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the hardware used to collect the data and by the speed of computers used to process the data that prevents future progress? If so, advances in computing might mean that the Muescales referred to by you could be brought forward considerably and that vehicles might be able to operate at higher speed.

Answer *(Prof. C. Thorpe)*:
Is the main speed limitation the lack of computer power? Yes, mostly. If had much faster computers, we could drive more rapidly. There are still some sensor limitations. For instance, our range scanner takes 1/2 second to scan an image. If the vehicle moves too far during that time, we can get smeared or stretched images. Color cameras are faster, getting an image in 1/30 second, so maybe stereo vision will be better. But even with fast computers, there are still many areas that we do not understand well enough to build reliable systems for all situations.

"The Trends of Supercomputer"

Mr. M. Maruyama

Question
User environment is very important for usage and architecture of supercomputers. How many jobs are processed simultaneously at your supercomputer in typical?

Answer *(Mr. M. Maruyama)*:
Depending on situation, but typically 4 to 5 jobs are executed simultaneously.

Question
How do you think degree of parallelizm in general purpose application software?

Answer *(Mr. M. Maruyama)*:
There are the following four kinds of parallelizm; 1) job level, 2) subprogram level, 3) job step level, and 4) loop level. Job level is taken care by scheduler in the multiprograming environment. Subprogram level and job step level are depending on algorithm of applications. Loop level is similar to vector processing. Combining all parallelizm, degree of parallelizm is very high and multiprocessor architecture is natural for that purpose.

Comment *(Dr. T. Shimizu, S. Sakata)*:

Abstract
An Outline of the structure analysis program SIMUS, which was developed for HITAC S-810, is described. Some examples of computer simulation in structural design are shown. They are oxidation process of semiconductors, thermal stress variation during welding, and large deformation of a solid.

1. Introduction
In engineering and design of machines and devices prediction of their performance and reliability can be carried out by computers. Particularly in the development of new machines and devices a number of computer simulations are carried out to estimate vaious aspects of mechanical engineering such as structural integrity, vibration, fluid- and thermo-dynamics and so on. Recently a remarkable progress in computer simulation technology has been noted because of the introduction of supercomputers as well as advanced numerical analysis methods like the finite element method. In this paper some examples of computer simulation is mechanical engineering and design field are introduced.

2. Structure Analysis Program SIMUS for Supercomputer[1)]
Structure analysis program SIMUS and developed on a supercomputer of HITAC S-810/20. In order to fully utilize the powerful capability of the supercomputer, the following items are very important. (1) The use of D0 loop to get high ratio of vectorization (2) The use of longer vector to get high speed of vector operation (3) Parallel utilization of multi processors. The analysis model shown in Fig. 1 was used to see the capability of SIMUS in terms of computing time. Test results are summarzed in Table 1. The computing time was shortened to 1/30 compared with the conventional scalar operation.

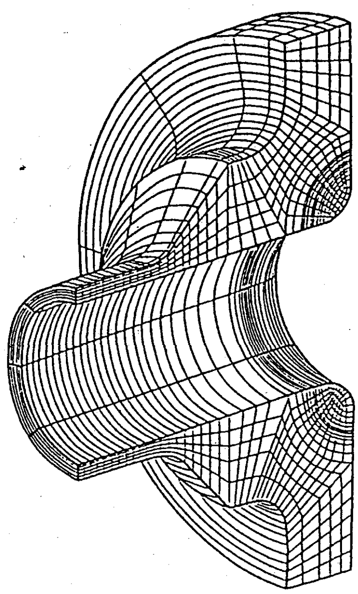


Fig. 1 Analytical model (Ex. No. 4)
No. of Node: 10077
D.O.F: 30231
No. of Element: 1992

3. Examples of Computer Simulation

LIFE ESTIMATION OF IC PLASTIC PACKAGES[2)]

In the temperature cycling test of plastic encapsulated integrated circuits (IC's), large thermal stress develop within the packages due to the thermal expansion mismatches among the elements of the structure. This stress sometimes causes cracking in the plastic encapsulants as illustrated in Fig. 2. Hence estimation of the temperature cycling life is an important issue in the structural design and materials selection of the packages.

The temperature cycling life of packages was estimated by analyzing the stress intensity factor K for cracked packages and measuring crack propagation characteristics of the encapsulants. The stress intensity factor K was analyzed as a function of the crack length by means of the finite element method. The crack length was varied from 0.05 to 1.45mm depending on the crack growth during the temperature cycling. An example of the finite element meshes used in the analysis is shown in Fig. 3. The total number of nodes and elements were 1264 and 2314 respectively. The computed K data were combined with the fatigue crack propagation rate data obtained with laboratory test specimens, and the crack propagation behavior in the package was estimated. An example of the estimated results is shown in Fig. 4. The tendency of the

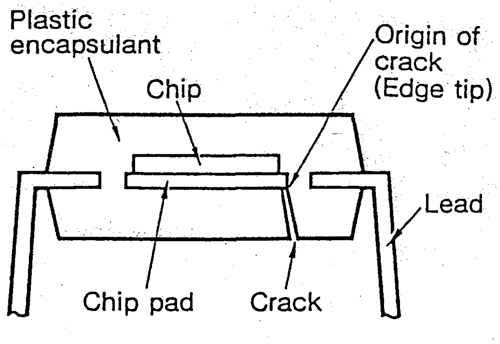


Fig. 2 Cross section of cracked package

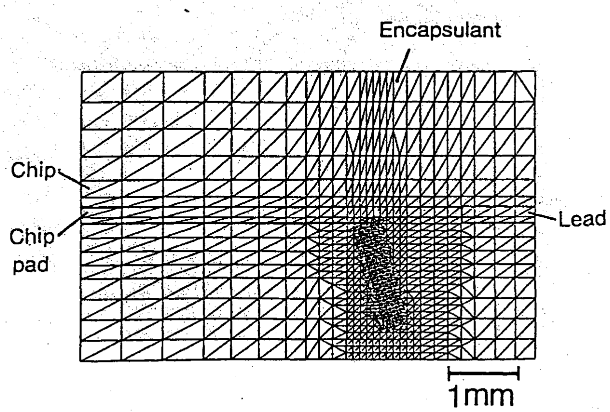


Fig. 3 Finite element mesh

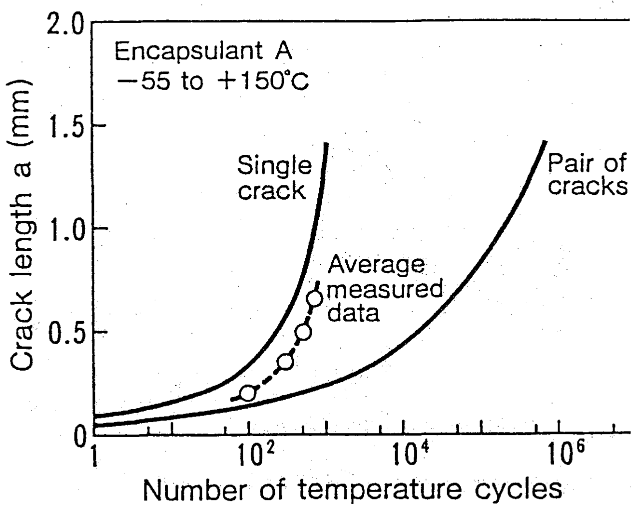


Fig. 4 Estimation of crack propagation behavior in package

estimated crack propagation behavior correlates fairly wel with the experimental data. This method enables packag designers to readily evaluate the effect of material pro perties and package geometry on the life of the packages.

SIMULATION OF OXIDATION PROCESS IN LS DEVICE[3)]

The thermal oxidation of silicon has played an importan role in the development of silicon integrated-circui technology. Stable silicon dioxide provides an excellen interface to the silicon substrate and is important in bot MOS and bipolar technology.

It is well known that stress is induced by the volum expansion resulting from a chemical reaction at the oxide silicon interface during silicon thermal oxidation. In local oxidation of silicon (LOCOS) structure, this oxida tion-induced stress often generates dislocations in silico depending upon the thermal oxidation conditions an nitride film thickness.

A two-dimensional oxidation model is introduces t analyze the stress induced in the oxide during silico thermal oxidation for the LOCOS structure.

In the model, it is assumed that oxidation consists of tw basic process: oxidant diffusion into the oxide an thermo-elastic deformation of the oxide. The analysis o this process is performed using the finite element metho the results are shown in Fig. 5.

THERMAL STRESS SIMULATION DURING WELDING[4)]

In pipe structures there are a number of weld joints suc as butt-joints, T-type and cross joints. These joints wer fabricated by welding which generates residual stress i the weld lines. In the view point of structural integrit

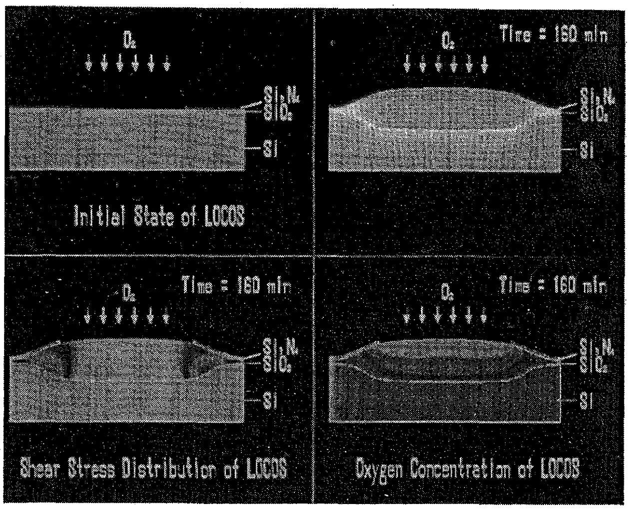


Fig. 5 Simulation of oxidation process of LOCOS

esidual stress may be harmful, because it degrades fatigue strength and corrosion resistant properties of the piping systems. Therefore it is very important to evaluate the magnitude of the weld residual stress and sometimes to reduce the stress with appropriate technologies.

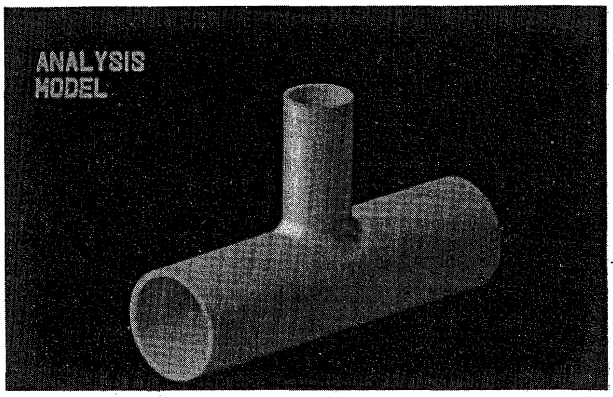
The case shown here is a T-joint pipe which is constructed by welding as in Fig. 6 (a). To evaluate the residual stress around the joint, thermal stress variations were analyzed during temperature cycling due to welding and IHSI (Induction Heating Stress Improvement). Analysis conditions are listed in Table 2. Fig. 6 (b) shows the residual stress distribution after welding and Fig. 6 (c) shows the one after IHSI treatment which is very effective in reducing the weld residual stress in piping systems.

LARGE DEFORMATION OF SOLIDS SUBJECTED TO IMPACT FORCE[3]

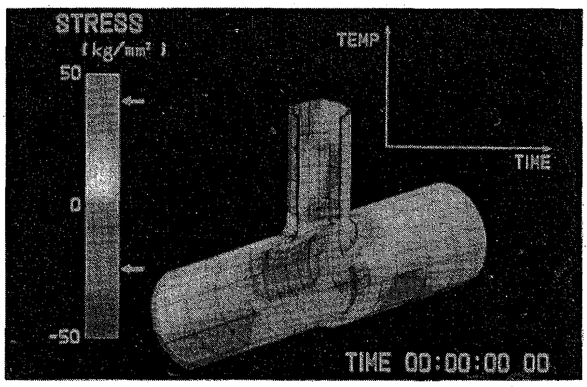
Dynamic, inelastic and large-deformation of solids and structures during blast or impact loadings can be analyzed effectively using an explicit finite element code, in which motion equations are integrated explicitly, especially with a supercomputer. Fig. 7 and 8 show an example of such a large deformation analysis, in which a golf ball is hit by a club head with an extraordinarily high speed of 200m/s. Tabe 3 and 4 show the computational parameters and results, respectively.

4. Future Trends of Computer Utilization in Structural Design

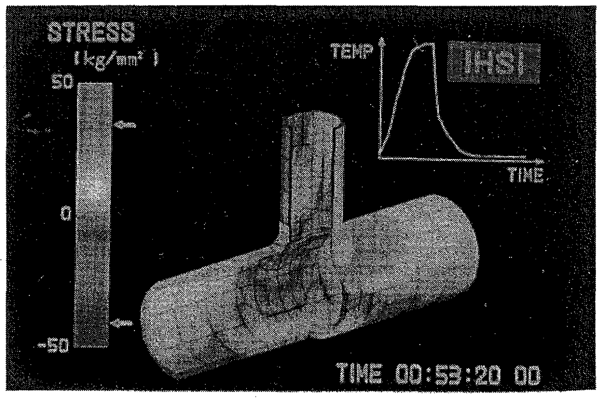
A supercomputer has shown its great power in engineering and design, as described above however greater capability is needed to solve highly nonlinear problems in a reasonable time in order to perform the design by simulation concept. Fig. 9 shows the trends of stress analysis and supercomputers. The computing speed will reach in GFLOPS range, then very highly nonlinear time dependent problems like LSI process simulation will be solved completely. As time goes on, the role of supercomputers in engineering and design becomes greater and greater to give designers the strategy of design with appropriate models. Then it is understood that modelling method is very important as well as numerical analysis one.



(a) Analysis model



(b) Weld residual stress



(c)Residual stress after IHSI

Fig. 6 Thermal stress simulation of pipe-to-pipe joint during welding and IHSI

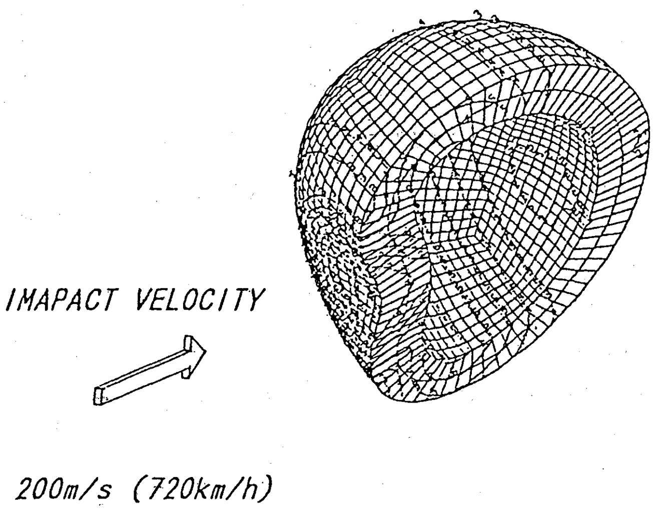


Fig. 7 Large deformation of golf ball at impact

Table 3 Computational parameters

Golf ball	Mass	45.4g
	Diameter	43mm
Number of elements		2400
Number of time steps		12500 (0~1ms)
CPU time used		6min (S810/20)

Table 4 Calculated results

Club head speed	Ball speed
200m/s	279m/s
100m/s	176m/s

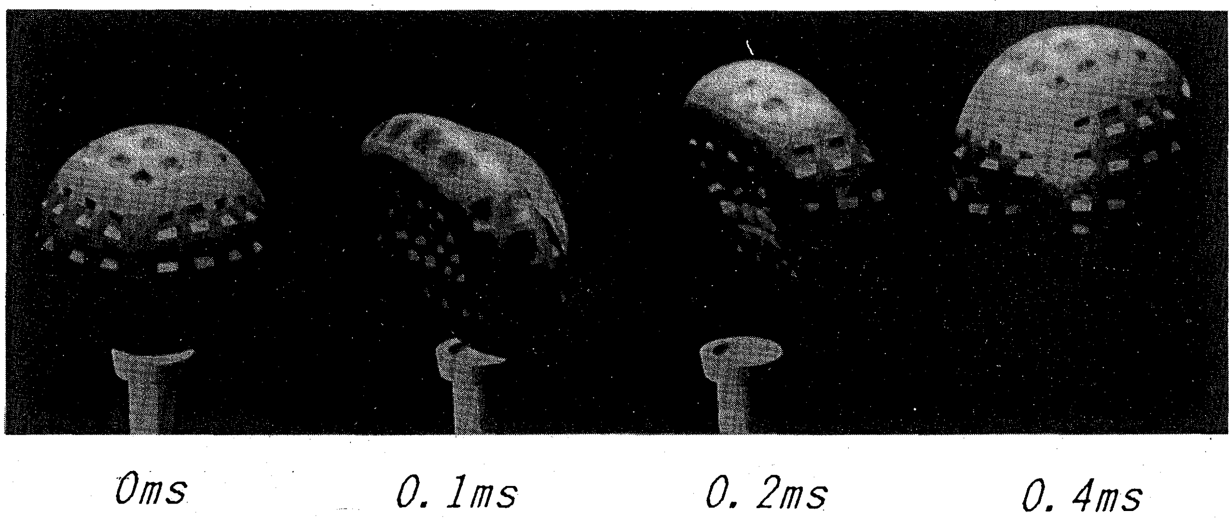


Fig. 8 Deformation of golf ball impact by club head with a speed of 200m/s.

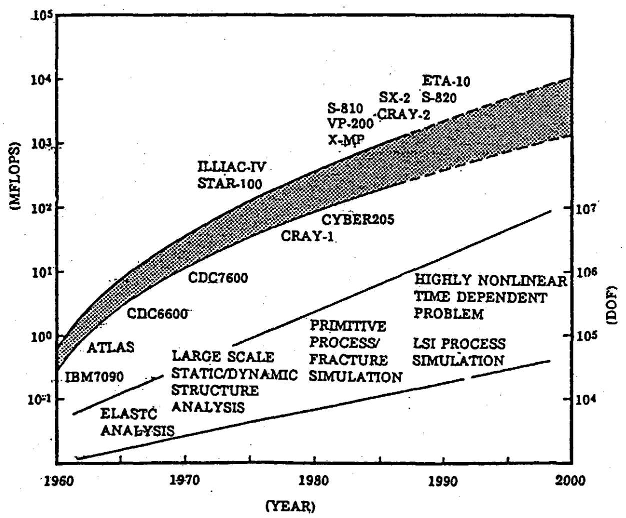


Fig. 9 Trends of Stress Analysis in Structural Design and Supercomputer

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Comment *(Mr. T. Kato)*:

Abstract
The history, definition, architecture, characteristics, applications and future trends of supercomputers are well discussed in the report of Mr. Mitsuru Maruyama of Century Research Center. In this discussion some of these aspects are reported from the following three points of view in order to supplement Mr. Maruyama's report; 1) Multiprocessor architecture, 2) Size reduction and cooling technology, 3) Some examples in the advanced computational mechanics.

1. Multiprocessor Architecture

In the science and engineering computations, sequential, array and input-output processings are all mixed. Therefore the well balanced performance improvement between those processings is essential to realistic reduction of computational time.

Almost all the current supercomputers are taking the approach so called vector-pipeline processing in order to increase performance to solve matrix equations which are delivered from most of the discreatizing methods such as finite element method and finite difference method.

Some supercomputers are taking multiprocessor approach in addition to vector-pipeline approach in order to take advantage of large scale paralleism often found in physical phenomenon as well as science and engineering computations. Already more than one thirds of the supercomputers now under operations are multiprocessor vector-pipeline computers.

This section discribes definition of substantial performance of supercomputers first and then discusses the necessity of multiprocessor supercomputers for improvement of substantial performance.

1.1 Substantial Performance

The current supercomputers are so called "vector-pipeline computers" which apply parallel processing technique to mainly vector arrays or should be said the inner-most Do-loops in the programs. Applying multipipelines and multi-functional units helps improvement of theoretical peak performance. The well known Amdahl's law express the characteristics of such vector-pipeline computers;

$$P=SR/(a+R(1-a)) \qquad (1)$$

where

P; performance, S; scalar performance,

R; maximum acceleration ratio, a; vectorized ratio.

One can say the peak performance of supercomputers does not represent the total system performance by observing equation (1).

In order to find the realistic total system performance, the following integrated Amdahl's law is defined;

$$\begin{aligned} P_S &= \int P da \\ &= \int (SR/(a+R(1-a)))da, \\ &= SR[\ln(a+R(1-1))/(1-R)], \qquad (2)' \\ &\doteq SR \ln(1/R)/(1-R) \quad \text{(for a=0 to 1.0)}, \qquad (2) \end{aligned}$$

or by normalizing equation (2)′, one can obtain

$$P_S = SR[\ln((a_2+R(1-a_2))/(a_1+R(1-a_1)))] / ((1-R)(a_2-a_1)) \quad \text{(for } a=a_1 \text{ to } a_2). \qquad (3)$$

We call this P_S of equation (3) the theoretical substantial performance which represents average system performance of vector-pipeline computers. Depend on one's own workloads, a_1 and a_2 can be defined. For the typical scientific and engineering workloads, one may choose 0.3 and 0.8 as a_1 and a_2, respectively. For the highly optimized scientific and engineering workloads, one may choose 0.5 and 0.95 as a_1 and a_2, respectively. From above equations, one can observe; a) scalar performance is still the dominant factor for the improvement of substantial performance, b) vector-pipeline system does not effect so much to the improvement of substantial performance in typical workloads.

1.2 Parallel/Multiple Processing

There are the following two ways to make twice or four times faster systems; a) to have twice and four times faster scalar and vector functional units in the CPU, b) to have twice and four times more scalar and vector functional units and use those in parallel. a) is very important and must be considered at first, it depends on, however; improvement of not only architectural design but also circuit technology and cooling technology. The current progress of those technologies is very rapid, but necessities for faster computers seems more rapid. Therefore, the higher dimension of parallel processing such as b) is natural choice. About multiple functional units, one way is to arrange some add-units and multiply-units in one CPU. But the usage of supercomputers is usually under multi-user and multi-job environment, therefore it is clear that multiple CPU arrangement is most appropriate from view point of effective usage of computational resource. The speed-up factor P_m of multiple processor computer systems is expressed by the following Ware's equation;

$$P_m = T[\partial(T/M) + (1-\partial) + q(\partial, M)], \qquad (4)$$

where T, ∂, M, q are processing time by single processor, parallelized ratio, number of processors and overhead, respectively. If the overhead can be ignored then equation (4) is same form as Amdahl's law. Some supercomputer manufacturers chose tightly coupled multiprocessor system with few very fast processors as shown in Figure 1 instead of many slow processors in order to achieve the

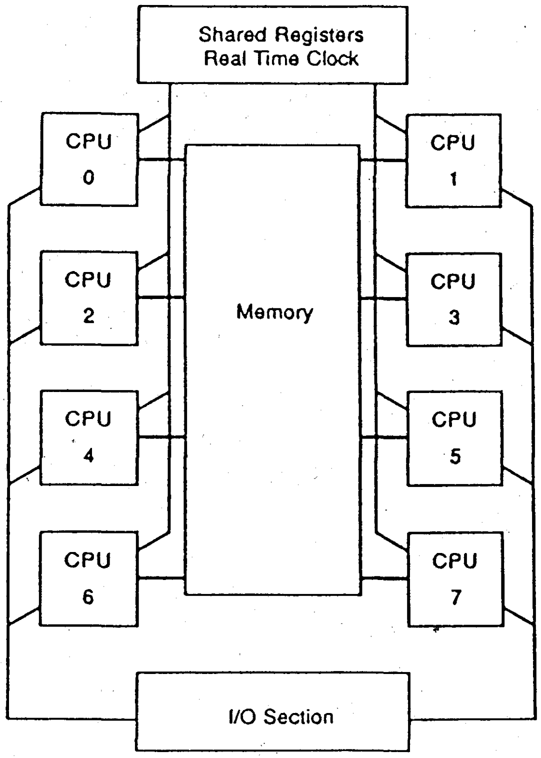

Figure 1 Tightly Coupled Multiprocessor

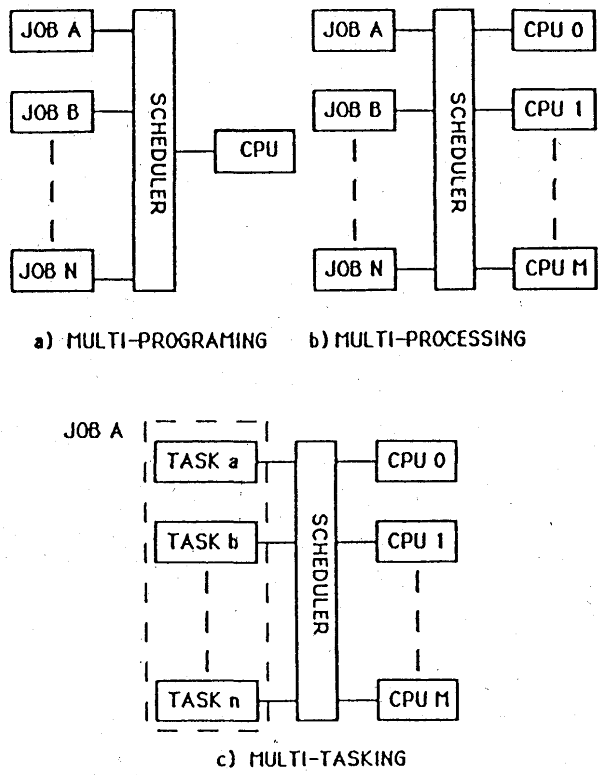

Figure 2 Parallel Processing

higher substantial performance. The advantage of tightly coupled multiple CPU systems shown in Figure 2 comparing to multiple pipeline, multiple vector processing units systems and losely coupled multiple CPU systems is to be able to apply three kinds of parallel/multiple processings such as multiprograming which utilizes one CPU to multiple jobs, multiprocessing which utilizes multiple CPUs to multiple jobs and multitasking which utilizes multiple CPUs to one big job in FORTRAN level. Figure 2 explains such parallel/multiple processings. For the jobs with low degree parallelizm multiprograming and multiprocessing can be applied as losely coupled vector-pipeline system and for the jobs with high degree parallelizm multitasking can be also applied as tightly coupled vector-pipeline system, therefore in the any kind of circumstances all the computational units can be effectively used in the tightly coupled multiprocessor systems.

2. Size Reduction and Cooling Technology

As discussed in the above section, building faster scalar and vector functional units in the CPU is very important to make computers faster. But also functional units and registers and main memory must be connected in shortest distance in order to minimize communication time between those elements. The most current circuit technology makes 2 nanosecond of machine clock period possible. 2 nanosecond is the time the light moves only 60 centimeters. If machine size is much bigger than 60 centimeters, then actual performance of the system becomes slower despite functional units can be operated as 2 nanoseconds of pipeline pitch.

It had been said that the size of large building is required to achieve computational power equivalent to human brain many years ago. However it was obviously wrong. Supercomputer must be small in order to reduce travel distance of electrons and increase computational power. In order to reduce the size of computer system the density of the internal circuit must be higher and higher density circuit causes higher heat even circuit itself is melted down by its own temperature. Stable and efficient cooling system must be applied in order to avoid such a trouble. The following liquid cooling technologies have been applied in the current supercomputers; 1) freon cooling which inside of chassis is cooled by similar manner as refrigerator, 2) freon cooling with thermal conduction modules, 3) liquid immersion cooling which all the circuits and power supply are immersed in the liquid such as carbon fluoride, 4) liquid nitrogen cooling, 5) carbon fluoride thermal conduction modules.

3. Example in the Advanced Computational Mechanics

Supercomputers have been well utilized among many scientists and engineers in order to simulate very complicated physical phenomena. The biggest factor of such as

upercomputers' success is in the vector processing tech-
ıique, which is applied in almost all the supercomputers, ince the vector processing is especially suitable to the natrix calculations and most of the discretizing tech-ıiques used for the numerical simulations are resulted in he matrix calculations.

ł.1 Impact Analysis

mpact problems of structures have been analysed in nany fields such as safety analysis of nuclear pressure 'essel, automotive crash, bird impact of airplane window hields and meteorite impact to spacecrafts by finite ·lement method.

Three dimensional impact analysis, which includes mate-ial and geometrical nonlinearities and transient response, ɔf structures is one of the most typical examples of simul-ıtions to be possible because of supercomputers' power.

Ⅎor low velocity impact, Lagrangian finite element method vith explicit integral scheme can be utilized well. Figure 3 hows such an example, automobile crash simulation. 45 ninutes to 4.5 hours of computation time is required to 'inish this nearly 7000 nodes and 8000 elements problem ɔn supercomputer system.

Ⅎor high velocity impact or structure-fluid coupled im-ɔact, Lagrangian finite element method can not be applied ınd ALE (Arbitrary Lagrangian Eulerian) finite element nethod is appropriate.

Ⅎigure 4 shows simple example of such a structure-fluid ;oupled impact analysis.

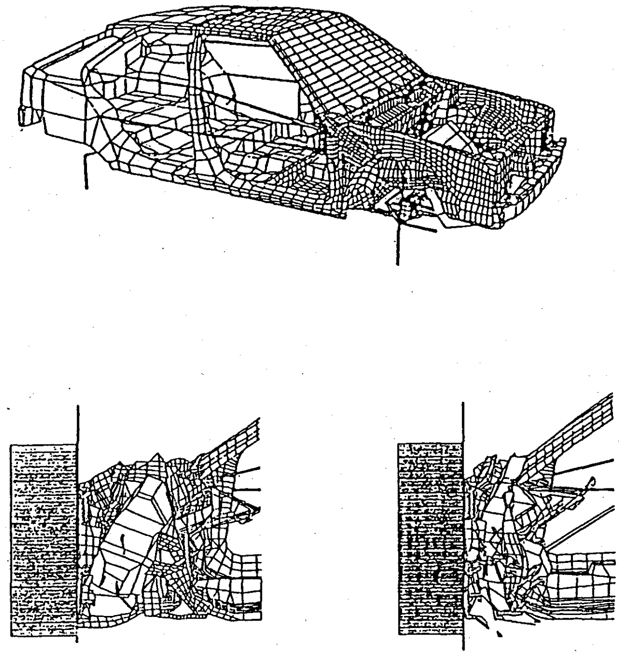

Figure 3 Automotive Crash Analysis

3.2 Metal Forming Processes and Solidification Processes

Sheet metal forming, drop forging and dye forging are the ;ubjects of metal forming processes. Casting, melting, ;olidification of artificial materials such as plastics and ıomogenization are the subjects of solidification pro-:esses. Those problems are usually having the coupling of thermal and mechanical characteristics in addition to the following characteristics common to the above impact problems; 1) Complicated geometry, 2) Geometrical non-linearity, 3) Material nonlinearity, 4) Contact & friction at the boundary.

If the problems are simplified then rigid-plastic behavior or elasto-plastic behavior can be assumed and fully implicit Lagrangian finite element method are applicable.

If material flows are large then the above simplification does not work and again ALE finite element method must be incorporated. Figure 5 shows simplified dye forging analysis, even such a simplified analysis with nearly 700 degree of freedom requires 10 to 50 minutes of computa-tion time on the supercomputers.

4. Conclusion

Finite element method has been well utilized in the advanced computational mechanics especially with super-computers. In order to solve more complicated problems

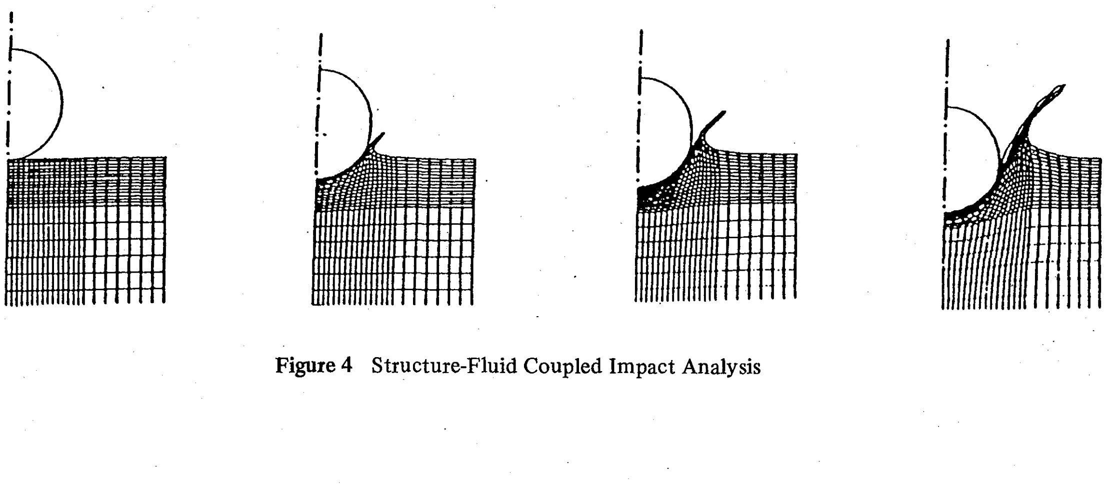

Figure 4 Structure-Fluid Coupled Impact Analysis

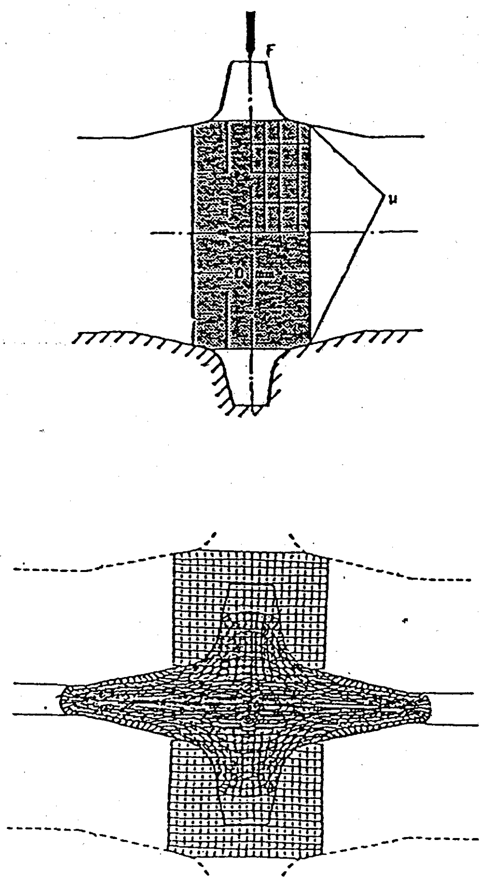

Figure 5 Dye Forging Analysis

typical approach of finite element method is being changed from implicit to explicit, from Lagrangian to ALE because of the following two reasons; 1) physical natures of the methods allow more complicated and more realistic problems to be solved, 2) the methods are more suitable to multitasking as well as vector processing to reduce computational time. Future supercomputers will be smaller but more memory, more number of CPUs and more single CPU vector and scalar power will be equipped along efficient and stable cooling technology.

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"Future Direction of Welding Structure Profuction"

Prof. J.L. Pan

Comment (*S. Fukuda*) :
As the products are getting more and more diversified and new welding technologies are emerging up, it becomes often necessary to introduce a new way of thinking.
In the former times. manufacturing was made in accordance with the requirements of design. But today we have new welding technologies such as laser or robotics. In applying these new techniques, it would be much easier if we change our design of machines and structures to suit to these new techniques rather than to apply new techniques to the conventional designs. Thus, it seems to me that we should not consider manufacturing alone but we should consider manufacturing and design interactively at the same time. I should be very happy if I could have your opinion on this point.

Answer (*Prof. J.L. Pan*)

1) Generally speaking, design should be reasonable so that manufacturing is possible. The manufacturing technique should be good enough to meet the requirements of design. Sometimes when a new manufacturing technique is found, it may tremendously change the relationship between design and manufacturing. For example, if EB or laser is to be used for welding of thick wall pressure vessels, it will change the design and ease the manufacturing.
2) Concretely if talk about arc welding robot application, I would like to say that the main direction is to improve the manufacturing technology. Because the design could not change the picture of uncertainty of manufacturing conditions. For example, inaccurate groove preparation and assembly of weldment made on site in open area. That is the reason why I emphasis the intelligent control of welding process and expert system for welding engineering.

Concluding Remarks

Prof. S. Fukuda and Prof. H. Murakawa

Up to now, computers have been utilized to process numbers. But symbolic processing is becoming easier and easier with the rapid improvement of computer environment. What should be emphasized is that numerical processing is of course very important but we should also pay more attention to the utilization of symbolic processing. One such example is the image processing Dr. Thorpe me