Joint Research Report by Japan Automobile Manufacturers Association, Inc. and Japan Agency for Marine-Earth Science and Technology

Representative: Hiroyuki Umetani, Japan Automobile Manufacturers Association, Inc.

Authors: Hiroyuki Umetani, Katsuhiro Miyoshi, Kazuhiro Sato
Japan Automobile Manufacturers Association, Inc.

Keywords: automobile, collision, aerodynamics, precision enhancement, real-time processing

Japan Automobile Manufacturers Association, Inc. and Japan Agency for Marine-Earth Science and Technology conducted joint research between April 2006 and March 2007. This joint research aimed to advance "A Study of the High Precision and Real-time Simulation of Automobiles in Their Entirety by Using the Earth Simulator" - a two-year joint research project conducted from June 2004 to March 2006 to examine new ways of simulating automotive performance in the near future, and address important issues and challenges. This report sums up the project findings and future challenges.

1 Joint research details

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) proposed a joint research project entitled "A Study of Simulation of Automobiles in Their Entirety by Using the Earth Simulator" to Japan Automobile Manufacturers Association, Inc. (JAMA). Both organizations conducted joint research for about two years from June 2004 to March 2006. The theme of this joint research, based on a proposal made by JAMSTEC with regard to the environment and needs around automotive development, was set as "A Study of the High Precision and Real-time Simulation of Automobiles in Their Entirety by Using the Earth Simulator." As a result of this project, collision analysis demonstrated, by using the Earth Simulator, that 10 million elements can be implemented within a practicable calculation time (of 18 hours). At the same time, aerodynamic analysis allowed us to understand phenomena that cannot be reproduced through conventional calculations by making calculations for 90 million elements, and thus increased the precision of analysis. Upon analyzing the combustion of engines, however, the lack of available software capable of allowing the Earth Simulator to fully exhibit its capabilities became clear, indicating that many issues must be addressed before this simulation can be performed.

Based on these project findings, we decided to focus on collision and aerodynamic analysis during this fiscal year. We employed an even larger analytic model and considered the possibilities and issues of superlarge-scale analysis necessary in the near future.

The emergence and widespread use of the supercomputer in the 1980s significantly affected the automotive development process.

Before that time engineers had to minimize the size of calculation models, which kept calculation time within a realistic range. Consequently, engineers were then required to estimate various phenomena. Recent dramatic advances made in computers, calculation methods, and related pre-postprocessing technology, however, have allowed engineers today to perform analyses on a scale previously unimaginable. As a result, automotive development became much more efficient. Everyone now recognizes that simulation plays a vital role in automotive development.

Given these dizzying advances in simulation, the requirements for simulation have become increasingly diverse and complex. Everyone knows that simulation is necessary to address environmental issues typified by global warming, safety mechanism required at an even higher level, and attempts to explore corrective actions while elucidating complex phenomena.

Demand is high not only for expanding the scope of such application, but also for higher precision to achieve higher development efficiency and shorter analysis time. Technical development to meet these demands is the mission of engineers engaged in simulation.

Against that background, this research is intended to address issues considered impossible only a few years ago due to limited hardware performance. The scope of study for this fiscal year, particularly based on findings obtained by projects conducted up until last fiscal year, focused on "collision simulation" and "aerodynamic simulation around the car body," two typical examples of automobile simulation, and investigated the limits of precision with regard to analytic model scale.

The ESCAR Working Group under the JAMA promoted this project. The group consisted of all 14 automaker members of the JAMA, JAMSTEC, and NEC as the secretariat. On a working level, the nine software suppliers: LSTC, ESI, Mecalog, Ricardo, CD-adapco, IGENIE, CDH, Altair Engineering, and the Japan Research Institute were jointed for porting their software packages to the Earth Simulator, along with performance tuning and other aspects.

The following describes the joint research in detail. In order to simulate automobiles in their entirety, it was decided that research for this fiscal year would employ a superlarge-scale precise simulation model of a scale even larger than that of last year. The subsequent sections describe the detail activities conducted in fiscal year 2006.

2 Project findings and future challenges

2.1 Collision analysis

2.1.1 Project findings

The activities conducted in fiscal year 2005 showed that the superlarge-scale vehicle model of 14 million elements improved the accuracy of acceleration-time graph of the floor in the case of frontal collision against a rigid wall. The project for this fiscal year was intended to: (1) apply the model to an analysis of frontal collision against ODB (Offset Deformable Barrier) and improve computation performance; and (2) improve the accuracy of acceleration-time graph of the floor under a driver's seat.

With regard to the computation performance mentioned in (1) above, the study revealed that there had been a problem until last year (as shown in Fig. 1) where as simulation progressed, the elapse time got longer considerably. This was because the ODB frontal collision model had a lot of ODB-related contact definitions which caused big difference of the computation load between the front and rear, and also between right and left, which resulted in bad parallelization efficiency. In the research conducted in this fiscal year, by using sophisticated domain decomposition method, we succeeded in improving parallelization efficiency and avoiding a slowdown. As a result, the total elapse time – about 300 hours as converted to 80ms before the project (Fig. 1) – was successfully shortened to 130 hours (Fig. 2).

The acceleration-time graph of the floor described in (2) above, left some problems to be resolved unfortunately, as shown in Fig. 3. These problems include two big ones. One is that there is large difference of acceleration-time waveform between simulation and actual experiment from 0ms up to 25ms, where the vehicle crashes into an ODB violently. The other is not to simulate the timing of peak acceleration. These problems are presumably due to such causes as the ODB being made of a material which is softer than that of the vehicle, resulting in large deformation locally, and wide-ranging material rupture. Rupture phenomenon are currently described by deleting elements when an applied stress exceeds a certain level. This, however, causes a greater force imposed on their adjacent elements suddenly after their deletion. Therefore, this modeling method may need to be reviewed to get to more accurate analysis, which is not easy.

As described above, in the ODB frontal collision analysis model, microscopic phenomenon like rupture is closely related to accuracy. A collision analysis might reach a stage which introduces new challenging techniques such as multi-scale simulation.

Fig. 1 Elapse time (before the project)

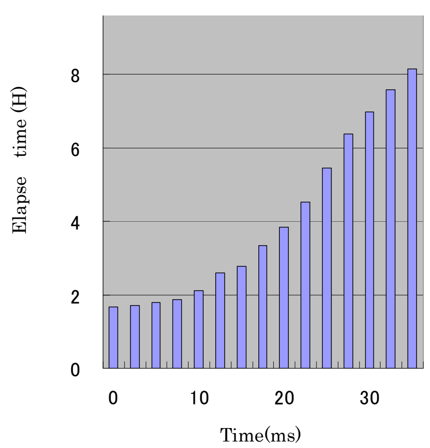


Fig. 2 Elapse time (after the project)

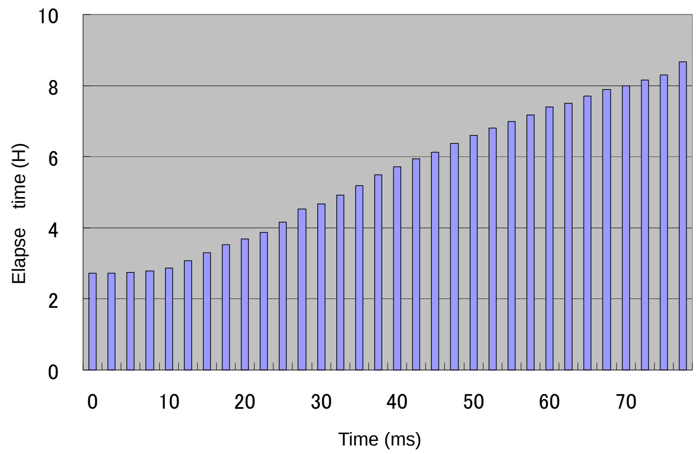
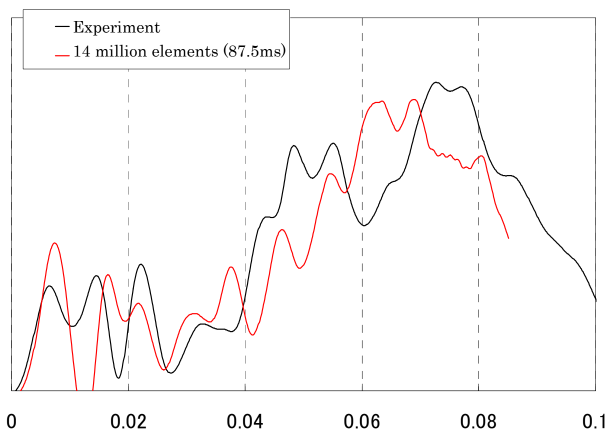


Fig. 3 Acceleration-time graph (driver)



2.2 Aerodynamic analysis

2.2.1 Background and project details

In aerodynamic analysis commonly utilized these days, automatic grid generation technology is used for tetrahedral and hexahedral elements to enable an analysis of complex shapes. In the automatic generation of grid from CAD data, however, CAD data may need some touch-up depending on workmanship. Moreover, the quality of grid shapes may affect analysis precision. Even though grid generation is a very important step for analysis, the experience of the grid-generating person is one that cannot be ignored.

This prompted us to develop a flow analysis method (mesh-free method) that requires no complex grid generation. This mesh-free method enables analysis to be conducted directly from a group of points representing the shape of an object without conducting the bothersome task of grid generation. As a result, this method significantly enhances the process of aerodynamic analysis and represents a so-called next-generation analysis method.

This mesh-free method, however, entails large-scale calculations in exchange for its advantage of not requiring grid generation. This method is therefore limited in terms of applicability on ordinary computers and has thus far been unable to conduct adequate validation. The Earth Simulator, a superlarge-scale computer, has now been used to consider the practicability of this next-generation analysis method with regard to analysis precision and calculation time.

2.2.2 Project findings

Table 1 lists the size of each model, memory required for calculation, number of CPUs, and calculation times. As shown in the table, it has been demonstrated that calculations can be performed within about 18.6 hours even in superlarge-scale analysis involving 4 billion points – the most used in the present project.

Fig. 4 compares the pressure distribution (analysis result) in the center cross section of vehicles obtained for each model size with the experiment values. Here, since solving the problem of insufficient memory capacity took much time in calculating the model of 4 billion points, calculations were only conducted once during the present project period. As a result, parameter tuning could not be conducted to increase analysis precision, and results comparable to the experiment results were unavailable. However, the results obtained with up to 900 million points allowed us to demonstrate that the analysis results approached the experiment values as the grid interval was narrowed. This indicates that realizing superlarge-scale analysis makes it possible to reproduce a pattern where the flow near the vehicle center runs along the trailing edge of the roof. This allowed us to predict analysis results even closer to the experiment values by conducting even larger-scale analysis. Figs. 5 and 6 show the patterns of flows as determined in analysis, revealing that the simulator accurately grasped the flows around complex shapes.

Table 1　Calculation time and memory size

	14-million-point model	100-million-point model	900-million-point model	4-billion-point model
Grid size	10 mm	5 mm	2.5 mm	1.5 mm
Memory usage/ CPU	43MB	256 MB	480 MB(*1)	750 MB(*2)
Total memory size	3 GB	33 GB	123 GB	1,536 GB
No. of CPUs	64 CPUs	128 CPUs	256 CPUs	2048 CPUs
Calculation time	1.4 H	5.1 H	27.5 H	18.6 H

*1: Program modified partially to reduce memory space requirement

*2: Program modified partially to equalize memory allocation of each CPU

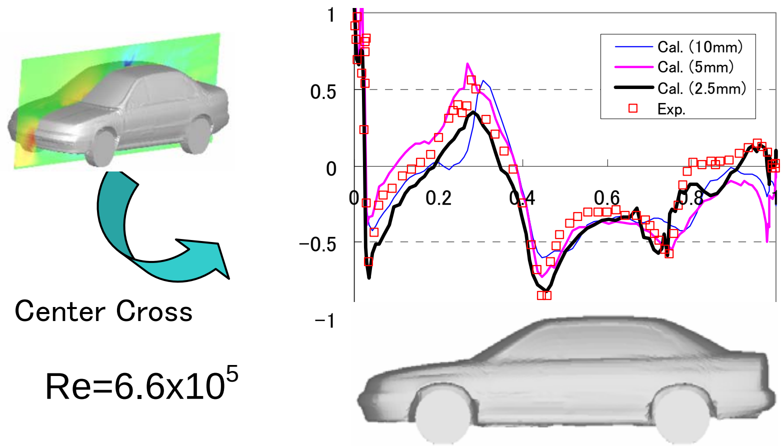


Fig. 4　Comparison of pressure distributions at center cross section of vehicles

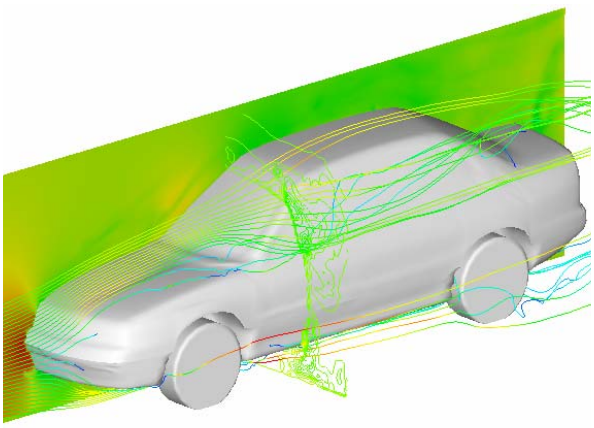


Fig. 5　Analysis result: Flow of the entire vehicle

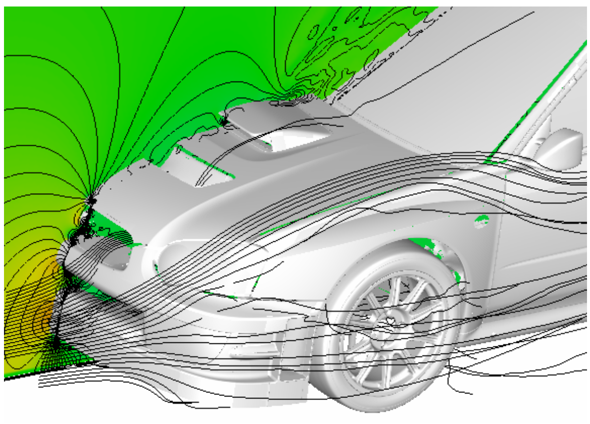


Fig. 6　Analysis result: Flow around the front part of the vehicle

2.2.3 Future challenges

The joint research conducted by the JAMA and Japan Agency for Marine-Earth Science and Technology has been completed with the results obtained from this fiscal year.

3 Conclusion

Table 2 Conclusion

<table>
<tr><th>Type</th><th>Actions taken</th><th>Findings from FY 2006</th><th>Details of the findings</th></tr>
<tr><td>Collision</td><td rowspan="4">A superlarge-scale analysis (10 times the conventional scale) was conducted to assess:
- pre-post environment
- analysis precision
- calculation time</td><td>ODB analysis precision
Acceleration: △
Calculation time: △</td><td>Calculation time shortened successfully.
Acceleration precision remained unimproved.</td></tr>
<tr><td rowspan="3">Aerodynamics</td><td>Calculation scale: ○
(4 billion points)</td><td>Models of up to 4 billion points analyzed successfully.</td></tr>
<tr><td>Precision (nonsteady-state analysis): ○</td><td>Analysis of a 900-million-point model produced results close to the experiment values. The 4-billion-point model failed to be adequately validated due to lack of time.</td></tr>
<tr><td>Calculation time: △</td><td>It was demonstrated that the 4-billion-point model could be calculated within a day.
(18.6H/2048 CPUs)</td></tr>
</table>

The Earth Simulator enabled a superlarge-scale simulation of automobiles, which had been considered impossible only a few years ago due to hardware constraints. This project demonstrated that the time for increasing precision and creating an analysis model could be shortened. The challenges and limitations in superlarge-scale analysis were also clarified.

The joint research of the JAMA and JAMSTEC has been completed with the findings obtained from this fiscal year.

Last but not least, we would like to express our sincere appreciation to the personnel of JAMSTEC for their devoted efforts in realizing and conducting the joint research, and to the personnel of NEC and software suppliers for their valuable support in the research.