WHITE PAPER

Extending Innovation in Virtual Product Development with the IBM® Cluster Solution for Computer Aided Engineering

Sponsored by IBM
Srini Chari, Ph.D., MBA
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Executive Summary

Over the last 40 years, the use of Computer Aided Engineering (CAE) has increased by several orders of magnitude in industry and research laboratories, largely due to the impressive advances in computing architectures as well as in the algorithmic techniques created to exploit these architectures. Each major innovation in the computing industry has directly enabled CAE practitioners to solve more realistic and complex engineering design and simulation problems, resulting in better products faster. This investment by the community in adapting CAE applications to take advantage of newer computing architectures has paid off handsomely.

Many companies are discovering that CAE can slash production time, optimize designs, and prevent expensive rework. As a result, CAE has grown in importance earlier in the product development cycle, and no longer consigned to the final stages of the design and manufacturing process. Smaller component suppliers with limited skills and resources are increasingly using many CAE applications for more sophisticated analysis such as crash analysis, non-linear metal forming, and computational fluid dynamics in addition to traditional structural analyses. This has increased collaborative and iterative product development and design optimization throughout the manufacturing supply chain resulting in dramatic reductions in the time to market. In order to be competitive and responsive, small and medium suppliers are increasingly using CAE solutions that need High Performance Computing (HPC) systems. The availability of flexible and cost-effective cluster computing solutions compatible with desktop Computer Aided Design (CAD) environments has helped to further energize CAE adoption among these suppliers.

However, “White Box” (Clusters assembled from piece-parts with no single centralized support,) systems simply cannot meet all the business objectives for smaller manufacturing organizations that are often limited in skills and resources to manage and deploy distributed or cluster computing solutions. Specifically, they fail when it comes to: reduce total cost of cluster ownership, manage disparate servers, execute numerous and diverse CAE workloads concurrently, and achieve more flexible resource management. To reduce the total cost of ownership for manufacturers and their suppliers and manage an inherently diverse CAE workload, a flexible, affordable, balanced cluster environment with an optimized implementation of major CAE applications is needed.

The IBM Cluster Solution is a family of systems that provide the choice of several high-performance processors, storage, cluster operating systems and middleware, and high-speed interconnects. The IBM Cluster Solutions are delivered jointly with leading CAE application providers and supported by IBM. These reusable, certified, and customizable solutions aggregate and optimize a portfolio of hardware, software, and services components from IBM, AMD, Intel, Microsoft, Voltaire, major CAE application providers, and other business partners. They are tailored to maximize the total value of ownership for manufacturers and suppliers. The IBM Cluster significantly enables and extends engineering and design innovation throughout the supply chain. An affordable, scalable, and flexible solution; the IBM Cluster has even been deployed to advance CAE by solving some of the most challenging research problems.
Enhancing Computer Aided Engineering with the IBM® Cluster Solution

A Comprehensive and Flexible Industrial Strength Environment for Large Scale and Affordable Computational Fluid Dynamics and Structural Analysis

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Enhancing Computer Aided Engineering with the IBM® Cluster Solution

A Comprehensive and Flexible Industrial Strength Environment for Large Scale and Affordable Computational Fluid Dynamics and Structural Analysis

1. Introduction

Computer Aided Engineering (CAE) has revolutionized the process of design and development in the automotive, aerospace, process and chemical, and other industries. CAE slashes production time, optimizes designs, and prevents expensive rework. As a result, CAE has grown in importance earlier in the product development cycle, and no longer just consigned to the final stages of the design and manufacturing process.

This increased, routine use of CAE - structural analysis and computational fluid dynamics (CFD) - is often tightly coupled to the Computer Aided Design (CAD) process. This has substantially decreased the reliance on more expensive experimental techniques for applications such as stress and vibration analysis, crash analysis, metalforming, external aerodynamics, noise and vibration mitigation studies, and engine performance for both manufacturers and their suppliers.

CAE Combines Engineering, Mathematics, and Advanced Computing

In the last four decades, developments in novel algorithms, the increased and affordable access to high performance computers, and the availability of a broad range of commercial applications from companies such as ABAQUS, ANSYS, CD-ADAPCO, ESI, LSTC, MSC Software and others, have together further contributed to the widespread acceptance of CAE in the manufacturing and process industries and in government laboratories.

Effective CAE requires a fusion of interdisciplinary advances in engineering models, mathematical algorithms, information technology architectures, and disciplined software engineering. Moreover, the interdisciplinary nature of today’s large scale CAE problems (e.g., interior acoustics, crash analysis with biomechanical dummies, reacting turbulent flows, aerothermodynamics, propulsion, flight controls, vehicle climate modelling, etc.) requires the balanced use of computing capability for large scale non-linear simulations coupled with capacity computing capability for smaller production linear simulations.
Furthermore, a combination of high performance computing systems, massive storage systems, visualization and advanced instrumentation, applications and middleware, all connected by high-speed networks is needed for today’s CAE infrastructure.

**Linux Clusters Dominate High Performance Computing Environments**

The need to transcend Moore’s law through parallel computing has given rise to clusters, grids, and scalable parallel systems in recent years. Cluster computing integrates off-the-shelf commodity computers and resources that are integrated through hardware, networks and software to behave as a single computer with Linux as the dominant cluster operating system today. It goes beyond single-application parallel computing to incorporate load-balancing clusters and high availability clusters. The main benefits are scalability, availability, affordability, and performance.

Today Linux clustering is the dominant hardware trend in high performance computing, representing 52 percent of the high performance technical computing market and even higher in departmental or divisional environments, according to IDC.\(^1\) Adoption has been slowed by the need to transition applications and to improve cluster storage performance and cooling technology, and to reduce the total cost of ownership. Now, IDC believes clusters are becoming a standard method for managing workloads in technical computing centers.\(^2\)

**Large-scale CAE Applications Benefit from Cluster Computing**

CAE involves tackling a wide range of complexity in modeling structural and flow phenomena in or around complex shapes and geometries. The equations describing the physics are often a coupled system of non-linear, partial differential equations. These problems are often very large, tightly-coupled, and multi-scale. Parallel solution approaches based on parallel mesh-decomposition techniques are required to exploit these parallel or cluster architectures for large scale CAE problems.

Scalable cluster systems are tightly-coupled computers with high bandwidth and low latency interconnects between processors and even storage with an optimized message-passing library, such as MPI (Message Passing Interface). The IBM System Cluster 1350 is an example of a cluster computer that has been very effective in addressing these classes of challenging CAE problems.

**The IBM Cluster: Solutions Tailored to Maximize Total Value of Ownership**

The IBM Cluster Solution is a family of flexible, affordable, and powerful clustered systems packaged as racks and blades. The IBM Cluster ranks as the most flexible cluster platform available with the widest choice of processors, interconnects, software, and storage. Furthermore, clients have a choice of deploying IBM clusters from piece parts to completely integrated systems such as the IBM System Cluster 1350.

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\(^1\) IDC Research VP Christopher Willard, Ph.D., ISC 2006, reported in HPC Wire, June 30, 2006

\(^2\) Ibid.
Significant reductions in power consumption, cost, and space requirements are achieved through the use of innovative technologies in processors; advanced power, packaging and cooling; special and industry-standard interconnects delivering very low latency and high bandwidths; and scalable systems and storage management based on Linux. This performance, scalability, flexibility, and innovative design enables the affordable solution of a wide range of complex CAE problems today and in the future.

IBM Cluster Systems with several 100s of multi-core AMD Opteron or Intel Xeon nodes with the Linux operating system have been deployed for crash analysis and CFD at several automotive and airframe manufacturers. In some of these instances, the implicit structural analysis workload is currently being managed with systems based on the IBM POWER architecture.

**IBM Collaborates with CAE Application Developers to Drive Innovation**

CAE applications that are mapped, migrated, and optimized for the IBM Cluster architecture benefit greatly from this scalability and increased performance. This investment in application enablement permits higher levels of performance and scaling in newer generation of systems and technologies based on the IBM Cluster architecture. Worldwide, IBM continues its active collaboration with leading CAE applications developers to migrate and optimize their applications on the Cluster 1350 to solve challenging engineering problems in structures and fluids.

IBM offers access to pre-engineered and optimized Linux cluster configurations based on sizing expertise to run versions of leading providers of CAE applications including ABAQUS, ANSYS (Structures and Fluent), CD-ADAPCO, DASSAULT, ESI, LSTC, MSC Software, and others. Experience to date from the examples described later shows that large-scale fluid dynamics and non-linear structural analysis problems perform well and excel on the IBM Cluster while maintaining outstanding performance for smaller linear problems.

IBM also provides access to a wide range of HPC systems through the Deep Computing Capacity on Demand (DCCoD) centers. CAE applications developers and prospective users can test out and get in-depth experience on these systems in a cost-effective manner. This Deep Computing Capacity can be used to study large problems and generate solutions in interdisciplinary non-linear structural analysis and CFD on very large clusters.

**Tighter Integration of CAE with CAD Solutions Expands Design Optimization**

CAE solutions from major applications providers have become better integrated with desktop Computer Aided Design (CAD) environments. This enables the effective and rapid deployment of design and analysis solutions especially among smaller suppliers who currently have greater CAD expertise than CAE expertise. The availability of flexible and cost-effective cluster computing solutions compatible with desktop CAD environments will further energize increased CAE adoption.
IBM’s partnership with Microsoft and the planned support of the Windows Compute Cluster Server 2003 (WCCS) on the Cluster Systems will better integrate the CAD desktops to the CAE environment on back-end servers. The availability of validated, optimized CAE applications on Cluster Systems with WCCS will result in a tighter and very affordable integration of CAD with CAE. This will greatly benefit smaller organizations that have invested in desktop CAD solutions that typically use the Windows operating system. Smaller suppliers will now be able collaborate more effectively in design and development with larger manufacturers using CAE applications on WCCS and leverage their investments on CAD solutions on Windows desktops.

2. Overview of CAE Applications Trends – Computational Fluid Dynamics (CFD) and Structural Analysis

Computational and analytical sophistication is increasingly critical in structural analysis and fluid dynamics for optimal design and manufacturing. Extensive and increasing interdisciplinary studies combining structural analysis, fluid dynamics, and combustion drive up the demands on computing and data management capability.

*Modern CAE Requires Systems Optimized for Capacity and Large Scale and Coupled with Superior CAD Desktops*

Industrial CAE environments rarely rely on just one kind of application. Instead, they often run a mix of primarily finite element application and CFD software largely provided by a few key commercial software developers such as ABAQUS, ANSYS (Structures and Fluent), CD-ADAPCO, ESI, LSTC, and MSC Software. In addition, many specialized programs for more sophisticated non-linear analysis written in-house or elsewhere in the industry are also used. The solution of a single engineering problem frequently requires the application of several CAE applications and data is usually passed through proprietary neutral file formats, data interchange standards, or a system database. The tighter this integration is with CAD tools, the greater is the engineering productivity. Sophisticated non-linear structural analysis and computational fluid dynamics typically require large scalable computers while CAD tools run on desktops with superior graphics and visualization capability.

*Industrial CFD Problems Continue to Drive Large Scale Computing Requirements*

Direct solutions to the Navier-Stokes equations of fluid dynamics in typical vehicle configurations and operating conditions are still beyond the capability of today’s computing systems. Computations for chaotic, turbulent flows across various scales and regimes would require exascale (million teraflops) computers.

Fortunately, cluster systems with commercial CFD applications such as ANSYS FLUENT, STAR-CD, and others are often used to solve simplified forms of the Navier-Stokes equations to provide substantial engineering insights. The following table provides a summary classification of CFD applications and solution approaches. See the Appendix created from materials from the Bibliography for more details.
Equations | Mesh Types | Some Solution Approaches | Turbulence Models
---|---|---|---
- Euler | - Structured | - Finite Difference | - RANS
- Navier-Stokes | - Block-Structured | - Finite Volume | - DES
- Reaction-Diffusion | - Unstructured | - Finite Element | - LES
- Multi-Phase | - Overlapped | - Spectral | - DNS
| - Adaptive | - Explicit | | 
| - Meshless | - Implicit | | 

**Figure 1: Classification of CFD Applications**

**Structural Analysis Problems Require a Combination of Large Scale Parallel and Robust Capacity Computing**

Traditional linear structural analysis predicts the behavior of structures such as automobiles, airframes, bridges, and others by numerically modeling the physics of complex structures including all the details of geometry, materials, loads, supports, and failure theories. It proves the soundness of an engineering design without experimentally testing it. Advanced structural analysis examines dynamic response, stability and non-linear behavior. Typical industry applications include metal forming, crash analysis, and fracture mechanics.

The finite element method because of its versatility to handle multi-dimensional geometric complexity is the most widely used technique for computational structural analysis. The finite element method is inherently an unstructured grid approach that simplifies and solves the equations of structural mechanics. This method has been used for many engineering problems ranging from linear elastic structural analysis to more complex general-geometry, non-linear transient mechanics with complex material models. The solution approaches and algorithms have varied depending upon the geometry, physics, operating regimes and scales of interest, and availability of suitable computer architectures. Both implicit and explicit (primarily for crash analysis) time stepping approaches are used in conjunction with finite element methods. The following table provides a summary classification of structural analysis applications and solution approaches. See the Appendix created from materials from the Bibliography for more details.

Applications | Mesh Types | Some Solution Approaches | Material Models
---|---|---|---
- Linear static analysis | - Unstructured volume | - Finite Element | - Elastic
- Linear vibration analysis | - Unstructured surface | - Boundary Element | - Plastic
- Metal forming | - Adaptive | - Explicit | - Viscoelastic
- Crash analysis | | - Implicit | - Damage
- Fracture mechanics | | | |

**Figure 2: Classification of Structural Analysis Applications**
The Use of CAE Continues to Grow in Design and Development

More upfront CAE simulations are routine in the preliminary design and development phase. Parametric analyses over thousands of operating scenarios on very large meshes with 50 million or more unknowns are common in the aerospace and automotive industries.

In CFD, interaction aerodynamics, as opposed to component aerodynamics, is increasingly the norm as are interdisciplinary analyses such as design optimization, flight control, and interior acoustics.

In structural analysis, full vehicle dynamic response and crash analysis with occupant models are used in iterative design optimization studies. Crash analysis incorporates very sophisticated material models with very small explicit time steps to capture the rapidly changing physics. These simulations are very computationally intensive. Fortunately, most crash codes work well in parallel mode on cluster architectures with high-speed interconnects.

Figure 3: Results of Vehicle Crash with LS-DYNA and Experimental Tests (Courtesy National Crash Analysis Center)
Innovative Solution Approaches and a Comprehensive Computing Infrastructure Expands the Role and Value of CAE

The increased use of CAE in industry and the complexity of the simulations being performed, requires a combination of high performance computing systems, massive storage systems, visualization and advanced instrumentation, applications and middleware, all connected by high-speed networks. The computing challenges continue to push the envelope in high performance computing systems, algorithms, turbulence models, non-linear structural analysis, crashworthiness studies, geometric detail and scale. These CAE innovations will further expand the role and value of CAE in industry and research.

3. Computational Challenges in CAE

The need to transcend Moore’s law through parallel computing has given rise to multi-core processors, clusters, grids, and scalable parallel systems in recent years. Parallel solution approaches based on parallel mesh-decomposition techniques are required to exploit these parallel architectures for large scale CAE problems. Additionally, careful adaptation and tuning of these parallel algorithms on cluster platforms is needed to get the benefits of very large scalability and performance. Clusters based on standard microprocessors have been used to deliver performance for some CAE point-applications. However, many “white-box” systems are inadequate for the inherently diverse and complex CAE workload.

The Need to Transcend Moore’s Law through Parallel Computing

To process massive amounts of data, which provides valuable engineering insight; applications require massive horsepower, fueling the demand for clusters and scalable parallel computing using multi-core processors. These systems can be expanded with standard microprocessor nodes to keep pace with the increased processing needs driven by the dramatic growth of data and higher accuracy, especially for CFD and non-linear structural analysis. The growth in the resulting computing demands exceeds Moore’s Law. A scalable compute infrastructure is the only answer. Additionally, the price/performance ratios of these systems must make teraflops of processing power available at a fraction of the cost of a traditional supercomputer.

Novel Partitioning Schemes are Needed for CAE Applications to Scale

In general, many CAE applications can be adapted and optimized to scalable parallel architectures for large-scale simulations that require very high degrees of spatial and temporal resolution and accuracy. This requires the use of domain decomposition or mesh partitioning techniques coupled with the solution approaches. Many effective domain decomposition techniques have been devised over the last few decades. These approaches also work for complex geometries with unstructured meshes.
Large Scale CAE Applications Require Novel Parallel Algorithms and Systems

Very high performance computing is almost always accomplished through parallelism. However, obtaining parallel computing capabilities is difficult and complex because many practical CAE applications don’t multithread beyond a few processes. In order to scale further, parallelism must be at a very high coarse grain level. Novel algorithmic approaches in CAE based on domain or mesh decomposition strategies allow users to obtain the maximum advantage and scalability from parallel machines with large numbers of inter-connected processors. Domain decomposition techniques when coupled with parallel variants of multi-grid, explicit, and overrelaxation methods further accelerate complex simulations in fluid dynamics and non-linear structural analysis.

Careful System Specific Tuning is Needed to Further Boost Performance and Scalability on Cluster Platforms

Parallel application development and system performance for large-scale CAE applications also depend on the single processor and memory performance, the communication subsystem performance, I/O performance, and development tools for programming, debugging, and resource management. A significant improvement in performance and scalability can be obtained for CAE applications that are tuned and optimized for the specific parallel architecture. This often requires a combination of deep CAE algorithmic and parallel computing skills.

Clusters are used for a Wide Range of CAE Applications…But White Box Solutions are Still Inadequate

Finite element implicit structural analysis applications require cluster nodes with large memory and high performance I/O. At the same time, many crash analysis and CFD applications require large number of cluster nodes tied together with high-performance scalable interconnects and not much I/O.

In order to solve these growing compute requirements for complex CAE, “white-box” clusters are starting to become insufficient. “White-box” clusters with hundreds of processors are expensive to deploy and operate. The cost associated with providing support and maintenance grows exponentially. Also, management of such diverse collections of resources is difficult, and effective software solutions that can scale are only now beginning to appear in the market. Furthermore, the electrical power consumption and the physical facilities required to operate such large clusters are prohibitively expensive. These limitations of “white-box” clusters can be overcome with clusters such as the IBM System Cluster 1350 that have a wide-range of pre-engineered flexible hardware options, a balanced cluster software environment with systems and workload management, and optimized implementations of major CAE applications.

4. The IBM Cluster Solution

The IBM Cluster is a multi-server system, comprised of interconnected computers and associated networking and storage devices, and are unified via systems management and networking software to accomplish a specific purpose. With high-speed interconnects, it is particularly very effective for parallel CAE applications that use MPI
and domain decomposition. IBM provides a range of clustering flexibility built from piece parts for HPC savvy clients who benefit from the additional ability to better customize and optimize their CAE workload. While other clients benefit from a very robust integrated Cluster 1350 solution (described here in greater detail) with comprehensive support with pre-engineered and tailored CAE applications.

IBM Delivers Cluster Solutions across the Spectrum from Piece Parts to Integrated Solutions

IBM provides several clustering alternatives ranging from Roll Your Own (RYO) where the client bears all risk for sizing, design, integration, deployment, and warranty issues to a complete integrated solution (Cluster 1350) where a single point of contact is responsible for all issues.

Roll Your Own
For these clusters, the client orders individual components from a variety of vendors, including IBM. Then the client tests and integrates components or contracts with an integrator. Warranty issues must be addressed with each vendor.

IBM Racked and Stacked
Here, the client orders servers and storage in standard rack configurations from IBM. Then the client integrates IBM racks with 3rd Party components or contracts with an integrator. Client must address warranty issues with each vendor.

IBM Business Partner Integrated
The IBM Business Partner orders servers and storage from IBM and networking from 3rd Party vendors. Then the partner builds and integrates components and delivers to customer. Client must address warranty issues with each vendor.

IBM System Cluster 1350
A client orders the integrated Cluster 1350 solution from IBM, including servers, storage and networking components. IBM delivers factory-built and tested cluster ready to “plug-in” and the client has single point-of-contact for all warranty issues.

As shown in the figure, the IBM System Cluster 1350 has a wide-range of standard components that could be used separately in other types of computing configurations with compute nodes, networking adapters and switches, local and/or external storage, systems management software, and supports a portfolio of validated and optimized CAE applications. It can be configured and deployed to serve a broad range of functions, from server/workload consolidation to high-performance parallel computing tasks.
A Familiar, Optimized, and Innovative Software Environment

Three fundamental principles were followed when the system software was designed for the IBM Clusters: simplicity, performance and familiarity. Driving toward simplicity in the software design has allowed development of software that takes advantage of hardware features to deliver high performance without compromising stability and security. And by creating a programming and administration environment based on familiar programming languages, libraries, job management tools and parallel file systems, CAE application developers benefit from the innovative design elements of IBM Clusters without facing a steep learning curve.

Integrated with High Performance Visualization, File Systems, and Middleware

As mentioned earlier, in addition to high performance computing systems, massive file/storage systems, visualization and advanced instrumentation, middleware, all connected by high-speed networks are also needed for today’s CAE infrastructure.

With IBM’s Deep Computing Visualization, high-end graphical images are created in two visualization modes:

- Scalable Visual Networking (SVN)
- Remote Visual Networking (RVN)

SVN supports multiple high-resolution monitors or projectors for immersive, stereo visualization. RVN distributes graphical images to remote (collaborative) client stations.
These features help derive more accurate engineering insights from the higher resolution of the complex data obtained from CAE simulations on IBM Clusters.

The following High Performance Computing cluster software is now available on IBM Clusters: the General Parallel File System (GPFS) for Linux and Tivoli Workload Scheduler LoadLeveler for Linux. GPFS is the top performing cluster-wide file system for IBM Clusters, providing superior scalability and high reliability. Tivoli Workload Scheduler LoadLeveler is a job scheduler designed to maximize resource utilization and job throughput to get the most out of the available resources. IBM Clusters also support other workload management solutions available from partners. This combination of middleware enables the optimization and scaling of the IBM Cluster resources (processors and storage) for several, concurrent CAE simulations typical in parametric or design optimization studies.

**Innovative Power and Cooling Benefits**

The IBM energy management portfolio tackles the challenge to increase power and thermal efficiency and reduce costs on many levels. First, inside the system, all IBM System x™ and BladeCenter® servers start with Calibrated Vectored Cooling technology, which allows dual paths of air to each component, improving uptime and longevity, and reducing wasteful air movement and heat generation. Coupled with more-energy-efficient power supplies, IBM BladeCenter and System x servers can generate less heat in the critical AC-to-DC power conversion than many alternative systems from the competition. For clusters within a rack, IBM System x servers are designed to work at full density in a well-planned rack solution. They are also designed to operate at extended temperature ranges to keep the system up and running — even in extreme temperature and failure conditions. IBM rack-based cluster solutions are engineered to optimize air flow and prevent undesirable recirculation within the rack, so servers can run in optimal temperature conditions.

Blades-based clusters enable clients to pack more processors into the same power and cooling envelope as well as better utilize floor space and "right size" data-center design. With IBM BladeCenter, less power per processor means more processing capacity per kilowatt. The IBM BladeCenter runs cooler to deliver greater reliability. IBM believes that cooling and power costs could be reduced by up to 45% compared to the competition over the average life cycle of a cluster system.

For dense data center environments, IBM provides smart rack-level heat solutions like the super-efficient IBM Rear Door Heat eXchanger. The water-cooled door is designed to dissipate heat generated from the back of the rack to reduce the overall room temperature.

The IBM PowerExecutive™ solution is available for selected IBM BladeCenter® and System x™ servers and allows direct power monitoring through IBM Director. This solution helps customer monitor power consumption to allow better utilization of available power resources.
With this combination of benefits at the server and data center level, IBM systems can provide strong power and cooling benefits to Cluster 1350 customers. Check out http://www-03.ibm.com/systems/x/eei/ for additional materials.

**Technical Details of the IBM System Cluster 1350: A Cost Effective, Flexible, and Scalable Architecture**

The IBM System Cluster 1350—IBM’s high-performance, high-density Linux® cluster solution has a family of cluster node choices. There rack servers and IBM BladeCenter® blades designed with Intel® Xeon™ or AMD Opteron™ processors, adding to a portfolio of x86 architecture-based nodes. In addition, the IBM BladeCenter QS20 blade, featuring IBM’s Cell Broadband Engine™ (Cell BE) technology, can also be a Cluster 1350 node. When coupled with Power Architecture™ based IBM System p5™ servers and BladeCenter JS21 blades, Cluster 1350 clients can select the processor technology and system packaging that is exactly right for their CAE requirements.

Nodes designed with dual-core AMD Opteron processors include:

- IBM System x3455 – 1U (1 EIA unit) rack-mount server
- IBM System x3655 – 2U rack-mount server
- IBM System x3755 – 4U rack-mount server
- AMD Opteron LS21 for IBM BladeCenter – single-width blade
- AMD Opteron LS41 for IBM BladeCenter – single or double-width blade

Nodes based on dual-core Intel Xeon processors include:

- IBM System x3550 – 1U rack-mount server
- IBM System x3650 – 2U rack-mount server
- IBM BladeCenter HS21 – single-width blade
- IBM BladeCenter HS21 XM – single-width blade with 8 DIMMs

Nodes based on the Power Architecture include:

- IBM System p5 505 and 505Q – 1U rack-mount servers
- IBM System p5 510 and 510Q – 2U rack-mount servers
- IBM System p5 550 and 550Q – 4U rack-mount servers
- IBM BladeCenter JS21 – single-width blade

The Cluster 1350 combines the power of this extremely broad range of node choices with IBM Cluster Systems Management (CSM) for Linux software, IBM storage products and leading third-party networking components to create integrated, flexible offerings for
CAE environments. Cluster 1350 hardware is delivered configured, tested, and ready for software installation.

**A Wide-Range of Peripheral Options for High Performance**
The Cluster 1350 comes with several storage, switch technology and performance acceleration options – broadening choices for configuring Cluster 1350 solutions to meet custom requirements. The IBM System Storage™ DS4700 Express storage system offers up to 33.6TB of high-performance Fibre Channel disk storage. Ethernet switch options include the Force10 Networks E600i chassis and the Cisco Catalyst 6500 Series of Ethernet switches. Components for configuring clusters with InfiniBand interconnect technology delivering very low latency and high bandwidths are:

- Cisco SFS 7000P InfiniBand Server Switch
- Voltaire Grid Switch ISR 9024
- Voltaire InfiniBand Pass through Module
- Voltaire SDR and DDR Daughter cards for IBM BladeCenter
- QLogic InfiniBand HTX (HyperTransport Expansion) Adapter

**A Comprehensive Software Environment and Support**
Cluster 1350 systems are managed by Cluster Systems Management (CSM) for Linux Multiplatform V1.6 or CSM for Linux on POWER™ V1.6. CSM for Linux provides resource monitoring, automated operations, remote hardware control and command execution, configuration file management and parallel network installation. And, it helps ease administration and may reduce life cycle costs by allowing management of an entire Cluster 1350 system from a single management node. As workload demand increases, CSM allows incremental growth of the Cluster 1350 configuration without necessarily increasing the management complexity.

Optional software including IBM General Parallel File System (GPFS) for Linux V3.1 and HPC tools such as compilers, debuggers and libraries are available.

The Cluster 1350 supports these Linux distributions:

- Red Hat Enterprise Linux 4 (RHEL 4) AS and WS 64-bit
- SUSE Linux Enterprise Server 9 (SLES 9)

Installation Support Services are available through the Cluster Enablement Team (CET). CET is a technical team of Linux cluster software engineers, technicians and project managers skilled in the latest Linux hardware and software technology. This team can provide clients with Linux cluster services such as project management, pre configuration and cluster burn-in, software installation and interoperability, training, skills transfer and code porting and optimization.
IBM System Cluster 1350 Features and Benefits at a Glance

The IBM System Cluster 1350 is accompanied by a product and solution roadmap that will deliver increased performance and benefit for CAE applications. IBM continues to build and integrate new hardware, software, and solution components. The recent announcement to support Microsoft’s Windows Compute Cluster Server 2003 (WCCS) is just one example. The salient system details and benefits for the IBM System Cluster 1350 are summarized in the following table.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Benefits</th>
</tr>
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<tbody>
<tr>
<td>Integrated and tested hardware supported by IBM</td>
<td>• Provides validated configuration with a single point-of-contact for continuing support</td>
</tr>
<tr>
<td></td>
<td>• Can optimize time-to-production for high-performance Linux or Microsoft-based applications</td>
</tr>
<tr>
<td>Advanced IBM System x™ hardware</td>
<td>• Unique IBM Enterprise X-Architecture™ delivers powerful, scalable and reliable Intel processor-based nodes</td>
</tr>
<tr>
<td></td>
<td>• Revolutionary BladeCenter design delivers the optimal combination of performance, density and integration</td>
</tr>
<tr>
<td></td>
<td>• AMD Opteron processor-based systems optimized for HPC and BPC application environments, especially those that require maximum processor, processor/memory, and I/O bandwidth</td>
</tr>
<tr>
<td></td>
<td>• IBM PowerPC processor-based blade servers with competitive price/performance for versatile 64-bit peak computing including execution of operations on the same data set in parallel</td>
</tr>
<tr>
<td></td>
<td>• IBM processor-based nodes provide the reliability and performance of IBM Power Architecture™ for a variety of application environments</td>
</tr>
<tr>
<td>Power and Cooling</td>
<td>• Calibrated Vectored Cooling, Energy efficient power supplies, low-voltage processors, IBM Power Executive, IBM Power Configurator, Thermal Diagnostics</td>
</tr>
<tr>
<td>Industry-leading components</td>
<td>• Diverse component portfolio provides wider configuration choices</td>
</tr>
<tr>
<td></td>
<td>• Help maintain lower costs without compromising high quality and performance</td>
</tr>
</tbody>
</table>

Figure 5: IBM System Cluster 1350 Features and Benefits at a Glance

5. The IBM Cluster Solution Excels at CAE

IBM Cluster solutions perform very well for the inherently diverse CAE workload. Traditional implicit structural analysis applications such as ANSYS, ABAQUS, and explicit applications such as LS-DYNA and CFD codes like ANSYS FLUENT perform very well.

Prominent Commercial CAE Applications Perform Very Well on IBM Clusters

Recent advances in domain decomposition techniques make IBM Clusters with a high-speed interconnect such as InfiniBand very suitable for large-scale CFD and many non-linear structural analysis problems. These crucial engineering problems in the industry will require the computing performance and scalability that is practical only with large
number of cluster nodes. Many “bread and butter” implicit structural analysis
applications do not yet support domain decomposition approaches however most
support parallelism at the solver level and scale moderately.

**Large-Scale CFD Problem Scale Well**
Large scale CFD problems with over a million unknowns scale well when domain
decomposition techniques that are effective in balancing the computing load are coupled
with parallel solvers. Detached Eddy Simulations (DES) and Large Eddy Simulations
(LES) often require a very fine mesh that results in very large numbers of unknowns.
The ANSYS FLUENT CFD application demonstrates very good scalability and
performance. Also, interdisciplinary problems with multiple physics and/or shocks
increase the problem scale making the larger clusters even more attractive.

Complex, coupled, computationally challenging problems in flight control simulations,
design optimization, parametric studies iterating over thousands of design-space
parameters, and chemically reacting flows with multiple species also benefit
significantly from IBM clusters. These problems have additional unknown variables per
grid point beyond the normal fluid flow variables (velocities and pressures) thus
increasing the computational problem size. Also, many parametric simulations can be
done concurrently on multiple IBM Cluster partitions. All this will significantly reduce
simulation time for large-scale CFD.

**Explicit Nonlinear Crash Analysis Applications Scale Well**
Crash analysis problems with a few hundred thousand elements also benefit from
domain decomposition techniques. Solution providers such as LSTC (the developer of
LS-DYNA) have invested significantly to develop scalable parallel versions that not only
scale well on clusters but also accurately model very complex structural physics with
multiple contacts and impacts. Multi-car collisions modeling air-bag deployment and
dummy occupants require large clusters with very low latency interconnects such as
InfiniBand.

**Implicit Structural Analysis Applications Scale Moderately**
Implicit structural analysis applications without domain decomposition often do not
benefit much from large-scale parallelism especially over multiple sockets on clusters.
However, they benefit significantly from increased processor and I/O performance and
larger memories that are available on the IBM clusters. For example, Distributed ANSYS
does exhibit good scaling on a few processors especially with high-speed interconnects
such as InfiniBand.

**Tuning Further Enhances Scalability and Performance**
To take advantage of the IBM Cluster architecture, substantial performance tuning can
be achieved by careful load balancing, maximizing single socket performance,
maintaining data locality, minimizing cache misses, and maximizing the computation-to-communication ratio. Application performance can be further enhanced by the use of
optimized mathematical libraries and high-performance I/O solutions like GPFS.
This requires a very structured approach. It consists of first porting the application, then validating it on the IBM Cluster, and finally optimizing the application on the IBM Cluster. Careful performance tuning can enhance the performance of the application significantly but requires a deep understanding of the application and the cluster architecture. The investment made in developing these validated, optimized versions enables the solution of larger-scale problems with a substantial payoff in terms of obtaining engineering insight and value. Furthermore, this investment is continually enhanced as newer generations of cluster systems incorporating new components become available.

IBM provides access to clusters through the Deep Computing Capacity on Demand (DCCoD) center and several innovation centers around the world. Working collaboratively with IBM CAE experts, application developers and prospective users can test out and get in-depth experience on IBM’s latest cluster offerings in a cost-effective manner. For example, IBM is working very closely in Germany with ABAQUS.

**Examples**

IBM continues to work with CAE application developers to migrate and optimize their applications on clusters. These representative examples range from non-linear crash analysis to traditional implicit linear structural analysis. These examples illustrate the flexibility and performance of IBM clusters for an inherently diverse CAE workload. Moderate to large size examples have been chosen to demonstrate the unique value proposition of IBM clusters and the deep IBM CAE expertise in building tailored solutions.

**LS-DYNA**

LS-DYNA is an explicit finite element program for the analysis of the non-linear dynamic response of three dimensional structures developed by Livermore Software Technology Corporation (LSTC). Applications include vehicle crashworthiness, occupant safety and protection, and metal forming studies. LS-DYNA has nearly 100 material models to simulate a whole range of engineering materials from steels to foams. Version 970 has a very fast scalable parallel version which performs very well on IBM clusters.

A very large analysis on an IBM BladeCenter HS21 with Intel Xeon dual-core 3.0 GHz processors scales very well on the InfiniBand interconnect but doesn’t on a Gigabit Ethernet. This simulation for 2 milliseconds on a finite element model with 3.5 million elements does not include initialization time which is often very low. This example also illustrates the value of the InfiniBand interconnect for LS-DYNA whose performance is sensitive to the interconnect latency.
ANSYS

ANSYS is a general purpose finite element program that can be used in virtually any industry ranging from automotive to biomechanics. It solves linear and non-linear structural, thermal, electromagnetic, fluid dynamics, and coupled problems. Both direct and iterative solvers are used.

A moderately large linear static analysis with 750K degrees of freedom on the IBM Cluster x3455 scales well on a small number of CPUs. ANSYS recommends using high performance I/O and large memory on each node. Moreover, Distributed ANSYS requires high-speed interconnects such as InfiniBand for very large jobs to pass the several hundreds of gigabytes between processors for very large jobs with over 1 million degrees of freedom. These recommendations could extend scalability further.
Figure 7: ANSYS Performance on the IBM Cluster x3455 with AMD Opteron Dual-Core 2.4GHz for Linear Static Analysis with 750K Degrees of Freedom

ABAQUS
ABAQUS/Standard is a traditional implicit finite element analysis for static, dynamics, thermal problems with a wide range of contact and nonlinear material options. A moderately large analysis with about 470K degrees of freedom on the IBM Cluster x3455 scales well on a small number of CPUs.
**Figure 8: ABAQUS Performance on the IBM Cluster x3455 with AMD Opteron Dual-Core 2.4GHz 470K Degrees of Freedom**

**ANSYS FLUENT**

ANSYS FLUENT is a multi-physics CFD application that models compressible and incompressible flow, turbulence, heat transfer, and acoustics. It is widely used in the automotive and aerospace industries. The ANSYS FLUENT benchmark is composed of 3 sets of small, medium, and large problems. The benchmark is reported as a rate with higher being better.

IBM has recently conducted an extensive study on ANSYS FLUENT performance on the BladeCenter (ftp://ftp.software.ibm.com/eserver/benchmarks/wp_Fluent_021307.pdf). ANSYS FLUENT enables parallelism through domain decomposition and MPI. Since low latency is critical for performance, ANSYS FLUENT benefits from InfiniBand. The three large ANSYS FLUENT benchmarks scale very well on the IBM HS21 XM using 3.0 GHz Intel Xeon 5160 processors with InfiniBand.
6. The Future of CAE on Clusters

The economies of scale, scope, and power offered by cost-effective standard processors from Intel, AMD, and IBM will continue to increase the penetration of clusters in CAE. Smaller suppliers will increasingly use sophisticated CAE applications as they become more tightly integrated with desktop CAD environments. In order to compete, CAE application providers will need to support the distributed memory cluster architecture with scalable parallel versions of their applications. Once again, the symbiotic relationship between CAE applications and advanced computing architectures will enable engineers to innovate in product design.

Cluster Penetration will Increase as Differentiated Integrated Solutions are Delivered

Many manufacturing businesses have already realized the value of building their own Linux and Microsoft clusters using commodity hardware, standard interconnects and networking technology, open source software, and in-house or third-party applications. They are also increasingly realizing that the expense and complexity of assembling, integrating, testing and managing these clusters from disparate, piece-part components often outweigh any benefits gained. Companies such as IBM have built integrated
cluster solutions such as the IBM System Cluster 1350 that significantly reduce these costs and complexities for most engineering businesses.

Advances in power and cooling technologies, virtualization, storage and data management technologies, and pre-architected CAE solutions delivered jointly with major CAE application providers will further increase the adoption of these integrated cluster solutions.

**Tighter Integration Among CAE Applications and with CAD will Continue to Expand CAE Adoption**

CAE solutions from major ISVs have become better integrated with CAD/CAM environments. This enables the effective and rapid deployment of design and analysis solutions.

In the past, suppliers were often reluctant to embrace CAE because they incorrectly believed that only highly paid analysis specialists could grasp and apply non-linear structural analysis and CFD tools. The reality is that engineers can become competent in many available CAE tools with some basic training and practice.

Furthermore, many advanced applications such as LS-DYNA have been integrated with more mainstream environments such as MSC Software and ANSYS. In fact, both MSC Software and ANSYS market a version of LS-DYNA that has been integrated with their other standard offerings. The recent acquisition of FLUENT by ANSYS is another indicator of this trend in the CAE industry.

**In Order To Compete, CAE Applications Providers will Expand Investment and Support on Clusters**

In order to obtain the best parallel performance on clusters, CAE providers must use domain decomposition or sub-structuring approaches. Domain decomposition methods and parallel solvers are already being used in most CFD and crash analysis commercial codes. There is little doubt that distributed memory clusters will become the most dominant CAE platform. Furthermore, software providers such as UGS have a distributed version of NX Nastran that performs well on clusters. It is imminent that other dominant providers of implicit structural analysis applications will soon provide scalable parallel versions of their applications in order to compete.

In the early 1990s, LSTC – then a smaller provider of crash analysis solutions - was early to support distributed memory parallel architectures. The early scalable versions of LS-DYNA had limited functionality. Today, the scalable parallel version of LS-DYNA not only supports all the LS-DYNA functionality, it is also, perhaps, the most dominant crash analysis code.
7. Conclusions: The IBM Cluster Solution Enables Industrial Strength CAE

As shown in the examples, IBM clusters perform very well on large-scale industrial CAE problems. There has been a lot of progress over the last several years to overcome challenges in solution approaches, algorithms, and domain decomposition techniques. Both large-scale flow problems and crash analysis applications scale very well on IBM clusters with high-speed interconnects such as InfiniBand. Traditional implicit structural analysis applications also do benefit from the flexibility of hardware options, superior I/O and memory performance, and high-speed interconnects.

An integrated solution, the IBM System Cluster 1350 has a wide-range of pre-engineered flexible hardware options, a balanced cluster software environment with systems and workload management, and optimized implementations of major CAE applications. This is a very robust and scalable platform for industrial strength CAE. For the first time, many smaller suppliers with limited in-house skills will have an affordable CAE solution that will give them a competitive edge.

Acknowledgements

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References and Additional Reading


15. ANSYS, http://www.ansys.com


17. ABAQUS, http://www.abaqus.com

18. FHWA/NHTSA National Crash Analysis Center, http://www.ncac.gwu.edu
Appendix: Classification and Characteristics of CAE Problems

Both Computational Fluid Dynamics (CFD) and structural analysis approaches are described here in greater detail complementing the main section.

Applications

CFD Applications are Commercial and Research
Both commercial-off-the-shelf (COTS) and tailor-made, in-house codes (SOURCE) have been used for tackling CFD problems. In general, in the automotive industry, COTS codes such as ANSYS FLUENT, STAR-CD, AVBP, ANSYS/CFX, etc. have been used extensively for a wide range of applications such as external aerodynamics, underhood cooling, oil pumps, climate control, intake/exhaust manifold design, in-cylinder combustion, turbomachines, interior noise reduction, and catalytic converters. The aerospace industry uses a combination of COTS and SOURCE codes that have been adapted and customized from research and academic codes. Some examples are TRANAIR, FUN3D, NSU3D, and Overflow-D. Applications in the aerospace industry include aircraft aerodynamics, space vehicle aerothermodynamics, propulsion, missile aerodynamics, gas turbine combustion and flows, flow controls, and escape systems.

Structural Analysis Applications are Primarily Commercial
Commercial codes are widely used for structural analysis. These applications are widely used in the automotive and aerospace industry for component stress analysis, vibration analysis, metal forming, crash analysis, forging, aircraft flutter, design optimization and others. Traditional “bread and butter” structural analysis codes include implicit codes from providers such as ABAQUS, ANSYS, and MSC Software. Major explicit crash code providers are ESI and LSTC.

Solution Approaches – Structural Analysis Largely Uses Finite Element Methods
Most approaches follow the same basic procedure:

1. The geometry (physical bounds) of the problem is defined,
2. The volume/area occupied by the fluid or structure is divided into discrete cells (the mesh),
3. The physical model is defined - for example in fluid mechanics, the equations of motions + enthalpy + species conservation,
4. Boundary conditions are defined. This involves specifying the fluid or structure behavior and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined,
5. The equations are solved directly for linear problems or iteratively for non-linear problems as a steady-state or transient,
6. Crash analysis applications primarily use explicit time stepping with very small time steps,

7. Analysis and visualization of the resulting solution.

The stability of the chosen discretization is generally established numerically rather than analytically as with simple linear problems. Special care is taken to ensure that the discretization handles discontinuous solutions and contact/impact gracefully. The Euler and Navier-Stokes equations both admit shocks, and contact surfaces. Metal forming and crash equations involve impact, contact, plasticity, and damage.

Some discretization methods used include:

- **Finite volume method**: This is the "classical" or standard approach used most often in commercial software and research codes in CFD. The governing equations are solved on discrete control volumes. This integral approach yields a method that is inherently conservative (i.e., quantities such as density remain physically meaningful).

- **Finite element method**: This method is the most popular for structural analysis of solids, but is also applicable to fluids. The FEM formulation requires, however, special care to ensure a conservative solution for CFD.

- **Finite difference method**: This method has historical importance and is simple to implement. It is currently only used in few specialized CFD codes. The main disadvantage is that it requires structured meshes, coordinate transformations, or several meshes for complicated geometries. It is almost never used for structures.

The basic solution of the system of equations arising after discretization is accomplished by many of the familiar algorithms of numerical linear algebra. Linear structural analysis and many non-linear implicit structural analysis applications use direct solvers that often stress both the CPU and I/O systems of the computing platform. For some non-linear problems especially in CFD these equations are solved by a stationary iterative method, like symmetric Gauss-Seidel or successive overrelaxation, or a Krylov subspace method. In recent years, Multigrid algorithms that iterate between a coarse and fine mesh have become very popular, because of their efficiency for larger systems of equation, i.e. finer discretization meshes. Explicit time stepping methods do not require a matrix solution at each time step, and hence work well on distributed memory architectures with smaller available memory at each node and rarely stress the I/O system.

**Geometries and Grids**

Another fundamental consideration in CAE is how one discretizes the equations of motion in space and time. One method is to discretize the spatial domain into small cells to form a volume mesh or grid, and then apply a suitable method to solve the equations of motion. Such a mesh can be unstructured and irregular (for instance consisting of triangles in 2D, or pyramidal solids in 3D), or regular and structured. The distinguishing
characteristic of irregular meshes is that each cell must be stored separately in memory. Lastly, if the problem is highly dynamic and occupies a wide range of scales, the grid itself can be dynamically modified in time, as in adaptive refinement and grid redistribution methods. In general finite volume or finite element methods are used for unstructured meshes while finite difference methods are used for structured or block-structured grids.

**The Nature of the Equations Describing the Physics**

**CFD Applications have Several Turbulence Models**

The most fundamental consideration in CFD is how one mathematically represents a continuous fluid. The equations of fluid motion range from Euler equations for inviscid, to full Navier-Stokes equations for viscous flow. It is possible to directly solve the Navier-Stokes equations for laminar flow cases and for turbulent flows when all of the relevant length scales can be contained on the grid (a direct simulation). Wide-ranging multi-scale turbulent flow simulations require the introduction of a turbulence model. Large Eddy Simulation (LES) and the RANS formulation (Reynolds-averaged Navier-Stokes equations), with the $k-\varepsilon$ model or the Reynolds stress model, are two techniques for dealing with these scales. Detached Eddy Simulations (DES) is a modification of a RANS model in which the model switches to a sub-grid scale formulation in regions fine enough for LES calculations. Regions near solid boundaries and where the turbulent length scale is less than the maximum grid dimension are assigned the RANS mode of solution.

In many instances e.g. weather prediction, chemical and biological flows, propulsion, etc., other equations (mostly convective-diffusion equations) are solved simultaneously with the Navier-Stokes equations. These other equations can include those describing species, concentrations, chemical-reactions, heat transfer, etc. More advanced codes allow the simulation of more complex cases involving multi-phase flows (e.g. liquid/gas, solid/gas, and liquid/solid) or non-Newtonian fluids (such as blood).

Several turbulence models are currently used. These range from computationally simple models to models that require extremely large computing capabilities. The several pictures that illustrate these models have been obtained from the Center of Turbulence Research, Stanford University (http://www.stanford.edu/group/ctr/gallery.html).

**A Reynolds-averaged Navier-Stokes equation (RANS) is** the oldest approach to turbulence modeling. An ensemble version of the governing equations is solved, which introduces new apparent stresses known as Reynolds stress. This adds a second order tensor of unknowns for which various models can provide different levels of closure. Statistically unsteady (on non-stationary) flows can equally be treated. This is sometimes referred to as URANS. The turbulence models used to close the equations are valid only as long as the time over which these changes in the mean occur is large compared to the time scales of the turbulent motion containing most of the energy.
Large eddy simulation (LES) is a technique in which the smaller eddies are filtered and are modeled using a sub-grid scale model, while the larger energy carrying eddies simulated. This method generally requires a more refined mesh than a RANS model, but a far coarser mesh than a DNS solution.

Detached eddy simulation (DES) is a modification of a RANS model in which the model switches to a sub-grid scale formulation in regions fine enough for LES calculations. Regions near solid boundaries and where the turbulent length scale is less than the maximum grid dimension are assigned the RANS mode of solution. As the turbulent length scale exceeds the grid dimension, the regions are solved using the LES mode. Therefore the grid resolution is not as demanding as pure LES, thereby considerably cutting down the cost of the computation. Grid generation is more complicated than for a simple RANS or LES case due to the RANS-LES switch. DES is a non-zonal approach and provides a single smooth velocity field across the RANS and the LES regions of the solutions.

Direct numerical simulation (DNS) captures all of the relevant scales of turbulent motion, so no model is needed for the smallest scales. This approach is extremely
expensive, and intractable, for complex problems on modern computing machines, hence the need for models to represent the smallest scales of fluid motion.

Figure 12: Direct Numerical Simulations of Turbulent Flow over a Backward-Facing Step (Courtesy – Center for Turbulence Research, Stanford University)

Structural Analysis Applications Incorporate Complex Material Models
One fundamental consideration in structural analysis is how one mathematically represents a continuous solid or structure. The equations of motion range from simple static linear elastic systems to very complex transient, non-linear elasto-plastic systems with friction and impact. It is possible to directly solve these equations with the finite element method for many cases of engineering interest. However, this requires the use of multiple specialized applications with several material models and geometric non-linearity. Crash analysis is one of the most complex applications with large geometric and material non-linearity incorporating several material models.

Elastic materials are materials in which tensile loading applied to a sample will cause it to deform in a reversible manner. Each increment of load is accompanied by a proportional increment in extension, and when the load is removed, the sample returns exactly to its original size and configuration. However, once the load exceeds some threshold (the yield strength), the extension increases more rapidly, and when the load is removed, some amount of the extension remains.

Plasticity is a property of materials to undergo large deformation without fracture. This is found in most metals, and in general is a good description of a large class of materials. Perfect plasticity is a property of materials to undergo large shear deformation without
any increase of lateral or shear stress. Plastic materials that are not perfectly plastic are visco-plastic.

**Viscoelasticity** describes materials that exhibit both viscous and elastic characteristics when undergoing plastic deformation. Viscous materials, like gels, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both of these properties and, exhibit time dependent strain.

**Damage** typically occurs with an irreversible fracture. A break occurs after the material has reached the end of the elastic, and then plastic, deformation ranges. At this point forces accumulate until they are sufficient to cause a fracture. All materials will eventually fracture, if sufficient forces are applied.

Crash analysis incorporates several elastic, plastic, and damage models. Over the last few decades these models have been refined significantly to enable very accurate predictive modeling that can be verified with actual experimental crash tests.

**Domain Decomposition Techniques**

Novel algorithmic approaches in CAE based on domain or mesh decomposition strategies allow users to obtain the maximum advantage and scalability from parallel machines with large numbers of inter-connected processors. Before a calculation can be performed on a parallel computer, it must first be decomposed into tasks which are assigned to different processors. Efficient use of processor resources requires that each processor have about the same amount of work to do and that the quantity of inter-processor communication is minimized. Finding an optimal decomposition is hard, but due to its practical importance, a great deal of effort has been devoted to developing heuristics for this problem.

**More Information**

To learn more about the IBM System Cluster 1350, contact your IBM representative or IBM Business Partner, or visit the following Web sites:

www.ibm.com/systems/clusters/
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