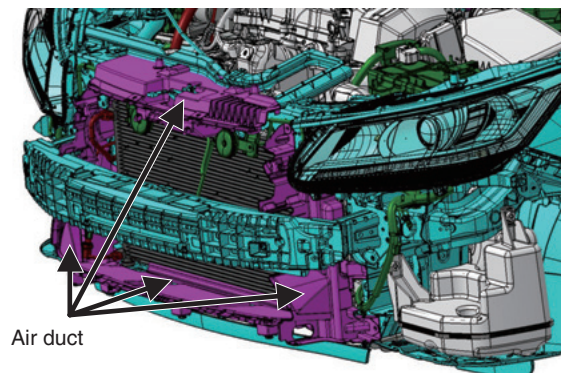


Fig. 17 Ducting around radiator

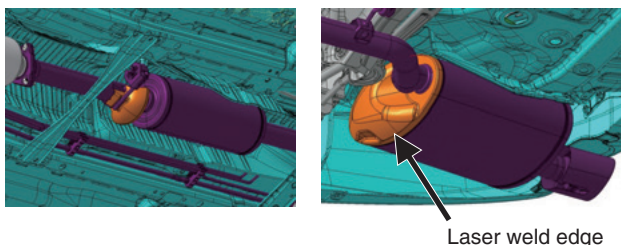


Fig. 18 Aerodynamically modified exhaust

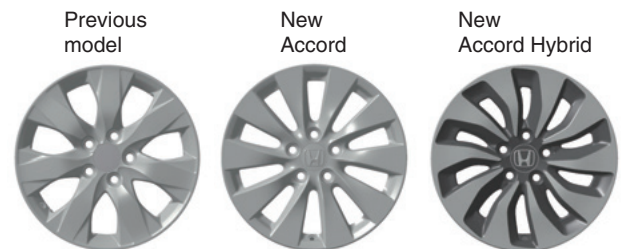


Fig. 19 17-inch wheel variations

8. Conclusion

Results from detailed prior studies were used to analyze airflow phenomena in the new Accord, and aerodynamic improvements were proposed accordingly. Incorporating those proposals at the package design stage of initial styling design enabled improvement of the aerodynamic performance of the exterior styling.

The under-floor flow design policy proposed in the prior studies were applied also to the under-floor devices. This yielded a balance between cost, weight, and fuel economy in the LX grade vehicle, which was taken as the base grade, so that a highly cost- and weight-efficient under-cover could be incorporated. In the Accord Hybrid, all the under-floor devices were adopted and aerodynamic performance was pursued.

In the LX grade vehicle, the increase in aerodynamic performance over the previous Accord did not exceed 1.3%. The decline in aerodynamic performance resulting from the change from steel to aluminum wheels and other measures to increase product appeal was absorbed by the improvement in the exterior. As a result, the vehicle achieved its goals for fuel economy of 24 mpg in city mode, 36 mpg in highway mode, and 30 mpg in combined mode according to U.S. Environmental Protection Agency standards.

The pursuit of aerodynamic performance in the Accord Hybrid led to an increase in aerodynamic performance of 8.3% over the EX grade of the previous model Accord, which had the same tire size. This contributed to achievement of 30 km/L fuel economy in JC08 mode.

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