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Review Report

Technology of Automobile and Visualization Studies

In Celebration of the 10th Anniversary of Journal of Visualization

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Abstract : Computer simulation and visualization techniques for automotive studies are reviewed through the history of computer-aided visualization techniques to celebrate the 10th anniversary of Journal of Visualization. Future direction of visualization study is also mentioned through the introduction of up-to-dated numerical visualizations.

Keywords : Visualization, Automobile, Computational Fluid Dynamics, Computer Aided Engineering.

1. Introduction

Ten years have passed since the first issue of the Journal of Visualization, published as an English international journal by the Visualization Society of Japan (VSJ). As a person involved in its publication, we are pleased for the 10 years anniversary and would like to bring it up as a unique journal in academia.

The history goes back in 1969, almost 40 years ago, when one of the authors (T.K.) first recognized visualization techniques. At the time he was a Ph D. candidate and attended one of the research committee (RC) relating to the fluid measurements of unsteady flow in the Japan Society of Mechanical Engineers (JSME). It was the time when the coherent structures of turbulent boundary layer was revolutionarily identified by "hydrogen-bubble method", and increasing attention was going to be paid to novel visualization techniques, as well as such a new and unknown physical phenomenon itself. At the same moment, Flow Visualization was going to be systematically treated as one of the engineering measuring techniques in the American Society of Mechanical Engineers (ASME). The heightened interest in the flow visualization encouraged us to hold the first symposium on visualization, which was followed by the establishment of the Flow Visualization Society of Japan (FVSJ), a later VSJ, accordingly followed by the first issue of the international journal focused on visualization.

At the present day ten years after the first issue, various English journals published by Japanese societies are generally more or less caught in a bind. A more and more innovative idea is necessary for the continued success and progress for the Journal of Visualization and consequently visualization study. Some avant-garde approaches are expected to be made at this stage of the 10 years anniversary.

2. Computer Aided Visualization

The contribution of computer techniques to flow visualization, which nowadays is a matter of common practice, began no more than thirty five years ago. In the RC-JSME in around 1969 for the fluid measurements mentioned above, T.K. was assigned to investigate visualization techniques for unsteady flows. At that time such a hydrogen-bubble or spark tracking method as utilizing an electric control had already been introduced, and he decided to pursue a possibility of new technique, a computer-aided visualization.

In fact, it was the time when computer-aided methods were going to prevail in many engineering fields, and the introduction of the computer methods to flow visualization was an inevitable condition. The CATV research workshop was established by the FVSJ, and studies on Particle Imaging Velocimetry (PIV) and Computational Fluid Dynamics (CFD) were about to begin.

Examples of measurements by PIV and Large Eddy Simulation (LES) of an early date are indicated in Figs. 1 (Kobayashi and Yoshitake, 1985) and 2 (Kano et al., 1984). Flows around a circular cylinder by PIV and turbulent flows over square steps by LES are visualized respectively, both of which were obtained in the late 1970's, more than thirty years ago. As the other extreme examples, the most recent achievements in PIV and LES are introduced in Figs. 3 (Li et al., 2001) and 5 (Tsubokura et al., 2007), which will be mentioned in detail later. Three dimensional flow structures of lobed mixing jet are clearly extracted by a state-of-the-art PIV in Fig. 3, and an application of LES for the aerodynamic assessment of a formula car is illustrated in Fig. 5, in which about ten-thousand times more numerical grids than those in Fig. 2 are utilized. The rapid development and progress of computers and related technology have been expanding use of computer-aided analysis and development, which is going to be a dominant tool in various industries.

In this article, we would like to introduce the trend of research activities based on computer simulation in automotive applications, then to mention the future direction of visualization technique.

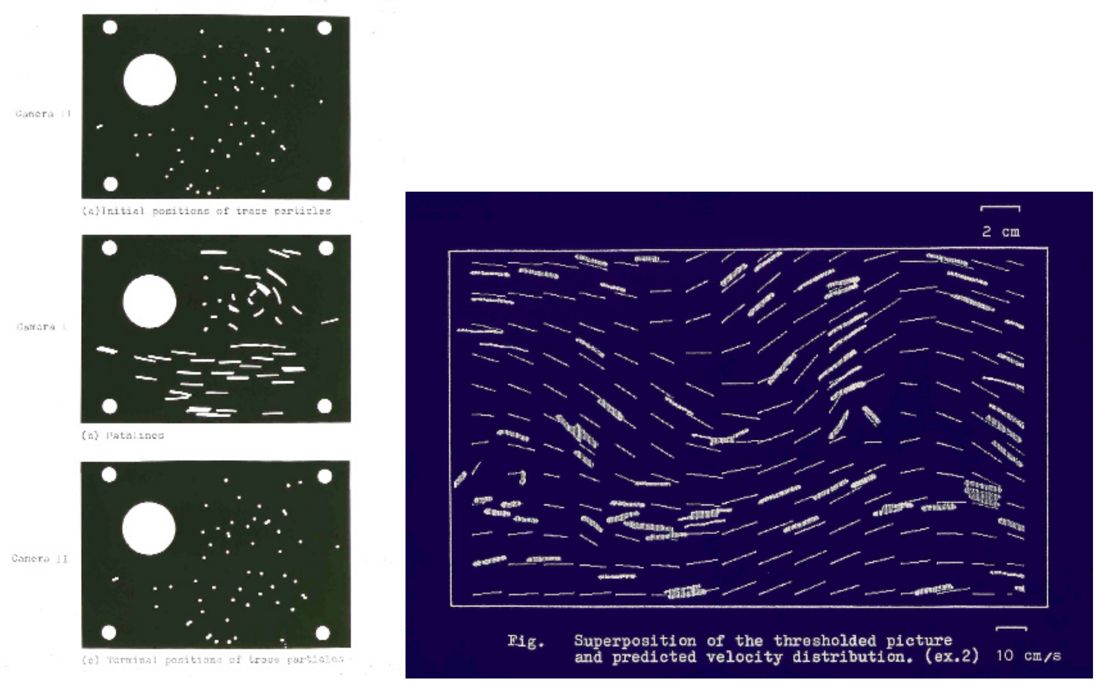

Fig. 1. PIV measurements of flow around a circular cylinder.

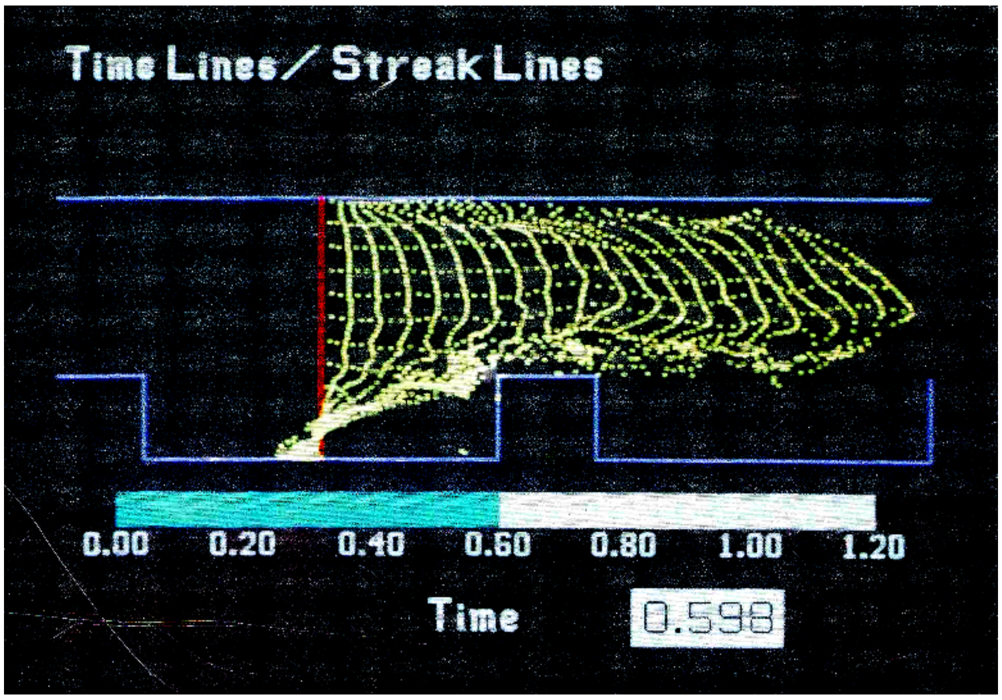

Fig. 2. LES of flow above the circular obstacle.

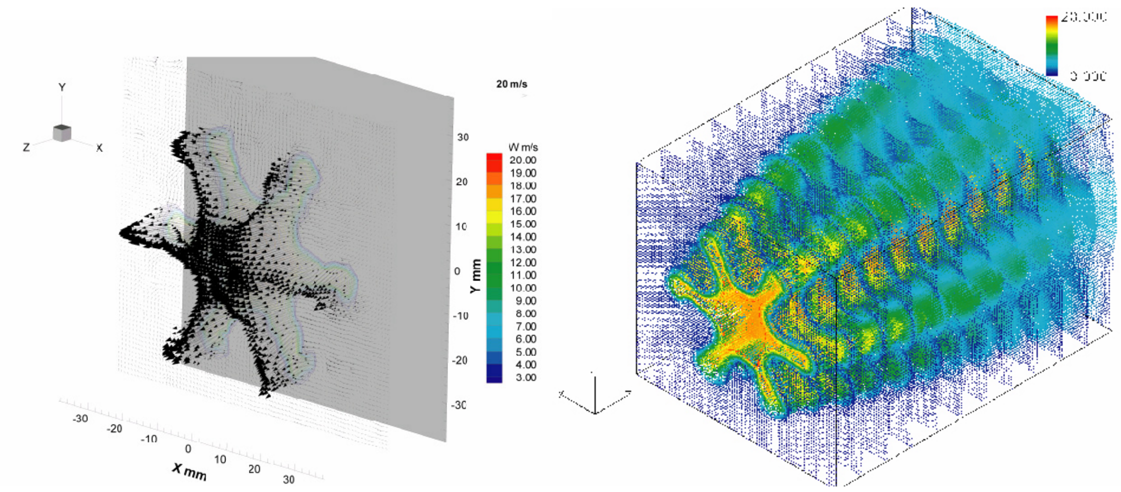

Fig. 3. Stereo PIV measurement of a Lobed Jet (left: 3-D velocity on 2-D plane, right: 3-D velocity in a 3-D space).

3. Computer Simulation and Visualization for Automotive Technology

The automotive industry has been actively involved in innovating research and development processes by introducing computer technologies. In fact, some sections relating to the Computer Aided Engineering (CAE) and Computer Aided Design (CAD), which has rapidly expanded for these ten years, have a serious shortage of manpower. Various computer simulations are progressively utilized in a development process in a sophisticated manner. We will introduce some examples of high performance computing (HPC) concerning the automotive study.

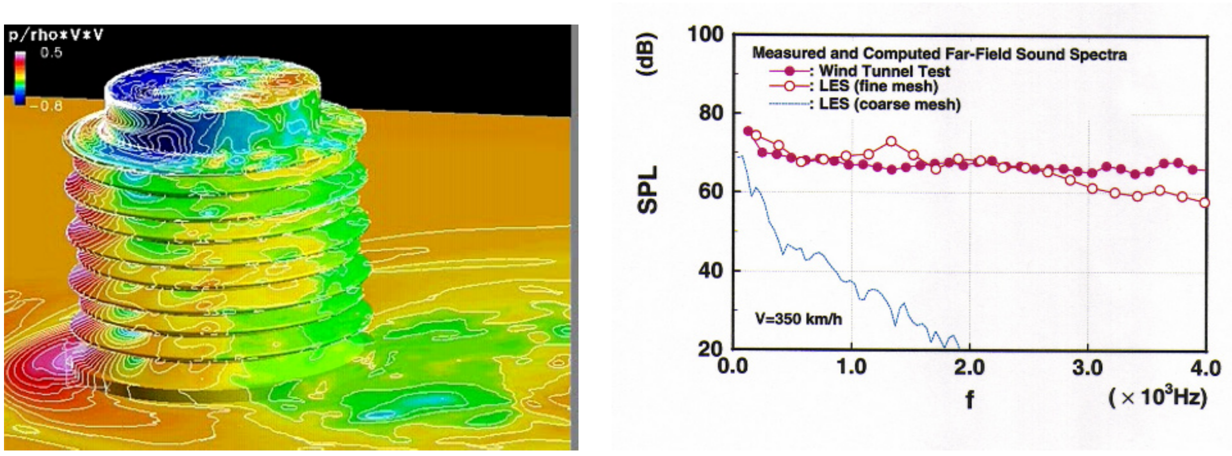

Fig. 4. Aeroacoustic analysis by LES (left: Pressure fluctuation distribution, right: Far-field sound spectra).

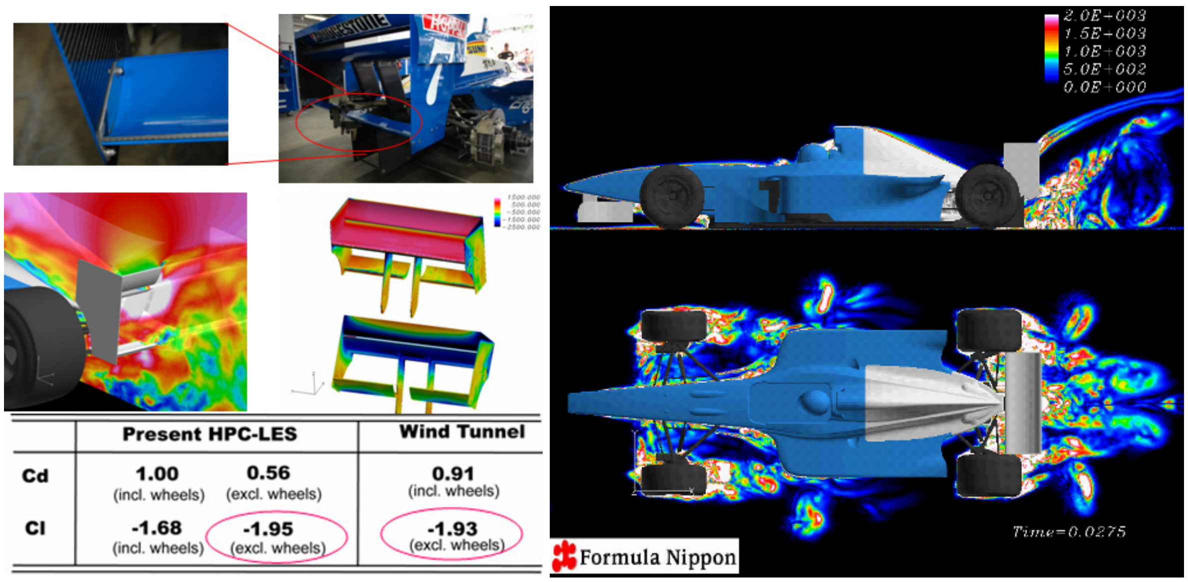

Fig. 5. LES for vehicle aerodynamics on Earth Simulator (left: Gurney flap and Aerodynamic performance, right: Snapshots of vorticity distributions).

The first example is the application of LES for the assessment of turbulence-generated noise, of which the most notorious is the one emanating from the side mirror. Once low-Mach number condition is assumed at the specified engineering flow field with complicated geometry, so-called splitting method is most commonly used, in which far and near fields of the object emanating the acoustic noise are predicted separately (e.g., Kobayashi, 2003). Aeroacoustic noise from the pantograph cover of Shinkansen, a high speed train, was estimated using LES based on the splitting method (Kato et al., 2003). Distribution of the instantaneous acoustic source generated by the turbulence eddies and its frequency spectrum are visualized in Fig. 4.

As the second example of HPC for automotive engineering, visualizations of a flow around a formula car using LES are shown in Fig. 5. The LES has been conducted on Earth Simulator using more than 120 million numerical elements, which is world largest class unsteady turbulence simulation for vehicle aerodynamics (Tsubokura et al., 2007). In a formula-car aerodynamics, tiny aerodynamic parts with the size less than 1cm drastically improve the aerodynamic performance in some situation, and the typical example is so-called Gurney flap named after its discoverer. The

Gurney flap is mounted on the trailing edge of front and rear wings as illustrated on the left of Fig. 5. Accordingly higher grid resolution of less than centimeter order using more than 100 million numerical elements is a necessary condition for the formula car LES. Concerning the aerodynamic characteristics of a race car, most important factor is the down force which acts as the negative lift of the vehicle. In the LES, the lift coefficient predicted shows good agreement with the wind tunnel data and its discrepancy is only a few percent. The next target of LES for vehicle aerodynamics is to predict unsteady aerodynamic forces which act in a sudden cross wind or cornering condition, all of which are difficult to estimate by the conventional wind tunnel test.

The third example is a CFD of blood flow. A study on cerebral aneurysm or arterial sclerosis using CFD is introduced here (Oshima, 2007), which is a good example of the application of simulation-visualization techniques; however no application of blood flow CFD has been reported to the impact biomechanics for the automotive engineering as of the moment. An integrative system of multi- scale/physics simulations, in which both blood flow (Navier-Stokes equations) and vessel (structure equation) are simultaneously solved, is proposed in the study. A remarkable characteristic of the system is the proposal of the simulation in which quantitative model relating the inner membrane model of the vessel wall to the surface friction are incorporated. It is expected that such a simulation technique will soon be utilized at the real medical scene.

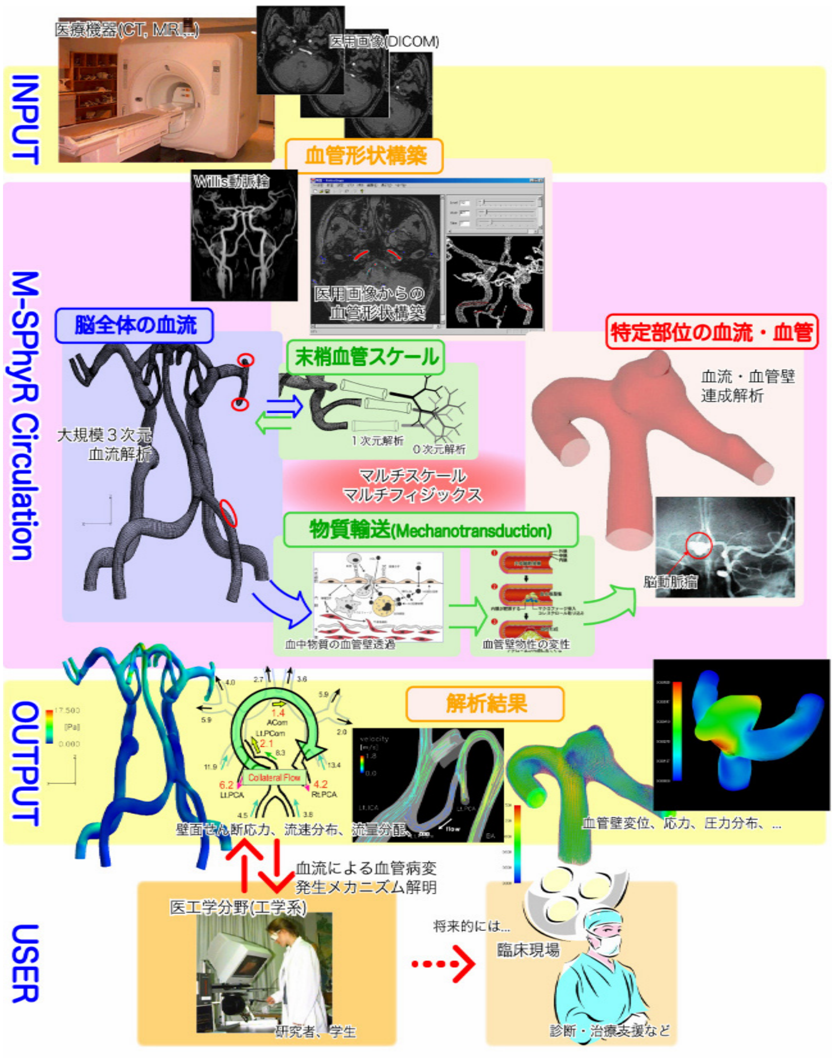

Fig. 6. Blood flow simulation system.

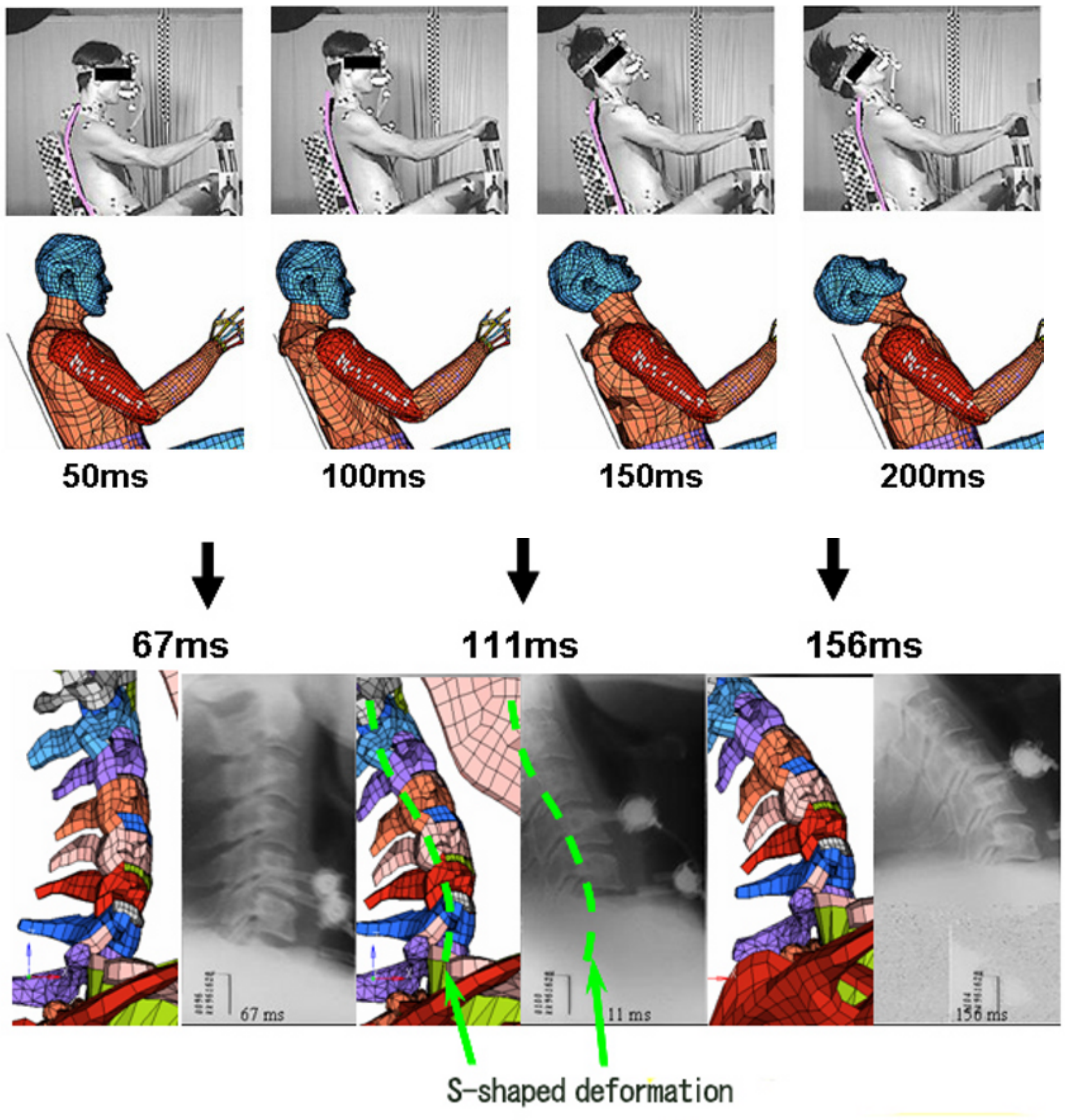

Fig. 7. Whiplash Injury Mechanisms Using Finite Element Human Model
(above: external behavior, below: internal behavior).

Finally, we would like to introduce a simulation for the impact biomechanics, as one of the good instances of frontier studies for the application of computer simulation. Damage mechanism of whiplash injury has been studied by both the voluntary experiment and the finite-element numerical model (Ejima and Ono, 2007), to correspond to the recent increasing trend of the injury. Figure 7 shows the pictures of the so-called thread experiments and its finite-element human body model, indicating how the cervical vertebra of the driver rear-ended is damaged through the exterior behavior. The speed of the supposed rear-end collision was set to only 8 km/h to secure the volunteer's safety. From the figure, we can observe that cervical part bends backward just after the rear-end collision, then shifting to a extending behavior at around 100 ms later the collision. The simulation model properly reproduces this behavior. The sequential internal X-ray photograph and numerical simulation of the cervical vertebra during the accident are indicated in Fig. 7 (below). A S-shaped deformation is observed at around 100 ms, which will causes disagreement between the head and the cervical part, then lead to serious shear deformation among the vertebra. As a result, a painful damage will be induced. The finite-element body model successfully predicts the same external S-shaped deformation, and will be able to be utilized to capture the deformation process of the vertebral body around the intervertebral joint, as the next step. Figure 8 (Holcombe and Ejima, 2007) is a result of more precise simulation by constructing the detailed cervical part to reproduce the localized deformation caused by the disagreement between the head and the cervical part. The detailed geometry for the finite-element analysis was reproduced based on the computerized tomography (CT) of the part, which was constructed as a CAD data of the cervical vertebra and the intervertebral joint. We can observe in the figure that, when upper part of the cervical vertebrae is initially loaded, then shear load is imposed, the contact surface of the intervertebral joint is deformed. Our next step is to investigate the relationship between the surface deformation and the pain caused, and it will be explained both numerically and experimentally through the microscopic visualization of the deformation.

These case examples clearly indicate following facts that: Firstly, when we investigate the ensemble characteristics of a nonlinear phenomenon, we can now measure its direct unsteady characteristics and then take the average of the results, in the way we really should; Secondly, the details of the shape which strongly affect the results are able to be precisely expressed; Then thirdly, entire or full scale simulation which consider whole shape or effects of products or targets are going to turn into reality. The rapid development of both computational hardware and software make a strong contribution to this progress. At the same moment, they also indicate that we are confronted with the difficulty relating to the interface for multi-scale or multi-physics phenomena.

In a few years, a petaflops supercomputer with the peak performance considerably improved against the Earth Simulator will appear in Japan, and one of the subjects hotly debated is how that can be used in industries. Some symbolic projects relating to the automotive technology are also going to be planned for the supercomputer, and one of them is the impact biomechanics simulation mentioned above. In the project, we try to simulate the whole car crash accident and to predict the damages of a passenger by the supercomputer. The aim of the project is not only to enhance the safety of an automobile in an accident, but also to provide valuable information for the emergency rescue. However, for the project, we have to unify the all state of the art simulation techniques mentioned above, and we still have a long way to go to realize the entire car-accident simulation.

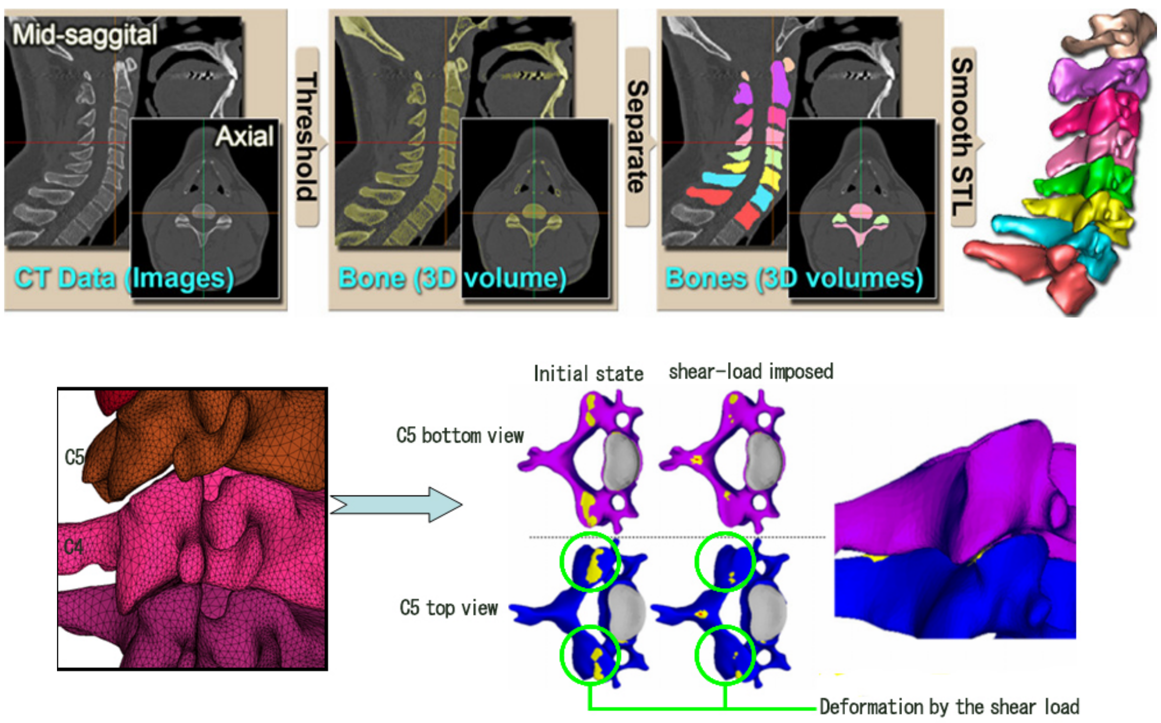

Fig. 8. Detailed analysis of the deformation of the intervertebral joint (above: FEM model construction from the CT data, below: deformation captured).

4. Concluding Remarks

Visualization has a huge variety of subjects and meanings. In this information-intensive society, visualization technique is in great demand as a communication tool. In fact, visualization is the most useful tool to express and figure out a phenomenon in such fields as a socioeconomy, politics, art, and sports, and the term *visualization* itself nowadays seems to become widely accepted and acknowledged. With regard to its application as a scientific analysis tool, we should consider following four topics: (1)What to be visualized (raising and figuring out an issue), (2)how it is visualized (choosing or developing a visualization technique), (3)how much it is visualized truly (validating the technique), (4)what was visualized exactly (explaining the results obtained). A great advance has been made in (2) and (3) for these twenty years, and various techniques have been organized and systematized. As mentioned above, the subject of both experimental and computational visualizations will be more and more abstruse, such as to develop an interface among multi-scale or multi-physics phenomena, and to explain fully dynamic objects.

References

Ejima, S. and Ono, K., A Study of Whiplash Injury Mechanisms Using Finite Element Human Model, Jido-sya Kenkyu, 29-3 (2007), 105-108 (in Japanese).

Holcombe, S. and Ejima, S., Development of Cervical Spine Finite Element Model for Facet Joint Injury Prediction, Proc. of JSAE Ann. Congress, (2007).

Kato, C., Kaiho, M. and Manabe, A., An Overset Finite-Element Large-Eddy Simulation Method with Applications to Turbomachinery and Aeroacoustics, Trans. of ASME, J. Appl. Mech., 70-1 (2003), 32-43.

Kano, M., Kobayashi, T. and Ishihara, T., Prediction of Turbulent Flow in Two-Dimensional Channel with Turbulence Promoters: 1st report, Numerical Prediction by Large Eddy Simulation, Trans. JSME B, 50-449 (1984), 257-264 (in Japanese).

Kobayashi, T. and Yoshitake, Y., Development of Digital Image Processing System for Pathline Pictures, Trans. of JSME B, 51-466 (1985), 1966-1970 (in Japanese).

Kobayashi, T. (edt.), Suuchiryuutairikigaku Handbook, (2003), 608-613, Maruzen.

Li, H., Hu, H., Kobayashi, T., Saga, T. and Taniguchi, N., Visualization of Multi-scale Turbulent Structure in Lobed Mixing Jet Using Wavelets, J. of Visualization, 4-3 (2001), 231-238.

Oshima, M., Multi-Scale and Physics Simulation of Organs, Tissues and Cells in the Cardiovascular System, 2nd Symp. on the "Revolutionary Simulation Software", (2007).

Tsubokura, M., Kitoh, K., Oshima, N., Nakashima, T., Zhang, H., Onishi, K. and Kobayashi T., Large eddy simulation of unsteady flow around a formula car on earth simulator, SAE 2007 World Congress, (2007), paper No. 2007-01-0106.

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