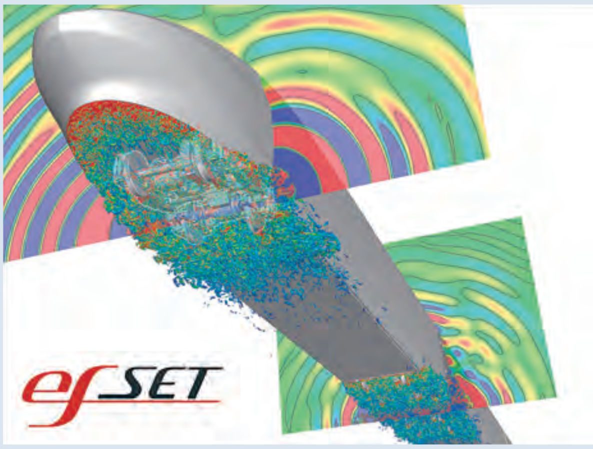
Development of High-speed Trains that Deliver “More Speed”



In meeting customer demand for faster trains, developers must also focus on achieving noise reduction and the development collision resistant structures. To this end, it is vital that noise and crash events are accurately reproduced in simulations and that they are used to perform thorough validation in advance.

Recently, we succeeded in reproducing these phenomena in the development of a high-speed train currently underway at Kawasaki. This was achieved through aeroacoustic simulations using the K computer and crash analyses using the finite element method (FEM). These technologies are expected to further accelerate the development of high-speed trains.

Introduction

Significant reductions in time spent travelling for business and leisure purposes are expected to further stimulate economic activities, bringing about greater economic growth. Therefore, demand for faster trains is increasing, not only in Japan but also for all the railways of the world.

1 Background

In recent years, there has been an increase in the momentum of the development of higher-speed Shinkansen and the introduction of high-speed railways in other countries. Under these circumstances, it can be said that the challenge of achieving “greater speed” boils down to two major factors: noise reduction and collision resistance.

Noise is generated mainly from pantographs and the lower part of carbodies. Greater speed will entail an increase in rolling noise and an even greater increase in aerodynamic noise. The former increases roughly with the cube of the speed, and the latter with the sixth power of the speed.

We have already made repeated efforts to identify the characteristics of noise produced by pantographs manufactured to overseas market specifications and to verify the analytical precision of comparisons against wind tunnel test results. Consequently, although we have qualitatively confirmed that the peak frequencies often match, we have not yet truly succeeded in making quantitative predictions for sound pressure levels due to the lack of grid resolution. In addition, noise from the lower part of carbodies contributes significantly more than that from pantographs, as overseas high-speed railways do not always have exclusive use of tracks or sound abatement walls while Shinkansen has those specifications and it is common in Europe for bogies not to have lateral covers or to be half-covered. Nevertheless, in the past, we did not carry out large-scale aeroacoustic analysis of noise from the lower part of carbodies using the real-life lengths of carbodies (3 or more carbodies), because detailed modelling of the sound source (bogies) was difficult and it has also been virtually impossible for any of our existing computational resources to do such analysis.

However, we have now begun to make use of the K computer to improve the accuracy of quantitative predictions about aerodynamic noise generated from pantographs, as well as to conduct research to predict aerodynamic noise generated from the lower part of high-speed railway carbodies through advanced large-scale unsteady computational fluid dynamics (CFD) analysis.

On the other hand, in the development of a collision-resistant structure, overseas railway carbodies are required, by standards, laws, regulations and specifications, to meet given collision resistance requirements. A typical example is the European collision resistance requirement standard EN15227, which requires carbodies to provide a reasonable level of survivable space in the event of a collision between two railway cars and a reduction in speed at the time of the crash. It is also expected that a collision resistance requirement will be added to the Code of Federal Regulation (CFR) in the United States for railway cars with a maximum speed which is 201 km/h or faster and slower than 354 km/h, with a view to ensuring safety for high-speed railways.

Railway car manufacturers are required to provide proof that their cars meet these requirements. However, it is difficult, both economically and physically, to conduct crash tests using the real-life lengths of carbodies. This is why it is now acceptable to prove collision resistance by conducting crash analyses and tests that demonstrate the analytical accuracy in line with the scenarios of the requirements mentioned above. Consequently, numerical simulation-based crash analysis has become an important technical tool for validating the collision resistance of cars.

2 Aeroacoustic simulations using the K computer

(1) The unique analytical method used by Kawasaki

The CFD software used in this study is "Cflow" which is developed by Kawasaki. Cflow consists of an automatic grid generator that allows for dealing with complicated geometries and a flow solver that employs low-dissipation scheme to capture unsteady flow characteristics and aerodynamic noise. This software has already been ported to the K computer, and parallelization has been carried out for super-scale analysis, for example through increasing the linear computation speed to enable parallel computation on thousands of cores. Although the original purpose of the software was to evaluate the aerodynamic performance of aircraft, new functions have been added in recent years to make it more applicable to railway cars, including those related to tunnel micro-pressure wave and cars passing each other, with the aim of expanding its scope of application to the products produced by Kawasaki.

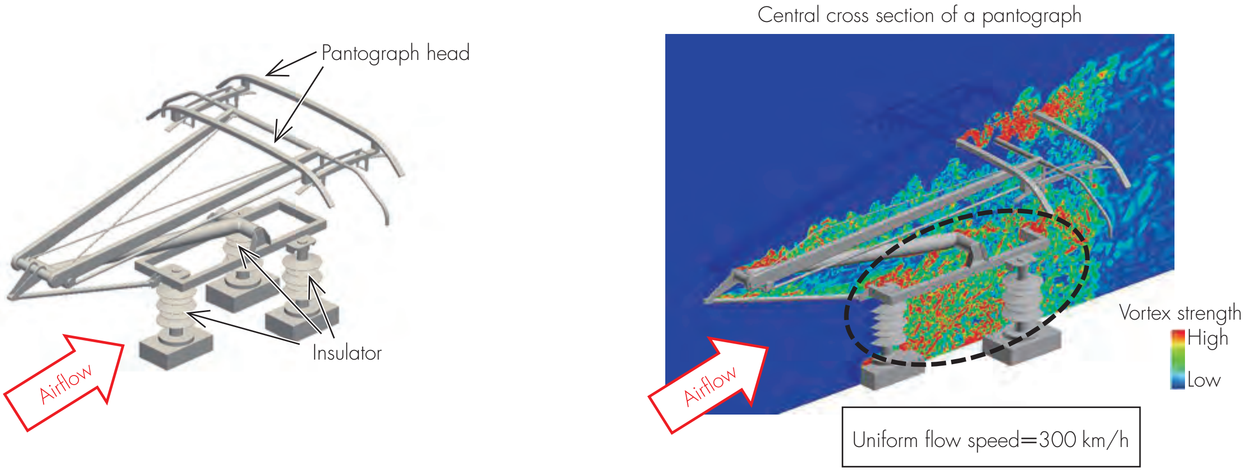
(2) Aeroacoustic simulation of a pantograph

Figure 1 (a) shows computational model of a pantograph. The computational grid consists of 410 million cells to achieve a higher grid resolution compared to the conventional grid of 153 million cells. The computational resources of the K computer, which we used this time, were equivalent to 2,048 cores (256 nodes). The speed of uniform flow is set at 300 km/h according to the conditions for the wind tunnel test.

Figure 1 (b) shows the vorticity distribution (instantaneous values) observed in the plane of the central cross-section to identify the areas that contain vortices. Wake vortices from the insulators are captured in detail in the area indicated by dotted lines.

Figure 2 shows the comparison of the sound pressure level (SPL) at a far-field observation point (25 m from the pantograph). The computational results we have obtained this time for SPLs at frequencies of 125 Hz–800 Hz, including those at the two peak frequencies (160 Hz and 315 Hz), which we had not been able to quantitatively predict in the past, are closer than ever before to the measurement results from the wind tunnel test.

Moreover, the precision of analysis has also improved at high frequencies of 1 kHz and higher. Thanks to the



(a) Computational model

(b) Isosurface of vorticity magnitude

Fig. 1 Aeroacoustic simulation of a pantograph

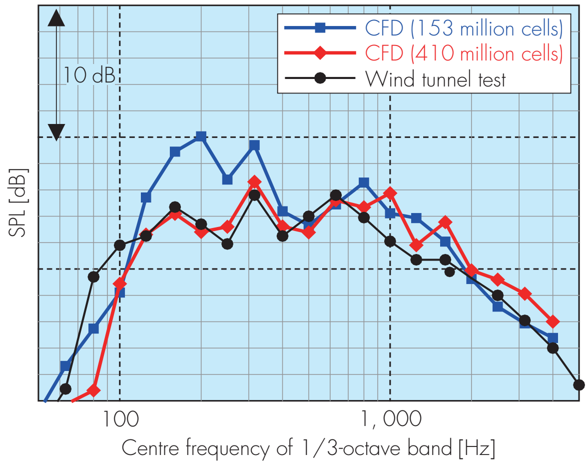


Fig. 2 SPLs at a far-field observation point

increased grid resolution, we have succeeded in improving the accuracy of quantitative SPL predictions.

(3) Aeroacoustic simulation of the lower part of "efSET"

(i) Computational conditions

The computational model is "efSET" with three (leading, intermediate and rear) cars which Kawasaki had developed for high-speed railways. As shown in Fig. 3 "Bogie (enlarged)," the radius arm type high-speed bogies[1] for the 1.5 cars in the front were modeled in detail. Regarding bogie covers, only the first one from the front of the train had a full cover (covered), and the remaining bogies had a half cover (non-covered). The computational model is on a real-life scale, with a 26.4-meter-long leading car and an inter-car distance of 0.5 meter.

Two types of computational grids were created, one with 832 million cells and one with 169 million cells (for checking the effect of bogie covers). Fine grids were placed in the car and inter-car areas to detect vortices, while relatively fine grids were set up in the upper and side areas of the cars to detect the propagation of sound waves. The train speed is set at 350 km/h to simulate a real-life running train. For the 832 million-cell computation, the 8,192 cores (1,024 nodes) of the K computer were used.

(ii) Computational results

Figure 4 shows the isosurface of vorticity magnitude (instantaneous values) to identify the areas that contain vortices. Strong vortices are generated by the edge of the skirt at the front of the train. The bogie areas are mostly where the turbulent flows are, while fine vertices are generated also from the entire bogie areas between the leading and intermediate cars. However, vortices generated by the bogies at the back of the leading car and at the front of the intermediate car are not as strong as those generated by the first one at the front of the train. Besides these, vortices are generated also by the lower part of the carbodies between the cars, which have not been observed in the conventional computation due to a lack of grid resolution.

Figure 5 shows the surface SPL distributions at 400 Hz on the surfaces of the leading carbody and bogies. Marked fluctuations are observed at the lower part of the carbody, where flows separated from the edge of the skirt become attached again. In addition, high level of pressure fluctuation is also observed on the outer surfaces of the

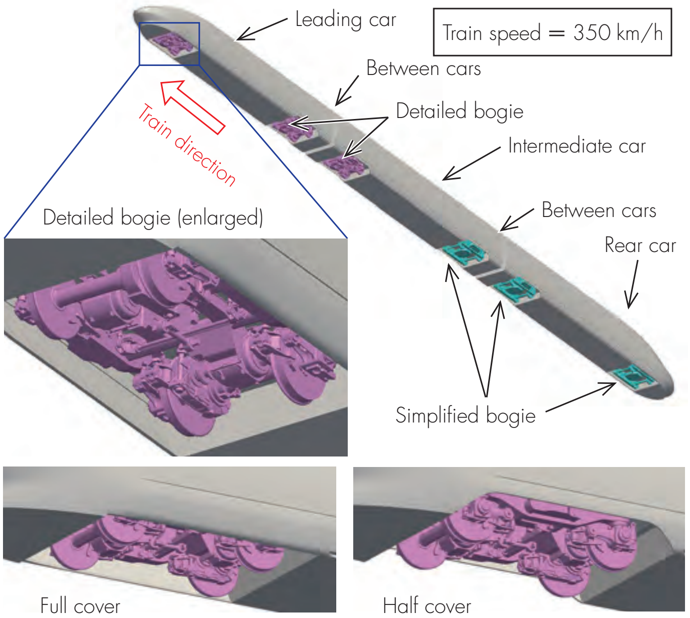
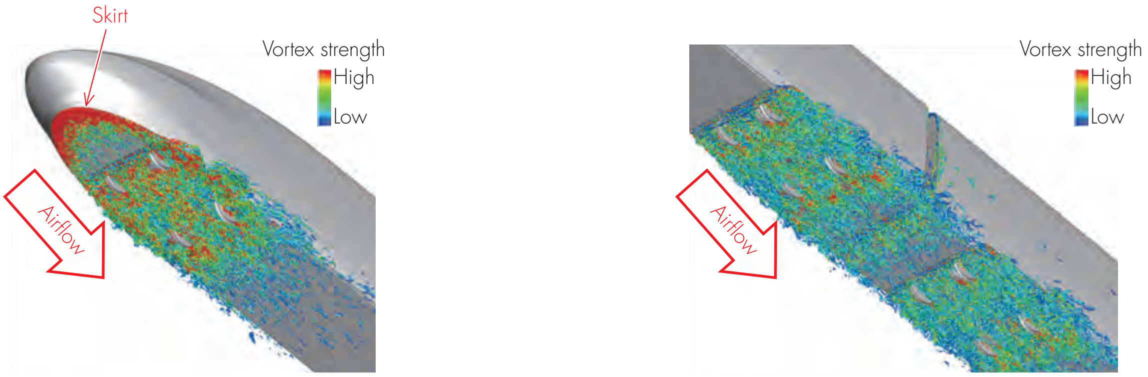


Fig. 3 Computational model (bogie)



(a) Leading car (b) Between the leading and intermediate car

Fig. 4 Isosurface of vorticity magnitude

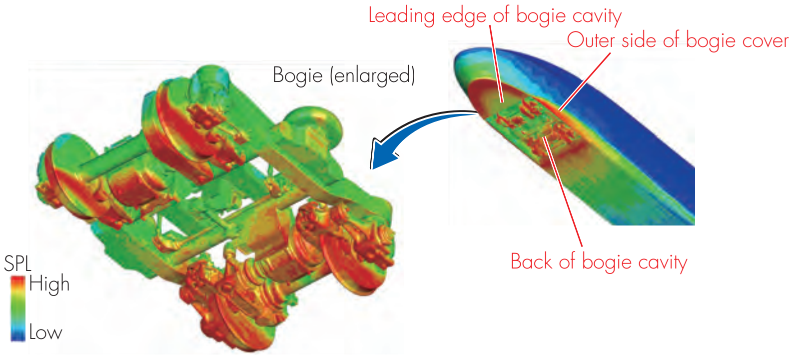


Fig. 5 Surface distributions of SPL at 400 Hz

bogie covers and at the back of the bogie cavities, while exposure to shear layers generated from the leading edges of the bogie cavities also causes significant pressure fluctuations on different parts of the bogies (wheels and machines). On the whole, aerodynamic noise is expected to be generated by the wide areas of the bogies.

Figure 6 shows the results of extracting and visualizing pressure fluctuations at 100 Hz via band-pass filtering, at a height of the upper surface of the tracks. In this figure, the red and blue short bands indicate that pressure waves fluctuated with fluid movement and the red and blue longer and blurry bands represent the propagation of sound waves towards outer areas. In this way, sounds radiating from the bogies are oriented towards the sides.

Lastly, we also examined what difference there is between when the bogies are covered and when they are not, as it is common in Europe for bogies to not have covers or be half-covered. The first car from the front of the train was half-covered in order to check the effect of bogie covers. Figure 7 shows the comparison of the sound pressure levels at a near-field observation point. As a result of the comparison, it is analytically confirmed that the noise level decreases at all frequency spectra when the bogie is fully covered, resulting in an overall reduction of 2.4 dB (A). As detailed modelling and super-scale analysis of bogies have become possible, we can now apply this to the noise evaluation of bogie covers.

※The carbodies are displayed as transparent.

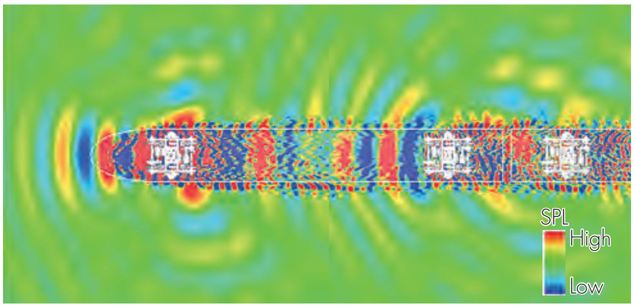


Fig. 6 Filtered pressure fluctuation at 100 Hz

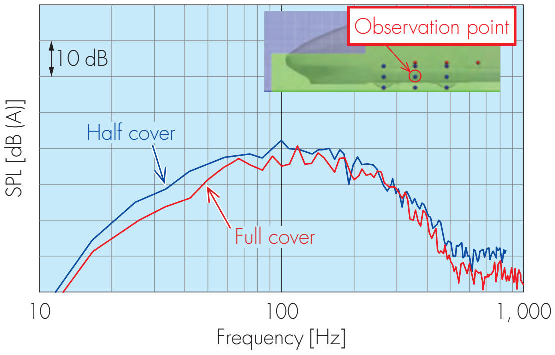


Fig. 7 SPL at a near-field observation point

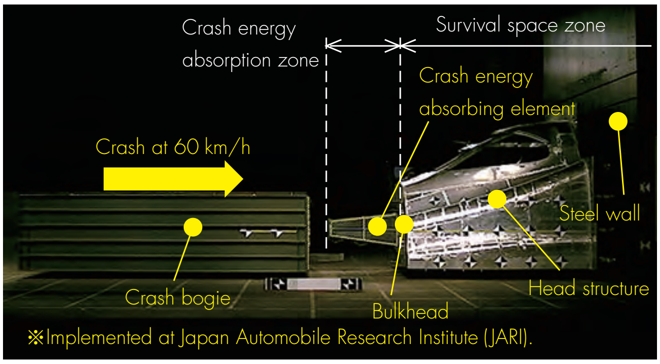
3 Crash analyses using the finite element method (FEM)

(1) Demonstration of the collision resistant structure of “efSET”

We have been working on the development of a collision resistant structure that conforms to EN15227 and CFR as elemental technology for efSET[1]. For efSET, to meet various requirement specifications, we have clearly distinguished between a zone for crash energy absorption and a zone for providing survival space for crew and passengers, and have developed a collision resistant structure based on the concept of modularizing crash energy absorbing elements. Simulation-based evidence for the collision resistance of this structure is certain to give Kawasaki a powerful competitive edge in attracting orders for train cars for overseas high-speed railways. Therefore, we have created a crash energy absorbing element and a head structure, based on the results of the examination of the distribution of energy absorption sites for overseas market specifications, and carried out a crash test for analysis. In the test, the head structure to which the energy absorbing element was attached was fixed to a steel wall, and a crash bogie with an estimated level of crash energy was crashed against the head structure at a speed of 60 km/h, as illustrated in Fig. 8.

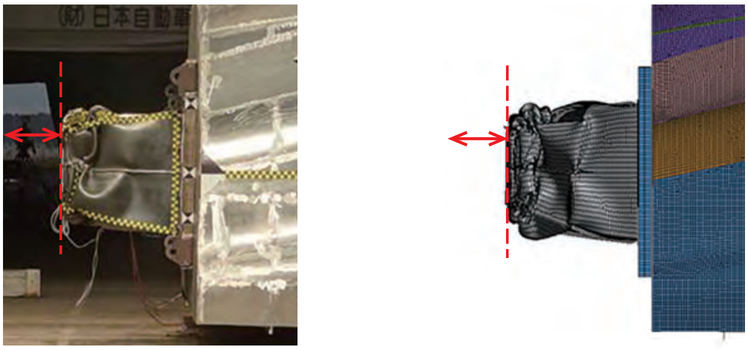
(2) Crash test results

This structure requires that in the event of a crash, only the crash energy absorbing element should deform to absorb the resulting crash energy, so that the survival space zone can be protected. As the deformation diagram in Fig. 9 indicates, both the test and simulation results show that the post-crash behaviour of the structure was in



※Implemented at Japan Automobile Research Institute (JARI).

Fig. 8 Crash test



Crush stroke (Amount of deformation after the crash)
→About the same results provided by both the test and simulation

(a) Test

(b) Simulation (FEM)

Fig. 9 Deformation diagram

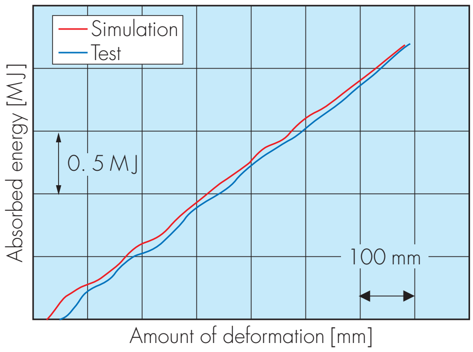


Fig. 10 Absorbed energy diagram

line with the above concept and that the structure has a satisfying level of collision resistance. Additionally, the state of deformation and the crush stroke of the crash energy absorbing element conformed to the results of the simulation performed in advance. A comparison of the amounts of absorbed crash energy of the crash energy absorbing element, shown in the diagram in Fig. 10, also confirmed that the simulation and crash test had about the same results.

Conclusion

We carried out large-scale analysis of aerodynamic noise using the K computer, by applying our internally-developed CFD software "Cflow" to the aerodynamic noise from the pantograph of a high-speed railway car and from the lower part of "efSET," which was also developed by Kawasaki. Our next task is to further improve analytical precision, while at the same time exploring effective noise reduction measures targeting the noise generation sources themselves by evaluating noise at a far-field observation point and identifying the dominant sites.

Our crash test results also showed the high precision of the collision resistance simulation in the crash analyses using the finite element method (FEM).

We aim to continue making these analytical technologies more and more sophisticated in order to accelerate our development of high-speed railway cars.

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