

Aerodynamic Development of 2014 Model Year FIT

Kentaro MACHIDA*

Munetsugu KANEKO*

Terumasa KOTADA*

Atsushi MURAKAWA*

Atsushi OGAWA*

ABSTRACT

Aerodynamic development of the 2014 model year FIT achieved an approximately 7% reduction in aerodynamic drag compared to the 2008 model, giving it among the world's lowest drag coefficients in the hatchback category. Based on wind tunnel testing and simulation results, a vehicle body with high aerodynamic performance was realized. The Honda-created CFD system was used for the exterior design development, helping to optimize aerodynamic shape while supplementing scale-model testing. For the platform development, CFD analysis of the flow field established a direction for enhancing aerodynamic performance and helped optimize the shape in detail. From this process, it was confirmed that to inhibit total pressure loss in the vehicle wake, it is important to ensure uniform flow velocity and pressure distribution in the vehicle front (including the engine room) and rear end.

1. Introduction

Reducing aerodynamic drag of on-road vehicles and thereby improving fuel economy and reducing emissions is important to mitigate the effects that vehicles have on the environment. Therefore, reduction of drag ($CD \cdot A$), that is, the coefficient of drag (CD) multiplied by frontal projected area [$A(m^2)$], is an important objective of aerodynamic development. Development of hatchback vehicles, however, has continued to focus on other marketability (safety, interior comfort, cargo capacity, and so on), which severely limits how far the vehicle can be downsized. At the same time, changes in vehicle shape to reduce drag are also naturally limited because they need to be balanced against styling design concerns. Therefore reducing drag poses the challenge of efficiently extracting features of improved aerodynamic performance and deciding how to balance drag reduction with other functions, such as crash safety, field of vision, and interior comfort^{(1), (2)}. Under these limitations, it is effective to analyze the flow around the vehicle by CFD simulation to establish a drag reduction strategy. Achieving the drag reduction target while quantitatively confirming aerodynamic performance in collaboration with the exterior styling and parts design sections would also appear to be an efficient approach. In addition to conventional wind tunnel testing and full-vehicle CFD, development of the 2014 model year FIT (new FIT) took advantage of Flow Analysis Simulation Tool (FAST)⁽³⁾, the Honda-created CFD system, to strike a balance with styling design and other functions. This report discusses the characteristic flow

field of a hatchback as determined from the aerodynamic development process, and introduces the technique that reduced aerodynamic drag in the new FIT.

2. Goal and Targets of Development

Changes in the drag of B-segment hatchbacks, a category that includes the 2008 model year FIT (previous model), are shown in Fig. 1. The figure shows drag distribution of various models as the ratio relative to the previous model ($CD/CD_{\text{previous model}}$). All plots shown in this figure were the test results obtained in Honda's full-scale wind tunnel. The goal at the start of development of the new FIT was to provide customers with reduced aerodynamic drag for better fuel economy, and aerodynamic performance

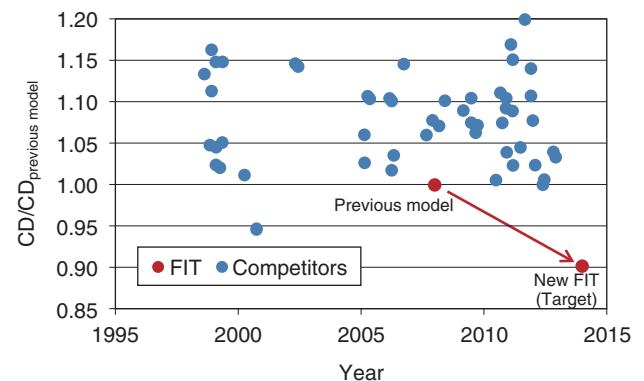


Fig. 1 CD history of B-segment hatchback

* Automobile R&D Center

that is among the best known in the segment. As preconditions, the vehicle had to retain the interior comfort (one of the FIT's strengths), and was therefore required to balance aerodynamic performance with the one-motion form and forward cabin form styling motifs.

Under these conditions, the new FIT took course to reduce drag without lowering A; that is, by decreasing CD alone.

Trade-offs between improvement of fuel economy with reduced drag and the other influencing factors were made, thus narrowing down the ideas to be addressed for improving aerodynamics. Aerodynamics items to be addressed in the new FIT, as listed at the start of development, are shown in Fig. 2. Here, items related to vehicle styling are classified as "Exterior design," and those related to the engine compartment including bumper and front grill, and underfloor are "Platform." The total drag target was set based on all of these aspects, and subsequently the development proceeded by evaluating the achievement of the targets simultaneously.



List of aerodynamic item		Target (compared to previous model)
Exterior design	Bumper, roof, pillar shape	-7.2%
	Adding A-pillar drip molding	
	Adding tailgate spoiler	
	Minimizing B-pillar gap	
	Optimizing side mirrors (shape and location)	
Platform	Optimizing shape of floor, engine undercover	-2.8%
	Adding rear engine undercover	
	Optimizing engine cooling airflow	
	Smoother underbody shape	

Fig. 2 List of aerodynamic items of new FIT

3. Aerodynamic Analysis of the New FIT

As Fig. 1 shows, the aerodynamic performance of the previous model was already among the best in the B-segment hatchback category. To further reduce drag in the new FIT, CFD analysis of aerodynamic phenomena started immediately after the development of the previous model was completed. Results were shared with styling design and engineering sections and a strategy was established for optimizing aerodynamics.

The following section introduces the aerodynamic characteristics of the new FIT in the styling design and platform development. Note the coordinate system used in this paper, wherein the X axis runs in the longitudinal direction of the vehicle, the Y axis in the transverse, and the Z axis out of the XY plane, as shown in Fig. 3.

3.1. Styling Design Development

The new FIT was the first model that took full advantage of the FAST system in the development. The FAST system performs aerodynamic simulation by automatically linking exterior surface design with predefined platform layout. This allowed engineers to run calculations efficiently, independent of their level of experience in CFD, whether they are aerodynamicists or stylists, and the results can be shared among them.

In the early phase of styling design development, a large number of styling proposals were analyzed and compared to the previous model. Figure 4 is an example of aerodynamics study results for various styling proposals. Here, analysis was done using models provided by the styling design section as well as models applying aerodynamic improvements. In this phase, the objective is not to narrow down the styling proposals but to extract features of aerodynamic improvement.

Among several features that were common in low-drag models as compared to the previous model, characteristics of the body parts that were especially sensitive to drag, specifically the front bumper, roof, and C-pillar side surface, were extracted from the analysis results. Figure 5 compares the surface pressure distribution of the previous model with that of the new FIT incorporating the aerodynamic features of each body part. To help prevent severe changes in pressure at the corner of the front bumper, the side surface length in the flow direction was increased, as was the radius of curvature [Fig. 5(a)]. In side view, the peak of the roof was moved forward as compared to the previous model so that pressure gradually increases toward the rear [Fig. 5(b)]. This coincided with the direction of styling that intended to give the form a sense of lively motion⁽⁴⁾.



Fig. 3 Definition of coordinates

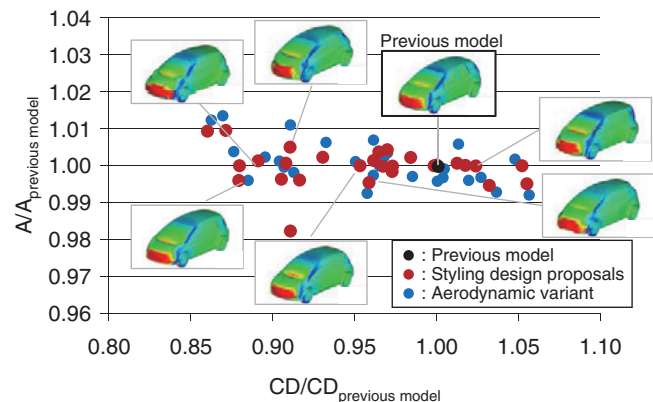


Fig. 4 Simulation results on styling development phase

In the previous model, the flow from the side tended to swirl around the C-pillar, behind the back of the vehicle, because of the shape of the pillar, hence the strong peak of negative pressure [Fig. 5(c)]. The new FIT therefore adapted the shape of the tail end so that it points outward in the down view, which weakened the negative pressure peak. For the front bumper, roof, and C-pillar, the objective was to reduce local pressure gradients, therefore causing the pressure at the tail end on all three surfaces to be equal. Simultaneously, the shapes of these parts were modified to rectify the air-flow magnitude in the X direction. As a result, the pressure on the back surface of the vehicle increased [Fig. 5(d)].

The stylists worked to balance aerodynamic performance and styling design with these features of aerodynamic improvement.

Figure 6 shows the pressure distribution along the X axis of the new FIT and previous model comparing surface pressure distribution quantitatively. The pressure distribution on the roof and rear gate along the section through the center of the vehicle is shown in Fig. 6(a). The new FIT shows less change in pressure distribution in the X direction and higher pressure on the roof. This is because moving the roof peak forward greatly increases the distance over which pressure can increase as the air flows to the rear. This increases pressure on the back of the vehicle as well. The pressure distribution on the section at mid-height of the C-pillar is shown in Fig. 6(b). Pressure on the forward side window is about the same as in the previous model, but at the C-pillar towards the rear, the negative pressure has a lower peak and smaller gradient. The results also show that

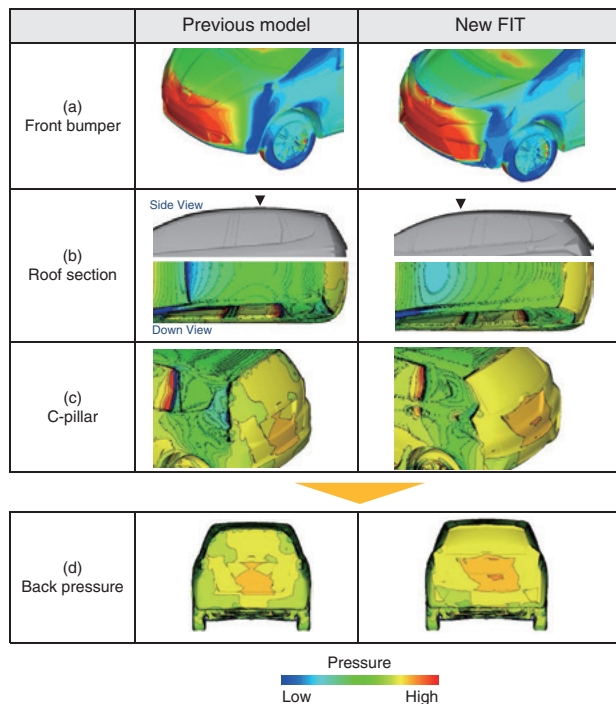


Fig. 5 Surface pressure comparison of previous model and aerodynamically optimized styling

in the new FIT, the pressure on the roof end is close to that on the C-pillar. These indicate that the new FIT achieved its goal of an exterior design shape with uniform pressure distribution on the vehicle surfaces extracted during the advance study.

Figure 7 shows the relationship between drag and total number of measurements taken during the entire period of development in wind tunnel tests using 25% scale models of the new FIT. Each dot in the figure represents one variation on the shape. In total, more than 2000 tests were run during development; however, the target drag level had already been achieved with the optimized aerodynamic shape found in the early phase, where FAST was used intensively. In most of the subsequent tests, the objective was to study the likelihood of achieving aerodynamics together with the desired exterior design, engineering, and production technology. However, the shape that achieved the target level of drag was efficiently proposed by applying the aerodynamic improvements found with FAST.

3.2. Platform Development

For the platform development, Fig. 8 compares the underfloor devices applied to the new FIT with those of the previous model. A cover was added at the rear end of the front sub-frame, which rectified the flow from the engine compartment. In addition, the cover surface area was increased to reduce total pressure loss at the rear of the underfloor, particularly around the rear suspension beam, to

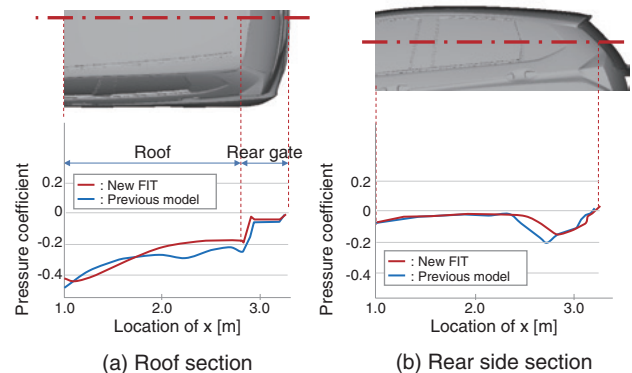


Fig. 6 Pressure coefficient on roof and rear side section

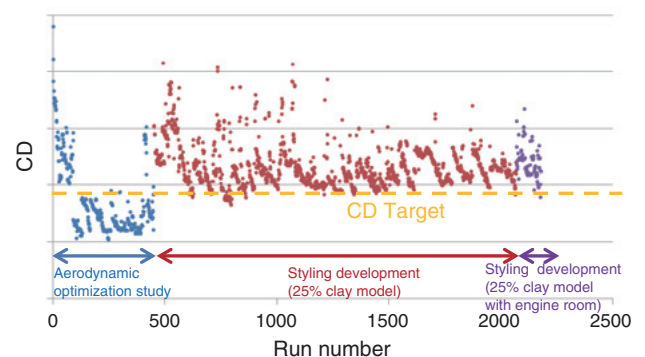


Fig. 7 CD history on wind tunnel tests

further improve aerodynamics.

The necessity of these aerodynamic devices was examined in terms of the target fuel economy and cost for each destination market, and the devices were selected accordingly.

For platform development, locations were extracted where great influences on aerodynamics are expected based on simulation results with the previous model. This section discusses the flow field around the front floor, which has a particularly significant effect, as well as the technique used to improve aerodynamics.

Figure 9 shows the pressure (left) and velocity (right) distribution on the YZ cross-section at the front wheel center position in the previous model. Paying particular attention to the pressure on the body side and underfloor, it shows that the pressure near the wheelhouse [Fig. 9(A)] is lower than that on the underfloor [Fig. 9(B)]. Due to this pressure difference, the airflow with less energy [Fig. 9(C)] is drawn from the underfloor to the front wheelhouse and

out to the body side. This flow results in an increase in total pressure loss at the back of the vehicle, which increases drag. This is the effect caused by the pressure difference between the bumper corner and underfloor. In order to restrain the total pressure loss by the flow from the front wheelhouse, pressure difference in this region needs to be reduced.

The surface pressure distribution of the previous model is shown in Fig. 10. Since its first generation, the FIT has been characterized by a shape with a short front overhang, based on the MM ideology, which creates strong negative pressure close to the front wheel edge [Fig. 10(A)]. This creates a large pressure difference with the underfloor, hence the greater impact of the outflow from the wheelhouse. Effective ways to control this in hatchbacks like the FIT are to reduce the negative pressure of the front bumper by optimizing the shape of the exterior design and to lower the pressure on the front underfloor. Since its first generation, the FIT has had a chin spoiler (air dam) to try to achieve this effect.

Based on these analysis results, using the previous model, a new shape was introduced for the new FIT in an effort to further increase the negative pressure on the front underfloor, which is to a bump at the leading edge of the engine undercover (Fig. 11). The airflow from the lower end of the front bumper accelerates as it goes around the forward edge with its small radius of curvature, producing

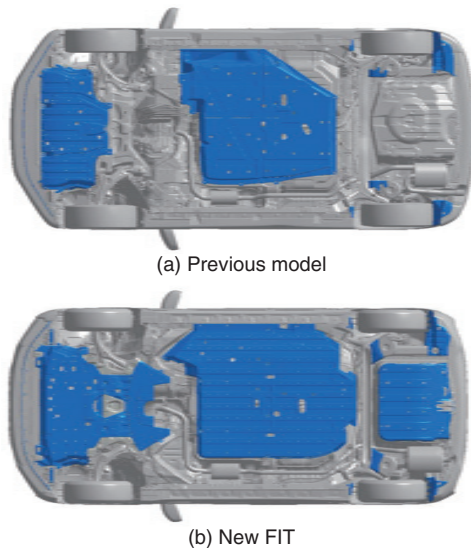


Fig. 8 Underbody covers

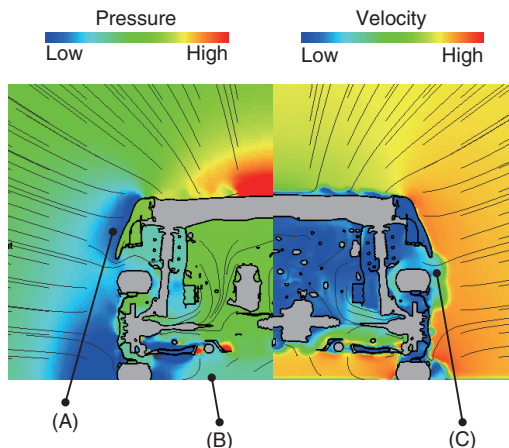


Fig. 9 Pressure (left) and velocity (right) contours at front wheel center section

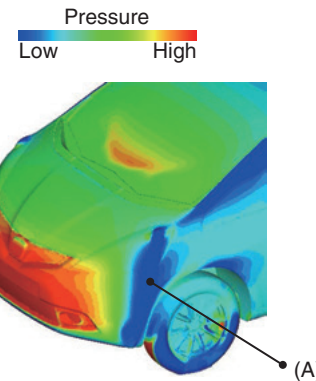


Fig. 10 Low surface pressure region at front bumper corner (previous model)

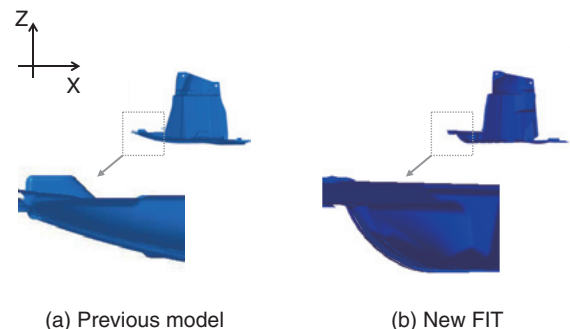


Fig. 11 Shape of engine undercover

a negative pressure peak in this area. Figure 12 compares the underfloor pressure of the new FIT and previous model. It shows that the new FIT has greater negative pressure under its undercover. To compare the pressure difference between the underfloor and front bumper, Fig. 13 shows the pressure distribution along the X axis for both the previous model and the new FIT. In the new FIT, negative pressure is increased in the area with the engine undercover, as indicated in Fig. 12. Optimization of the exterior design gives the new FIT a moderate pressure peak at the front bumper corner as compared to the previous model, resulting in a smaller pressure difference between the side and underfloor in the front section.

The flow velocity distribution at the underfloor along the section through the center of the vehicle is shown in Fig. 14 for both the new FIT and the previous model. The effect of reducing the pressure difference at the front decreased the total pressure loss of the underfloor. The new FIT shows higher flow velocity in most areas.

A cross-section of total pressure loss on the body side is shown in Fig. 15. Areas where the flow is losing energy are shown in red in this figure. Compared to the previous

model, outflow from the front wheelhouse in particular is being restrained on the new FIT [Fig. 15(A)] and has a smaller area of pressure loss towards the back of the vehicle. This is the result of creating uniform pressure at the front section, as shown in Fig. 13.

To improve the aerodynamics of the front, we not only investigated these factors but also worked to reduce engine compartment airflow resistance (cooling drag). To reduce cooling drag, it is important to efficiently draw incoming airflow from the front grill to the radiator and other cooling devices and reduce the flow volume to the minimum necessary. To do this, air guides were installed to restrict excess air from flowing out from the engine compartment to the underfloor and body side and optimized the cooling efficiency (Fig. 16). As a result, cooling drag was reduced 19% compared to the previous model when the grill opening was optimized.

Using these study results, a new platform was developed to reduce drag. The results were also used for other Honda models that share the common platform.

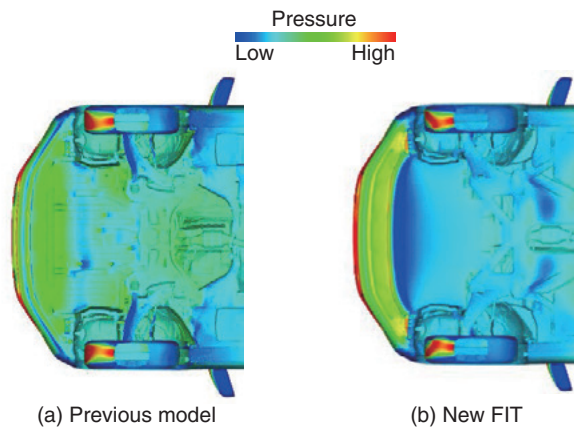


Fig. 12 Surface pressure distribution on engine undercover

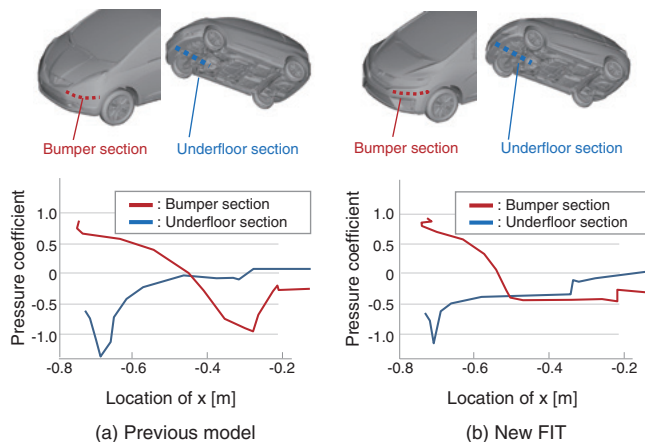


Fig. 13 Pressure coefficient on front bumper and underfloor

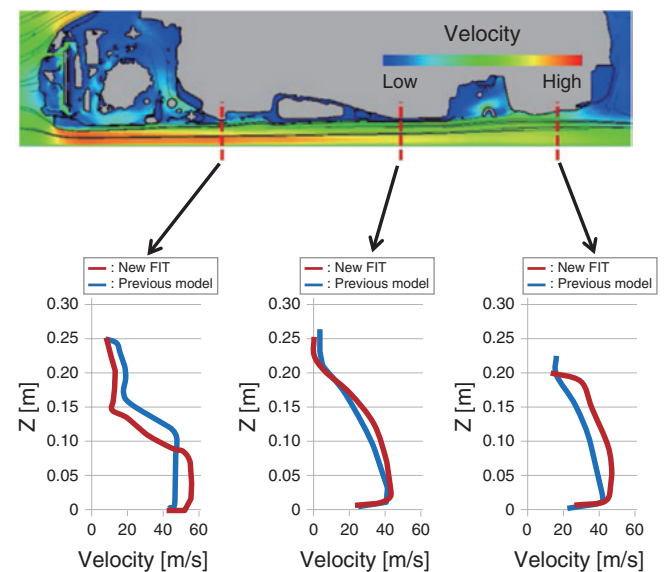


Fig. 14 Flow velocity on underfloor section

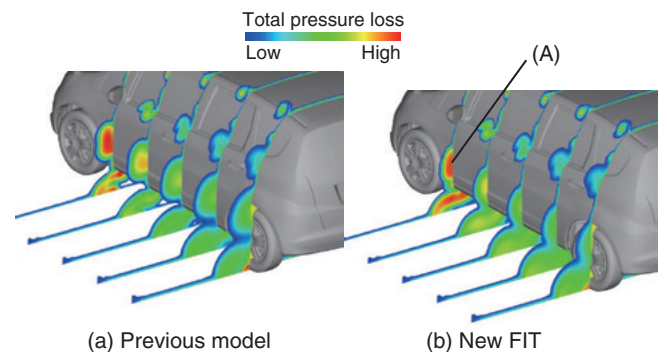


Fig. 15 Total pressure loss comparison of new FIT and previous model

3.3. Comparison of Wake

Drag factors acting on vehicle bodies are broadly classified into those that increase total pressure loss in the vehicle wake due to flow separation, and those that induce velocity components in the Y and Z directions due to pressure difference on the vehicle surface, so that the strength of the longitudinal vortex (a vortex with its axis in the X direction) increases. The following section compared the new FIT's vehicle wake with that of the previous model, with a particular focus on these factors.

3.3.1. Distribution of total pressure loss

The distribution of total pressure loss on the YZ section of the wake is shown in Fig. 17. In this figure, there is less total pressure loss where the red area behind the vehicle is smaller and is at a lower level.

In the wake of the new FIT, total pressure loss resulting from the A-pillar [Fig. 17(A), (A')] has been reduced. This is due to the pillar garnish on the new FIT. Furthermore, the area of the total pressure loss is smaller on the body side due to the newly designed platform, which reduces outflow from the front wheelhouse [Fig. 17(B), (B')]. On the other hand, the new FIT has greater loss near the center of the vehicle [Fig. 17(C), (C')]. This is because the downward flow (downwash) from the back of the roof is controlled at the vehicle center on the new FIT.

To make the difference between the new FIT and previous model clearer, Fig. 18 shows the difference in total pressure loss in the YZ section five meters behind the vehicle. Here, areas where the new FIT has smaller

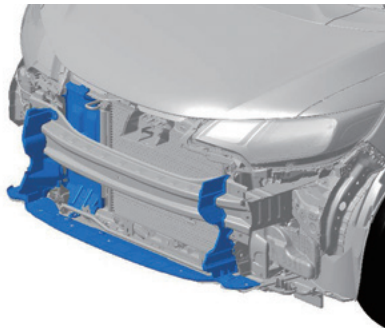


Fig. 16 Air guide devices in engine room

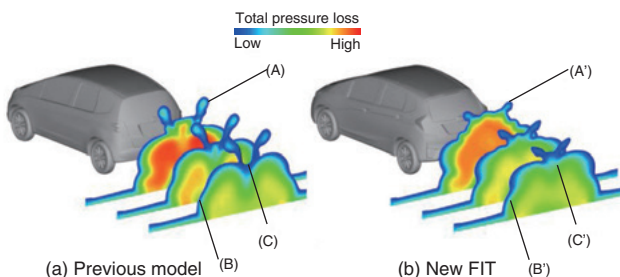


Fig. 17 Total pressure loss behind vehicle

total pressure loss, hence contributing to less drag than the previous model, are indicated in blue. The figure shows that the new FIT has less total pressure loss at the A-pillar [Fig. 18(A)] and side [Fig. 18(B)], and reduced loss in the entire cross-section. This confirms that it is mainly the A-pillar and body side that contribute to aerodynamic improvement by reducing total pressure loss.

3.3.2. Distribution of longitudinal vortex

Figure 19 shows the distribution of X-axis vorticity in the YZ section at the back of the vehicle for the new FIT and the previous model. Red indicates clockwise and blue counterclockwise strong vorticity. Vortices from the A-pillar [Fig. 19(A)] and a pair of longitudinal vortices behind the vehicle [Fig. 19(B)] can be observed, however these are smaller with the new FIT. This is because, in the exterior design, the roof peak was moved forward, and the C-pillar position and the shape of the lid light were optimized. That created a uniform pressure distribution on the vehicle surface and prevented the airflow from swirling around towards the back of the vehicle.

Longitudinal vortex drag in the YZ section behind

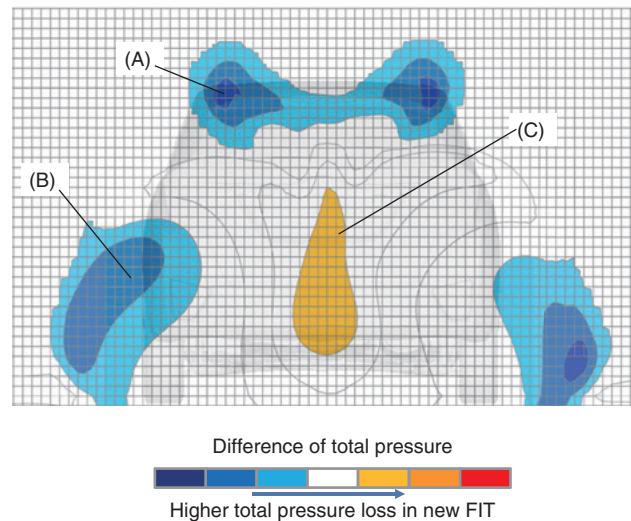


Fig. 18 Total pressure difference of New FIT and previous model

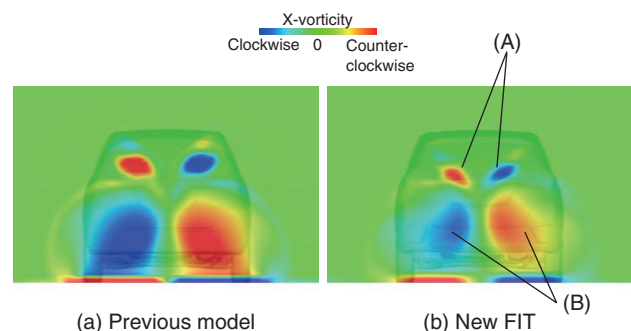


Fig. 19 Vorticity comparison of New FIT and previous model

the vehicle is shown in Fig. 20. This has a dimension of momentum per unit surface area, found by multiplying the density, ρ by the sum of squares of velocity in the YZ direction: $\rho(v_y^2 + v_z^2)/2$. It represents magnitude of air resistance resulting from airflow swirling behind the vehicle⁽⁵⁾. In the new FIT, longitudinal vortex drag is smaller, as shown in Fig. 20(A) and (A'). The difference is shown in Fig. 21. Here, blue indicates those areas where the new FIT has a smaller longitudinal vortex drag than the previous model. These are the areas that contribute to drag reduction. Longitudinal vortex drag is reduced in all areas with the new FIT, and there is a particularly great difference at the vehicle center. This is due to pressure on the vehicle surface being uniform with respect to the previous model, resulting in reduction of downwash from the roof and longitudinal vortex caused by the downwash [Fig. 21(A)]. In this area, there is a trade-off between increasing total pressure loss and controlling longitudinal vortex; however, Figs. 18 and 21 show that, compared to the previous model, the new FIT has lower total pressure loss, better control of longitudinal vortices, and less drag in total.

3.4. Aerodynamic Achievements of the New FIT

The efforts to improve the aerodynamic performance of the new FIT as described above were examined for commercial viability in close collaboration with the

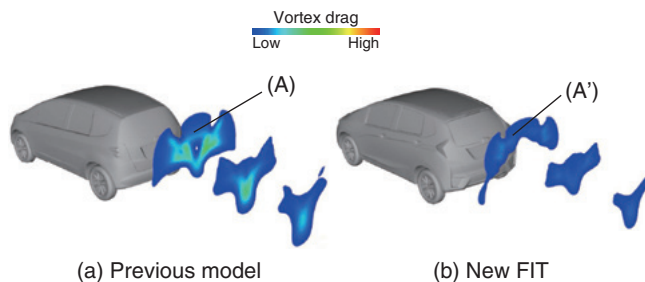


Fig. 20 Longitudinal vortex drag behind vehicle

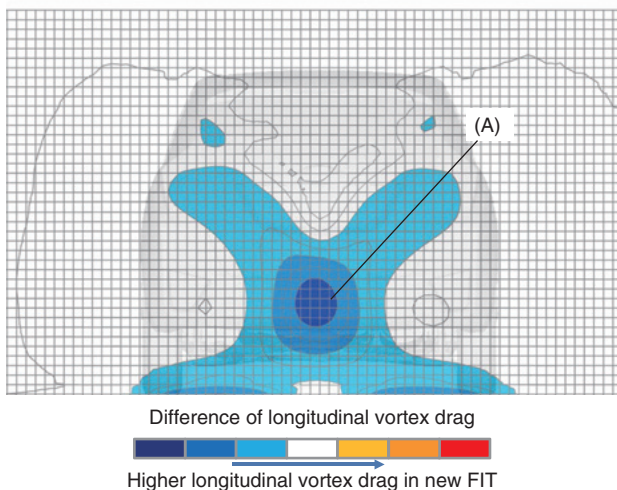


Fig. 21 Longitudinal vortex drag difference of new FIT and previous model

engineering section. Figure 22 shows the position of the new FIT's drag relative to other B-segment hatchbacks. The new FIT achieved one of the lowest drags known, as intended. This contributed to its excellent fuel economy of 36.4 km/l in JC08 mode.

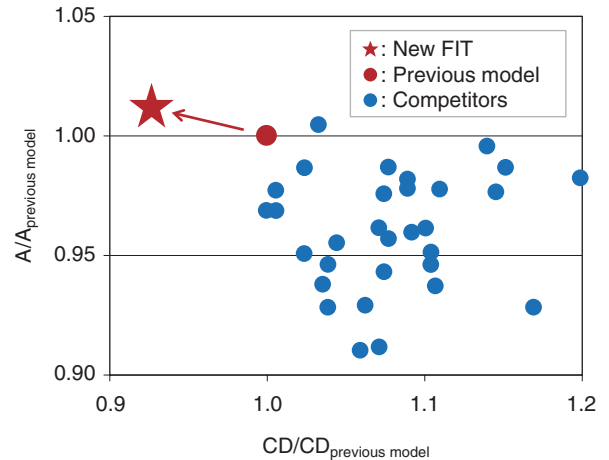


Fig. 22 Schematic of CDA

4. Conclusion

Based on wind tunnel testing and simulation results from the advance research in both the styling design and platform, a vehicle body with high aerodynamic performance was realized in the aerodynamic development of the new FIT. The results are summarized below.

- (1) In the development of the styling design, effective use of the CFD system and wind tunnel testing enabled both uniformity of flow velocity and pressure distribution around the vehicle body and a shape with the desired design characteristics.
- (2) In the development of the platform, the use of ducting in the engine compartment and optimization of the undercover shape optimized pressure around the front bumper. Thus, a vehicle body that minimized interference with the airflow of the exterior design was developed.
- (3) The aerodynamic vehicle body development technology described above reduced drag by 7% over the previous model and contributed to the excellent fuel economy of 36.4 km/l in JC08 mode.

References

- (1) Yamasaki, H., Toki, Y., Murayama, T.: Aerodynamic Technologies Adopted in the Third Generation Prius, Toyota Technical Review, Vol. 57, No. 1, p. 20-26 (2010) (in Japanese)
- (2) Ohira, H., Okamoto, S., Nakato, H., Kaya, M., Uematsu, T., Matsuoka, H.: Aerodynamic Development of All-

- New Mazda Atenza, Mazda Technical Review, No. 26, p. 65-70 (2008) (in Japanese)
- (3) Takiguchi, T., Ogawa, K., Tateyama, H., Oda, T: The Automatic Aerodynamic CFD Framework Employing Vehicle Specifications at the Concept Stage of Development, SAE Technical Paper 2013-01-0604 (2013)
- (4) Kitajima, Y., Murakawa, A.: 2014 Model Year FIT Design Based on New Honda Design Concept, Honda R&D Technical Review, Vol.26, No.1, p. 1-10
- (5) Hucho, W., Sovran, G.: Aerodynamics of Road Vehicles, Annual Review of Fluid Mechanics, Vol. 25, p. 485-537 (1993)

■ Author ■



Kentaro MACHIDA



Munetsugu KANEKO



Terumasa KOTADA



Atsushi MURAKAWA



Atsushi OGAWA