Report on the Joint Research by the Earth Simulator Center and the Japan Automobile Manufacturers Association

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The present study named the ES-CAR Project (earth simulator + car) was jointly conducted by the Earth Simulator Center (hereafter "ESC") and the Japan Automobile Manufacturers Association ("JAMA") from June 2004 to March 2006. With the help of the ESC's huge-capacity parallel supercomputer system, the ES-CAR Project is aimed at outlining a next-generation vehicle performance simulation that can be put to practical use from around 2010 or 3 to 5 years after the project's 2006 completion. The theme of the joint research was "all-inclusive accurate, real-time simulation." To realize all-inclusive vehicle simulation, it was decided to first formulate a method of improving the accuracy and speed in vehicle collision, aerodynamics, and engine combustion simulation. This report introduces the results of this research and how we will address said them.

Keywords: Vehicle, collision, aerodynamics, engine combustion, improving simulation accuracy, improving simulation speed

1. Contents of the Joint Research

The ESC proposed a joint research on "all-inclusive vehicle simulation using the Earth Simulator" to JAMA and thus the joint research project was conducted from June 2004 to March 2006, for about two years. The theme of this research was decided as "review of all-inclusive high-accuracy, real-time simulation using the Earth Simulator", taking into account the goals of the ESC, the environment and the needs for vehicle development.

It goes without saying that advances made in supercomputers have shortened the simulation calculation time and also have provided great benefit for the vehicle development sites. In the past when computer performance was relatively low, computing took considerable time, making it impossible to use computer simulation for vehicle development. Consequently, vehicle researchers had no choice but to simplify their simulation models, with its low levels of precision and accuracy being the major obstructions. Conversely, today a collision simulation on a one-million-element scale can be conducted overnight, making simulation a daily-use tool for evaluating vehicle designs. With the recent trend toward reducing vehicle development time, computer simulation is now widely used in evaluating vehicle performance, such as collision, aerodynamics, strength, and vibration noise, as well as in various fields of vehicle manufacturing like press process, so that the development of vehicles has become impossible without computer simulation.

Nevertheless, the application of simulation is still limited only to certain aspects of the vehicle. To be more specific, more than half of the items that must be evaluated and checked for developing a new car, are still being evaluated or checked by physical testing or traditional methods because there are technical difficulties to apply simulation to these items. In the meantime, vehicle development teams are being confronted by the growing demands to incorporate new technologies, meet stricter regulations, address environmental issues, and further shorten the development period. Consequently, there are mounting expectations for next-generation simulation to be more accurate, speedier, and applicable to a wider range of automotive aspects.

The ES-CAR Project was motivated by these expectations, years ahead of the simulation advancement schedules of most automakers. The practical goal of this project was set to investigate the maximum limit of simulation accuracy concerning "collision simulation," "aerodynamic simulation around the vehicle body," and "engine combustion simulation," which are representative examples of vehicle simulation.

For preparation, the ES-CAR working group was formed within JAMA. Its name was given by combining "ES" for the Earth Simulator and CAR. The working group's members were enlisted from each of the 14 JAMA automakers and from the ESC, with NEC Corporation representatives also participating in a secretariat capacity. The nine software houses that developed the applications used for the joint research—namely, LSTC, ESI, Mecalog, Ricardo, CD-adapco, IGENIE, CDH, Altair Engineering, and JRI—were invited to help porting the applications into the Earth Simulator (hereafter "ES") and improving their efficiency on ES.

To realize all-inclusive, accurate, and real-time vehicle simulation, it was decided to formulate the super-scale counterparts (representing a tenfold increase in elements) of the existing finite element models used for collision, aerodynamics, and engine combustion in order to improve simulation accuracy and speed. No automaker in the world had used finite element models of this vast scale. So as a first step, the activities conducted in FY 2004 centered on examining the operation of new large models and the possibility of improving related simulation accuracy and speed. Then the activities conducted in FY 2005, based on the execution results of the first step, centered on examining actual simulation accuracy and speed. The following describes the FY 2005 activities.

2. Current Activities and Future Plans

2.1 Collision Analysis

2.1.1 FY 2005 Activities

Since the results of the FY 2004 activities had demonstrated that the super-large-scale models of 10 million elements improved the transformation accuracy at the parts level, the FY 2005 activities centered on further detailing the overall vehicle models (engine, chassis, various calculating conditions) with the aim of 1) improving the acceleration time of full-lap frontal collision analysis, and 2) applying the models to offset frontal collisions and improving the simulation accuracy.

As a result, with respect to 1) improving the acceleration time of full-lap frontal collision analysis, we obtained the results as shown in Fig.1. It was found that the acceleration waveform of CAE reproduced that of the experiment very well, and that the maximum acceleration and its timing bear a close resemblance to the experimental results. In addition, as demonstrated in Fig. 2, it is apparent that the data on acceleration time for the front passenger seat were also well simulated with the experimental result except at around 40 ms. Judging from the above, we confirmed that the vehicle models used in the present study demonstrated substantial accuracy in evaluating full-lap frontal collisions, as well as the potential of applying the models to much more difficult cases such as the forecasts of passenger injury values or airbag deployment timing in the future.

Offset frontal collision analysis is now being examined based on the detailed models noted above.

2.1.2 Future Plans

Our activities in FY 2006 will involve: 1) enhancing accuracy in offset frontal collision analysis, and 2) attempting to simulate local physical developments using the above models.

In addition, the present high-accuracy collision analysis revealed that even the Earth Simulator, which provides the highest performance in the world, takes too much time for practical deployment (See the Fig. 3). The major reason for this should be that the effort to achieve ultimate accurate result by detailing the models reduces parallel efficiency. In FY2006, in consideration of the three aspects of simulation models, S/W, and H/W, we will investigate the cause of deteriorated performance in cooperation with the ESC. By implementing countermeasures, we will make further efforts to improve simulation speed toward achieving practical application, with our immediate goal set on overnight analysis taking 10 hours.

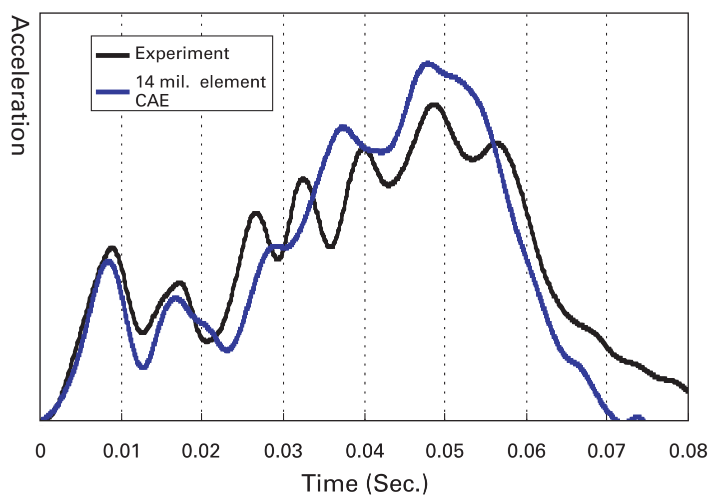


Fig. 1 Acceleration-Time Graph (Driver's Seat).

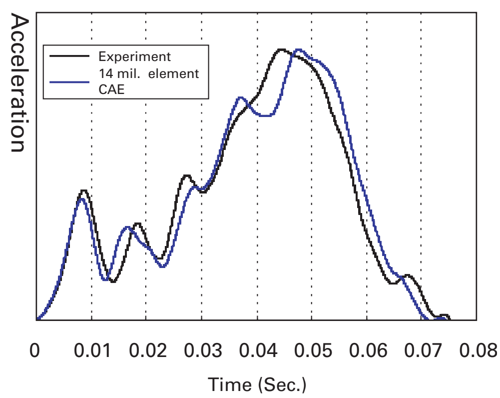


Fig. 2 Acceleration-Time Graph (Front Passenger Seat).

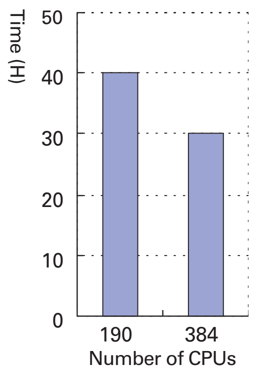


Fig. 3 Computation Time.

2.2 Aerodynamic Analysis

2.2.1 History and Activities

A hexahedron computational mesh, tetrahedron computational mesh, or a hybrid mesh is generally used today in aerodynamics analysis. While providing higher calculation accuracy, the hexahedron mesh is not suited for reproducing complex shapes. Conversely, the tetrahedron mesh can reproduce complex shapes easily but its calculation accuracy is relatively low. To examine the possible coexistence of calculation accuracy and shape reproducibility, large-scale calculation was performed using tetrahedron elements with impressive shape reproducibility, and attempts were made to improve calculation accuracy using element division.

In line with the results of the interim report and as a second step, calculation models of 40 million and 90 million meshes, which reproduce detailed body shapes, including the engine room, under the floor, and suspensions, were created by leveraging the characteristics of the tetrahedron mesh that are said to reproduce complex shapes easily. In doing so, element division and element segmentation were optimized, and the airflow around the vehicle body was calculated using a calculation model of the actual vehicle in order to examine the accuracy in reproducing airflow.

2.2.2 Simulation Results

The time required for calculation using the 90-million-mesh model is about 120 hours as shown in Table 1. By comparing the calculation results with the experimental results, more accurate calculation results due to the precise element division were verified in the size of the boundary layer separation areas and the reproduction of disturbances in each part of the car body including under the floor. As an example, the condition of disturbances under the floor formed angular shapes was clearly reproduced in angular patterns as shown in Fig. 4 because of the precise element division. Fig. 5 shows the condition of the airflows along the sides of the body. Here too, in much the same way as under the floor, the disturbances behind the wheel housings as seen in the experiment were reproduced in the simulation. The above results show that complex airflows around the vehicle body can be analyzed with higher accuracy by detailing elements and optimizing element division.

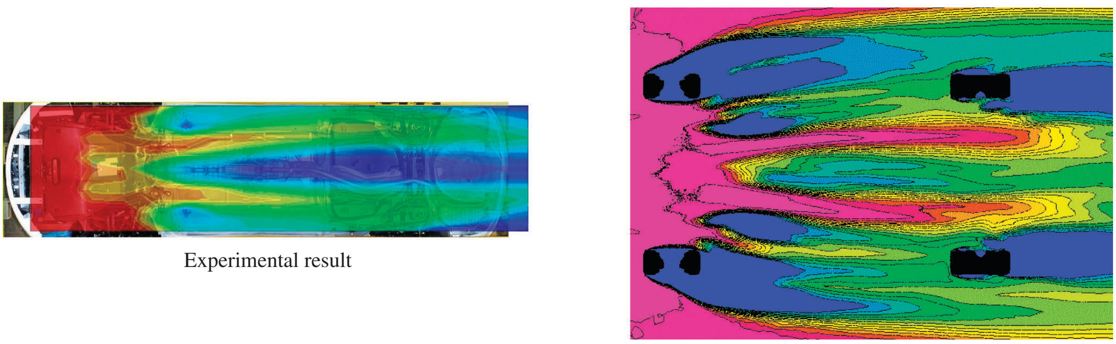
2.2.3 Future Plans

In FY 2005, we found that by using super-large-scale analytic models, the complex airflows around the vehicle body can be analyzed with significantly high accuracy, although it still takes considerable time.

In FY 2006, an aerodynamic analysis using the mesh-free method will be reviewed. In addition, we will explore ways of striking a balance between analytical accuracy and real-time simulation by using this method that dramatically reduces analytical time.

Table 1 Computation Time and Required Memory Size.

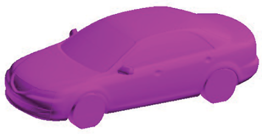
	40million elements	90million elemen
Memory Size/CPU	1742MB	4160MB
Total memory size	111GB	133GB
CPU Number	64	32
Computation Time	45hours	113hours



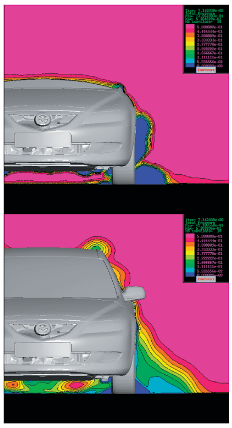
Experimental result

90 million elements

Fig. 4 Pressure distribution: XY section at 100 mm from ground.



YZ section at body side



90 million elements

Experimental results

Fig. 5 Pressure distribution: YZ section at body side.

2.3 Engine Combustion

We examined the compatibility of multi-cylinder and multi-cycle engine combustion analysis with the Earth Simulator by using off-the-shelf fluid analysis software. As a result, it became clear that much of engine combustion analysis involves moving boundary calculation that moves valves and pistons, the input and output of data for this calculation, and such scalar calculations as fuel spray calculation. Since these considerations inhibit the Earth Simulator from exercising its full performance capability, we decided to discontinue this study.

In this time, we found there is no software products or computers that allow us to conduct this study, and that we must address a number of issues in our conducting the engine combustion simulation.

3. Conclusion

We have examined the simulation accuracy of a super-large-scale analytical model using a resolution 10 times greater than that used for conventional analytical models that can be only achieved by the Earth Simulator which has the world's fastest execution speed, and obtained successful results in improving accuracy. At the same time, we have clarified issues that must be overcome for practical application. We have also discussed with the ESC regarding the joint research activities to be conducted in FY 2006. Meanwhile, we will expand the scope of our research as well as resolving some issues toward achieving practical application this year.

We would like to thank the ESC personnel who cooperated in realizing and implementing the joint research and the personnel of the companies who supported our research.

Category	Contents of Study	Results	Program for FY 2006
Collision	Conducted super-large-scale analysis (10 times greater than that used for conventional models) Examined analytical accuracy and calculation time	Accuracy Deformation: ○ Acceleration: ○ Calculation time: △	High-accuracy examination of offset collisions Faster speed toward practical application
Aerodynamics		Accuracy: ○ (Steady state) Calculation time: △	High-accuracy examination of mesh-free method without grid generation and evaluation of its practical application
Combustion	Engine combustion – Super-large-scale (10 times greater than that used for conventional models) – Multi-cylinder – Multi-cycle Examined analytical accuracy and calculation time	Examination discontinued due to considerable calculation time required	No programs in this fiscal year

地球シミュレータセンターと自動車工業会による共同研究の報告

プロジェクト責任者
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‘04年6月から、’06年3月までの予定で、地球シミュレータセンターと、日本自動車工業会の共同研究を実施。この研究は、地球シミュレータという超大規模のスーパーコンピュータを活用して、3年〜5年先の自動車性能シミュレーションのあり方を検討することを目的としている。共同研究のテーマは「地球シミュレータを活用した自動車まるごと、高精度、リアルタイムシミュレーションの検討」とした。自動車まるごとシミュレーション実現にむけ、まずは、車両の衝突・空力・エンジン燃焼等各シミュレーションの高精度化、リアルタイム化の検討を実施した。ここでは、その活動結果と今後の進め方について述べる。

キーワード：自動車，衝突，空力，エンジン燃焼，高精度化，リアルタイム化

1. 共同研究内容

自動車まるごとシミュレーション実現にむけ、まずは、車両の衝突・空力・エンジン燃焼等各シミュレーションの高精度化、リアルタイム化の検討を従来のシミュレーションモデルの10倍以上という超大規模な高精度シミュレーションモデルを使って実施することとした。これだけ超大規模なシミュレーションモデルは、世界の自動車会社でも実施の実績がなく、‘04年度は、第1STEPとして動作検証と、超大規模モデルによりシミュレーション精度がどれくらい向上するかを中心に研究を実施した。’05年度はその実施結果をもとに

具体的な高精度、リアルタイム検証を実施した。‘05年度の実施内容について、説明する。

2. 実施結果

世界最速の実行性能をもつ地球シミュレータでしか検証することができない従来の解析モデルの10倍の解像度をもつ超大規模解析モデルにてシミュレーション精度検証を実施。

精度向上については、大きな成果をだすことができた。

と同時に、実用化に向けての課題もあきらかにすることができた。

現在、2006年度も共同研究活動を実施するようESCと協議をすすめており、来年度は、研究対象を広げるとともに、実用化に向けての課題解決をはかっていく。

最後に、共同研究の実現、実施にご尽力いただいたESCの方々、研究をサポートいただいた協力会社の方々にお礼を申し上げ、結びとする。

区分	実施内容	結果	来年度の取り組み
衝突	超大規模解析実施 （従来の10倍） 解析精度、計算時間を評価	精度 変形：○ 加速度：○ 計算時間：△	オフセット衝突の高精度検証 実用化に向けた高速化
空力		精度：○（定常） 計算時間：△	格子生成を伴わない メッシュフリー法の高精度検証と 実用化検討
燃焼	エンジン燃焼 ・超大規模（従来の１０倍） ・多気筒 ・多サイクル 解析精度、計算時間評価	計算時間大のため、 途中で打ち切り	来年度は取り組み無し