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Purpose:

The purpose of our publication is to provide technical and industry information

In This Issue – Titles:

Automotive Door Sealing System Analysis

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General Motors Corp.

ABSTRACT

Door sealing system is one of the most important automotive quality issues. Problems with door seal system could cause water leakage, wind noise and hard to open or close, which impair customer's satisfaction of the vehicle. That is why the door seal problem is always among the Hardy Perennial Top 10 list in JD Power Tracking Study.

The design rationality and manufacturing process are important aspects for the functionality and performance of a sealing system. However, the door sealing system involves many design variables and manufacturing variables. It is almost impossible to precisely confirm individual quantitative effects on functionalities of these variables. Therefore, computer based simulation of door sealing system is more practical since it can isolate the critical factors and it is cost effective and time efficient.

LS-DYNA was used to simulate door seal system. The key structural component, the rubber seal, was modeled and simulated. Different types of elements, material models and contact algorithms from LS-DYNA element, material and contact libraries were tried and compared. Consequently, the best modeling and simulation technology was developed for the door sealing system analysis.

The newly developed method showed the great potential of comprehensive studies of door sealing system. The analysis results provided some major parameters, such as seal deformation, contact pressure and energy transformation, which would influence the functionality and performance of the door sealing system. The analysis results have been compared with some available test data, and very good correlations were obtained. The analysis also evaluated the influence of manufacturing deviations. With the results obtained from this analysis, the relationship between the major parameters could be established and used as a tool to derive a better sealing system design at early stage. This analysis method could also be used to evaluate the influence of certain type of process error. Eventually, this analysis method will be developed into a tool that is capable of predicting water leakage, wind noise and hard to open/close problems caused by either product design or manufacturing process.

INTRODUCTION

To develop high quality vehicles in a timely fashion necessitates a design process, which should not only conform design specifications but also could be evaluated mathematically prior to hardware build. It is too slow for the fiercely competitive market to iterate the process of design, physical prototype, test and redesign. Furthermore, it is not feasible to conduct a sufficient number of hardware tests to accurately determine expected conformance rates. GM and some seal suppliers have been using analysis method to support door seal design for quiet long time. The existing method could make some reliable prediction, like seal Compression-Load Deflection (CLD) curve and deformations at different seal cross sections. Some important parameters could be evolved by the existing analysis method. However, the analysis result from existing method would not provide adequate information if a sealing system is to be evaluated, such as the overall seal transient deformation, contact pressure and seal strain energy contributed to door closing effort based on door closing motion.

The scope of this paper has introduced that LS-DYNA was used as an analysis tool to the door sealing system analysis. The analysis results provided some information, which are either unavailable from any other sources or requires much more work to get. This new developed method showed the capability of providing more accurate and detailed information depending on the complexity of the math structure model.

APPROACH

LS – DYNA explicit code was used as the solver for this door sealing system analysis. By choosing proper element type, material model and contact algorithm, the analysis method has successfully captured the door closing dynamic effect and seal material non-linear nature.

The analysis has overcome several technical difficulties, such as large stiffness difference between sheet metal and rubber material, extremely small element size and fairly long run time. Since LS–DYNA was more often used for crash analysis, the difficulties caused by rubber material nonlinear nature and small element sizes are not often experienced by majority users. This new approach by LS–DYNA has resolved these difficulties by refining model mesh and adjusting solving parameters.

The analysis model has included critical parts to represent the door system. The major influencing factors have been extracted from results. However, this method holds the promise of simulating with more detailed structure model and providing further required information.

DISCUSSION OF RESULTS

CLD Curve

Fig. 1 has shown the analysis result of CLD curve. By applying Displacement Vs. Time load curve, the resultant force Vs time curve from seal at door nominal position was generated. The test CLD curve was shown in Fig. 2 by courtesy of SaarGummi Americas. Comparing the analysis result to the test result, they shown a reasonably good agreement within 10% error range. This correlation verified the material model used in LS–DYNA.

Energy Transformation

The energy transformation curve from analysis was shown in Fig. 3. The seal strain energy was about 1.75 joules when the door was fully closed at nominal position. To validate the analysis result, a test was performed on the vehicle with different conditions that were listed in Table 1. By subtracting the minimum energy required to close the door with the seal and without the seal, the seal strain energy could be got and was about the same as the analysis result. The conformance of the energy transformation between the analysis and the test results validated the analysis model further.

Figure 1: CLD Curve from Analysis

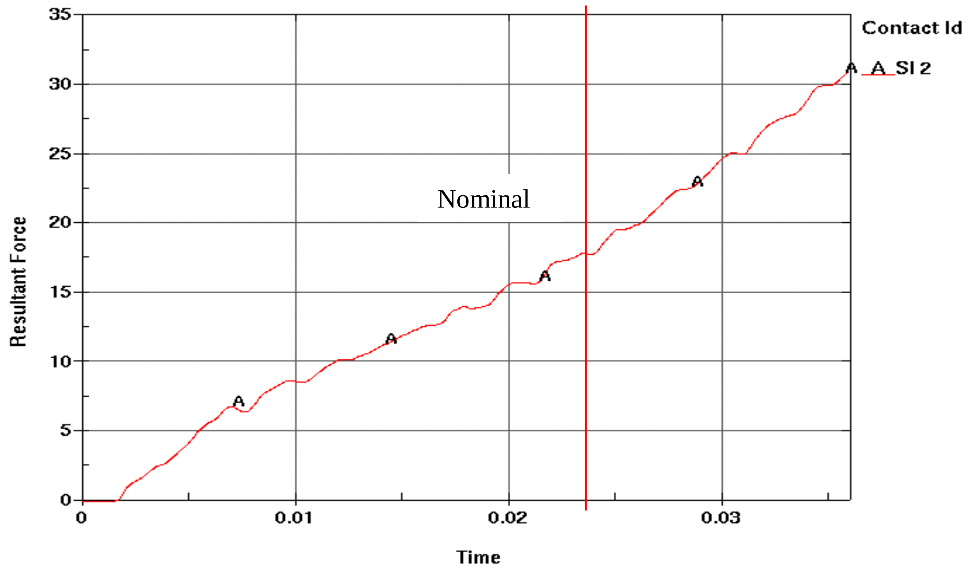
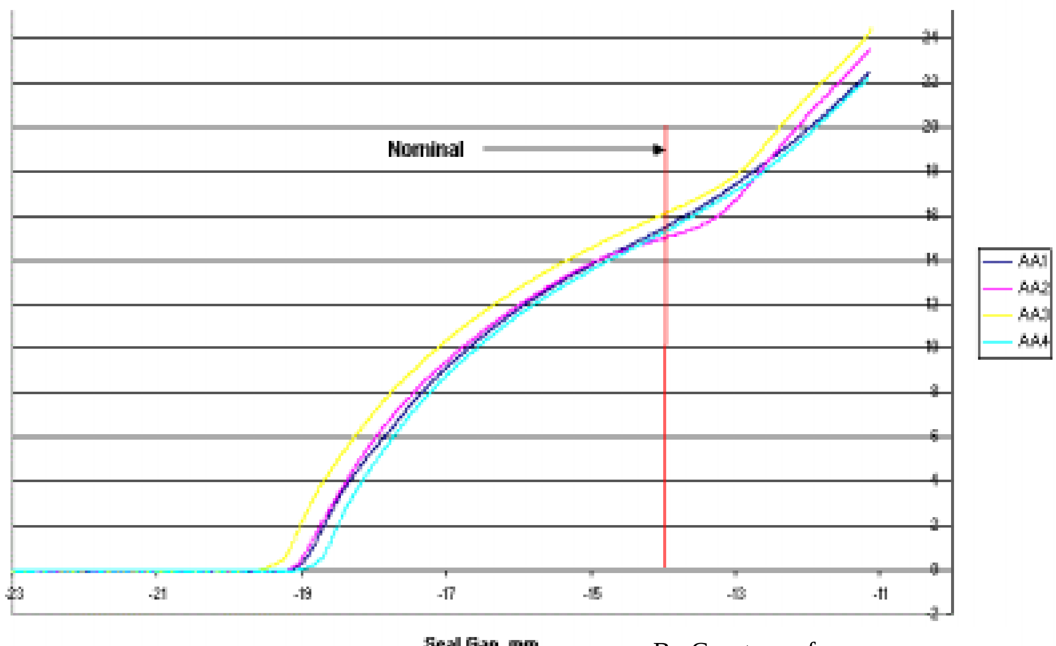


Figure 2: CLD Curve from Test



By Courtesy of
SaarGummi Americas

Figure 3: Energy Transformation from Analysis

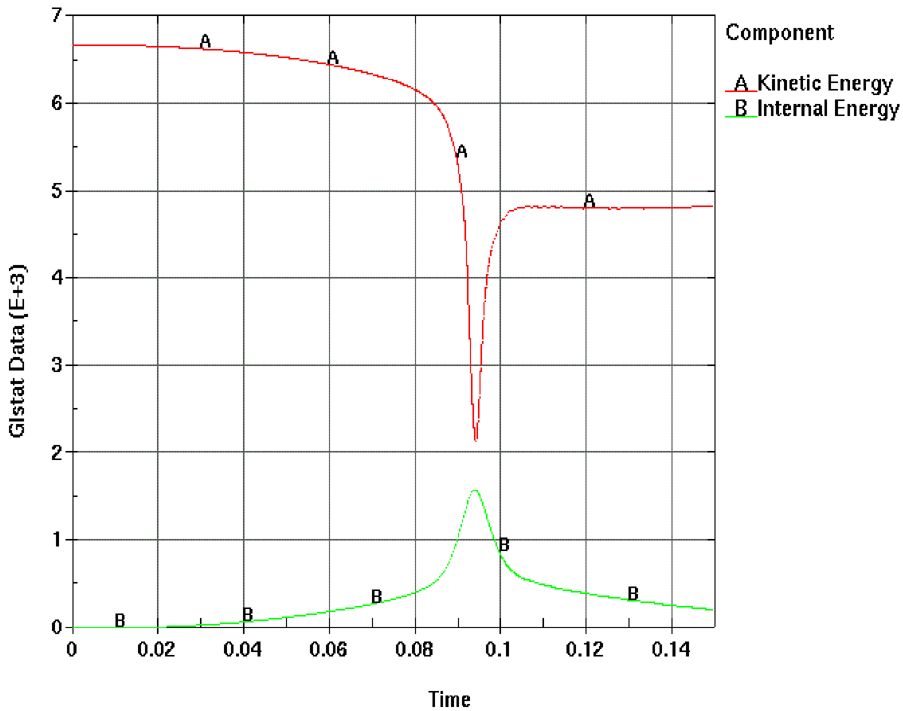


Table 1: Seal Strain Energy from Test

Test Conditions	Min. Required Energy (J)	Velocity (M/S)
With Primary Seal, All Doors Opened.	2.5	0.56
Without Primary Seal, All Doors Opened	0.75	0.24

Contact Pressure and Contact Area

Contact pressure and contact area directly influence door seal performance. To investigate contact pressure and contact area on the sealing surface is necessary. The compression force is a resultant of the integration,

$$F = \int_A p(\tilde{x})\, dA \qquad [1]$$

Where $p(\tilde{x})$ is the contact pressure distribution and A is contact area. It is important to control contact pressure distribution and contact area. This analysis could provide contact pressure and contact area information through out the whole seal and also on the time bases. This result holds the promise of further investigation of the relationship between seal performance and contact pressure and area.

It is important to evaluate contact pressure and contact area meeting the engineering requirement at early design stage. These two derivatives could be controlled by modifying input variables such as material property, cross section geometry, attacking angle and the shape of the indenter.

Water Leakage and Wind Noise

Water leakage and wind noise are the two major problems regarding to the door seal performance. Finding the root cause of water leakage and wind noise is the first step to resolve the problem.

Water leakage happens when the pressure outside of the vehicle overcomes the pressure at the sealing surface. To generate adequate contact pressure at the sealing surface could prevent water leakage problem. This does not only require a rational door seal system design but also a well controlled manufacturing process. Process error could completely jeopardize the performance and functionality of the door seal system even with a rational design.

Wind noise is generated by the presence of an unsteady fluid flow. Presence of the unsteady motion in a fluid medium and the vibration of the structure, which is coupled with a fluid medium, are the two main sources of sound. As a sound wave propagates, it disturbs the fluid for its equilibrium state. These disturbances are nearly always small. The pressure in a fluid medium at position x and time t has the mean and fluctuating parts, and can be written as:

$$p(x,t) = \overline{p}(x) + p'(x,t) \qquad [2]$$

where $\overline{p}(x)$ is the mean pressure and $p'(x,t)$ is the fluctuating pressure. The fluctuating part of pressure causes sound generation.

The door seal system primary function is to prevent water and dirt from entering the passenger compartment. Insulating the passenger compartment from exterior noise due to wind, traffic and other noise is another important function. Noise transmitting with zero net flow and aspiration are the two basic mechanisms to induce noise. Noise transmission with zero net flow is caused by the seal vibration response to the fluctuating pressure action on the exterior side of cavity. Aspiration is caused by the flow of air past through gaps between seal and the sealing surface. So, the low wind noise level could be benefited from no gaps between seal and the sealing surface and reduced the fluctuating pressure.

The functionality and performance of a door closure system includes: secure latch, no water leakage, low wind noise and proper closing effort. To get a fully functioned and a well performed system needs to have an excellent subsystem design combination and a less error process. Generally, a high contact pressure at the sealing surface is good for water sealing and isolating noise from exterior. There will be no gaps for water and noise to leak through into passenger compartment. However, high contact pressure will cause greater closing effort and reduce the fatigue life of the seal. Therefore, an uniform medium pressure is perfect. The uniform contact pressure through out the whole seal is based on the uniform seal margin. Therefore, control manufacturing process error appears to be very important. The bigger of the seal margin variances, the more of the chances for water leakage and wind noise penetration. To accurately predict water leakage and wind noise problems by using analytical method is still under investigation. More research work needs to be done definitely.

SUMMARY

It has been an encouraging experience to exercise LS–DYNA into a new territory. The analysis result shows the possibility to derive more information for door seal system engineers to get a better understanding of the door sealing system performance and functionality. Currently, activities are still underway to expand the capability and reliability of the analysis method.

ACKNOWLEDGEMENTS

The authors would like to express their thankfulness to Dilip Bhalsod for his generous technical support. Special thanks also go to John Komisak from Manufacturing Analysis Group, Michell Arnett and Jeff Hagman from Proving Ground for their help in different aspects. Also, we thank Dr. Robert Frutiger and management for dedicating resources so that efforts can be concentrated on improving and utilizing analytical tools.

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EYE in the Sky © Copyright SGI, 2002

SGI Helps Space Imaging Bring One-Meter Resolution Satellite Imagery to the Commercial Marketplace

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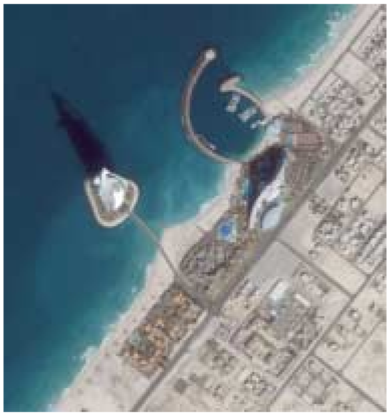
Images in this article can be viewed in full size at: http://www.sgi.com/features/2002/july/si/



One-meter resolution image of Dubai, United Arab Emirates

One-meter resolution image of Venice, Italy

Space Imaging, headquartered in Denver, Colorado, is a leading supplier of visual information products and related services derived from space imagery and aerial photography. The company collects earth imagery from its own IKONOS satellite and Digital Airborne Imaging System (DAIS-1™) and those of other satellite agencies, then processes the data and archives the imagery before making it available globally via the Internet and other channels. The successful launch of Space Imaging's IKONOS satellite in 1999--the world's first satellite to provide unclassified one-meter resolution imagery for commercial use--firmly established the company as a global leader in providing high-resolution satellite imagery.

Space Imaging utilizes SGI® high-performance computing (HPC) servers within its ground stations around the world to provide real-time image processing for its IKONOS one-meter high-resolution imagery. Space Imaging chose SGI systems because they provide cost-effective supercomputer bandwidth, throughput, and processing power.

According to John Copple, chairman and CEO of Space Imaging, "We have been able to lower the cost per unit of what we produce and make it feasible to bring high-resolution data to the commercial marketplace using commercial off-the-shelf computer technology available from SGI."

Collecting Geospatial Data

The IKONOS satellite can collect and process some 900 to 1,000 images per day and can revisit any location on earth every three days at high resolution. The satellite collects one-meter resolution black-and-white (panchromatic) images and four-meter resolution color (multispectral) images simultaneously. IKONOS performs these amazing tasks from an orbit 423 miles above the earth, moving at 17,500 miles per hour.

In addition to the IKONOS satellite, Space Imaging also uses its company-owned DAIS-1 to collect aerial imagery. Other satellites contracted to provide earth imagery include the two Indian Remote Sensing satellites, the U.S. LandSat, and Canadian RADARSAT.

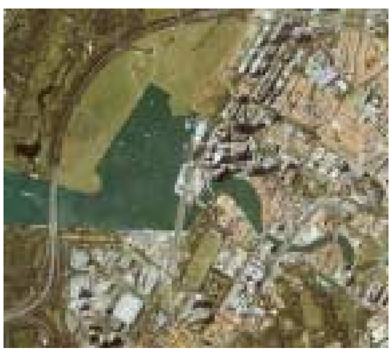
Space Imaging's products, services, and solutions serve a wide variety of markets throughout commercial, government, and consumer sectors, a market projected to be worth $2.5 billion by 2003.

Ground Stations: Staging, Processing, and Storing Imagery Data

Space Imaging utilizes multiple satellite systems to facilitate an efficient, global collection program that ensures customers are provided the best, most efficient service possible. The satellite imagery is transmitted to Space Imaging's ground stations along with those of its regional affiliates located in the U.S., Japan, South Korea, Turkey, Singapore, and the United Arab Emirates.

In a typical ground station, Space Imaging and its partner Raytheon integrate four SGI® Origin® 300 servers of various processor and memory configurations for the data capture server, compute server, database server, and media server. The companies also deploy five to 10 SGI visual workstations and a 3TB to 5TB SGI® TP9400 RAID storage system to optimize satellite ground station processing, archiving, production, data analysis, and quality-control functions

The company selected SGI Origin family systems because of their ability to provide real-time image processing of one-meter high-resolution imagery data relayed to ground stations by IKONOS. SGI systems provide the bandwidth, throughput, and processing power to combine imagery data from IKONOS with other geospatial data to produce 3D data sets of the world that can be navigated in real time. This combination of SGI hardware and Space Imaging data is ideal for the visual simulation industry.



One-meter resolution image of the city of Singapore

Invesco Field and Mile High Stadium, Denver, Colo.

Analyzing the Data

In addition to the visual simulation market, Space Imaging's CARTERRA™ Analyst software integrates geographic information systems (GIS), remote sensing, imagery analysis, photogrammetry, and cartography tools into a single workstation. The application enables customers to search, browse and retrieve images and data from a database, perform multispectral analysis, create and combine image files, generate reports and products, and create GIS databases of reports, data layers, and images. Space Imaging and SGI are providing customers of CARTERRA Analyst the option of using the SGI® File Server 830 system, using SCSI JBOD technology, or the SGI® File Server 850 system, using 2Gb RAID 5 technology.

A Relationship for the Future

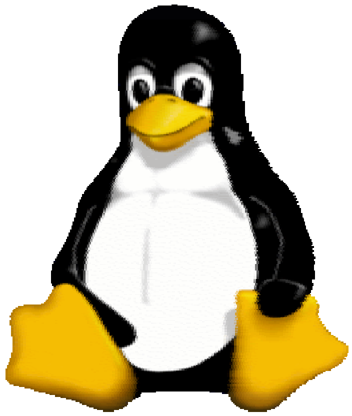
"This relationship with SGI demonstrates our commitment to working with premier technology providers who offer leading-edge solutions to the geospatial community," says Copple. "SGI is the only provider of high-performance computing systems powerful enough to provide mission-critical ground station image processing to the commercial, high-resolution satellite imaging market."

In November 2001, SGI and Space Imaging signed a teaming agreement to further expand cooperation and revenue opportunities in the geospatial marketplace. A joint strategic opportunity committee (JSOC) was formed to help determine mutual revenue goals and create mutual business opportunities from which SGI and Space Imaging can develop new solutions and generate incremental revenue.

Jeff Young, vice president of Global Solutions, Sales, and Marketing at Space Imaging and a member of the JSOC, points out that "SGI is an important contributor to our deliveries to [Space Imaging's] Regional Operations Center (ROC) affiliates. As we move from one-meter imaging solutions to half-meter imaging solutions, we expect to at least quadruple the volume of data required to cover the same geography. This will enable us to grow our existing ROC business as well as identify new growth opportunities. For Space Imaging to realize our expected growth potential in the near and long term, the data processing capabilities of SGI high-performance computers are critical to that growth."

As the demand for high-resolution satellite imagery continues to increase in the months and years ahead, SGI will continue working closely with industry leaders such as Space Imaging and Raytheon to provide the bandwidth, throughput, and processing power necessary to advance the ability of existing and future ground stations to receive and process imagery data from next-generation satellites

Linux Is Not A Fat Penquin
by Trent Eggleston, FEA Information Inc.



This quote is from Linus Torvalds, the original author of Linux, when he announced Linux v2.0 on Usenet:

Some people have told me they don't think a fat penguin really embodies the grace of Linux, which just tells me they have never seen an angry penguin charging at them in excess of 100mph. They'd be a lot more careful about what they say if they had. -- Linus Torvalds

The penguin was designed by Larry Ewing, lewing@isc.tamu.edu

The Origins of Linux

Linus Torvalds created the Linux operating system for the IBM® PC while he was a student at the University of Helsinki in Finland--he decided in 1991 to release it publicly mostly as a "look at what I've done - isn't this neat?" And it was neat: by 1993 you could download about twenty-five floppy disk images and install an OS on the IBM® PC with UNIX® commands, an X server and fully-loaded TCP/IP networking. The PC started to look like more than just a toy, but the penguin stilled looked friendly.

Torvalds claims that making the OS free was his single best decision, and that even his best technical work on the kernel of the OS paled by comparison. He commented that every hour he contributed turned into ten as application developers volunteered their time to work on this public OS. It would seem there was no financial advantage for Torvalds in all of this, but in a 1996 interview Torvalds explained the financial advantage to himself in one terse remark, " 'Resume: Linux' looks pretty good in many places." He further elaborated, "So yes, you can trade in your reputation for money. And the *good* thing about reputations (and intellectual property) is that you still have them even though you traded it in."

Torvalds retained the copyright to his work for the first six months or so, requiring that the OS not be distributed for money and that all changes be returned to him for possible inclusion in later releases. But that changed when people began requesting permission to copy the OS onto floppies and redistribute it to those who did not have an internet connection, for a fee of course. So Torvalds changed the copyright to a GNU "Copyleft", the GNU public license. This was a natural thing to do because the OS heavily depended upon the GNU C-compiler and because the GNU public license required developers to return all of their changes for possible inclusion in later releases. This licensing agreement created a public OS that people all over the world became anxious to develop for free, and which could be redistributed for profit.

More than 10 years later …

There are several flavors of Linux available today, the most popular being RedHat, SuSE, Mandrake, Turbolinux, Debian and Caldera. A typical installation now consists of about 1000 floppies (fortunately it comes on 2 or 3 full CD's instead) and includes a large collection of software drivers and applications:

1. Command sets richer than the average UNIX® installation.
2. Free C, C++ and Fortran compilers with graphical debuggers.
3. Support for multiple CPU's including, MPICH,

4. X Window and Motif user-interface libraries and development toolkits.
5. OpenGL runtime and development libraries for most common OpenGL cards.
6. Several window managers and desktop environments that combine the best features of CDE (the UNIX® Common Desktop Environment) and Windows.
7. Resource sharing software for sharing files and printers with machines running Windows, MacOS and UNIX® machines.
8. All the standard network services such as e-mail, DNS, http, ftp and telnet are included along with firewall software to protect those services from intruders.
9. Graphics design software.
10. Multimedia software, including games, CD-record and MP3 editing programs.
11. Free office suites such as StarOffice from SUN.
12. Support for multiple OS's on one machine.
13. Windows emulation software (WINE).
14. USB support for mouse, scanner, printer, etc.

RedHat Linux is used in the U.S. for general applications, while MSC.Linux is used by engineers for demanding scientific computations. SuSE is most popular in Germany because of its support for the German language. Among engineering MSC.Linux is gaining in popularity.

Linux: A Software Development Platform

Linux offers one major advantage over nearly every other platform when it comes to software development: basic development tools are free, including reliable C and C++ compilers. Microsoft® Windows users would expect to pay several hundred dollars for a C/C++ compiler and UNIX® users would typically pay between one and two thousand dollars for C/C++ compilers. A very good graphical debugger "ddd" is also free for Linux.

The Linux kernel is normally built using the GNU C compiler and this compiler is, therefore, one of the most reliable available for Linux. The GNU C++ compiler enjoys a similar reputation. Commercial C/C++ compilers are available for Linux, ones which are more efficient, but most people just stick with the GNU compilers.

Some of the other programming languages such as Fortran are not as well supported. For example, the free GNU Fortran compiler does not support Cray-style pointers. But there are good commercial Fortran 90/95 compilers that do support Cray-style pointers available from Absoft, IntelC and PGI to name a few. Some of these compilers offer support for parallel programs and take advantage of the Intel® architecture as well as offering branch prediction, speculation, software pipelining, automatic vectorization, and support for Streaming SIMD Extensions 2 (SSE2).

User-Interface Development

Motif® , developed by the Open Software Foundation, is now the standard Widget library for UNIX® user-interface development. Motif is an advanced set of user-interface Widgets that came about in the early 90's and which is built on top of Xt. The Xt toolkit is built on top of the X Window System and offers several simpler pre-made Widgets such buttons, text areas, etc, along with the event handling required for widgets. Motif® eventually displaced the competing UNIX® user-interface libraries and is now standard on every modern UNIX® system.

Motif was a stumbling block for Linux for many years. There were no implementations of Motif® available for Linux at first because the source code for Motif® was never made freely available. An attempt to create a Motif® knockoff named Lestif did gain great momentum in the mid 90's. Then around 1996 companies began licensing and selling OSF versions of Motif® for about $150. Finally in 1999 OSF released OpenMotif, a free Motif implementation for Linux and FreeBSD. Now all of the standard UNIX® user-interface libraries are available under Linux and Motif development under UNIX® can be done on a Linux machine for free. All of the Motif libraries required to run a Motif application are standard components of most Linux releases.

Other user-interface Widget sets are available under Linux as well. Some of the Widget sets that work well with Linux are also available for PC's running Windows. Unfortunately, there is still much to be done in order to make Linux or Microsoft® Windows GUI applications easily port to the other OS.

OpenGL® Support

SGI® created a standard graphics library specification for 3D drawing called OpenGL® and released a first version of this specification in 1993. Shortly thereafter, Microsoft® licensed SGI® 's implementation and specification of OpenGL for use in Windows 95 and Windows NT®, and game developers began to use OpenGL® for fast 3D rendering. Microsoft® then contracted SGI® to create a Device Developer Kit (DDK) for OpenGL®, thereby allowing hardware manufacturers to more easily design hardware-accelerated OpenGL® graphics boards compatible with Windows—this immediately launched a new OpenGL graphics board industry.

It seemed unlikely Linux would ever offer the same level of support for hardware-accelerated OpenGL® especially since the drivers would probably be written by volunteer programmers. Much to everyone's surprise, in 1998 SGI® teamed up with Nvidia® to create unaccelerated drivers for Nvidia® graphics cards under Linux with a promise to create fully accelerated drivers shortly afterwards. All of the Nvidia® graphics cards are now fully accelerated and in 1999 SGI® and Nvidia® formed a strategic alliance; just last week SGI® announced that some of its new desktop servers will include Nvidia® graphics cards. SGI® will also "transfer a word-class team team of 3D graphics engineers to NVIDIA® to work on its next-generation technology."

Nearly all graphics cards including ATI® and Nvidia® OpenGL® cards are fully supported by Linux. OpenGL® applications can be developed and deployed on Linux systems and can access the power of the modern PC OpenGL® graphics boards that are capable of rendering speeds of roughly 130,000,000 polygons per second. And today these cards cost only a few hundred dollars instead of the tens of thousands that they did only a decade ago.

Linux Network Servers

Linux machines are used throughout the world as servers for the web, ftp, mail, printing, file sharing, DNS and electronic commerce. Linux servers have become popular because they are reliable, configurable and there is a wealth of software available to get the job done for free.

The popular web server from the Apache Software Foundation is free, and books about the Apache web server are easy to find. Microsoft® supplies software offering FrontPage extensions for the Apache web server so that users can design and update their web server directly from Microsoft® FrontPage.

The sendmail program is a standard, dependable mail server included with Linux. Since 1998 the main mail server at LSTC has been a PC running sendmail under Linux. This mail server has not been rebooted for almost a year now.

Microsoft® file and print sharing is based on the Microsoft® SMB (server message block) protocol. Server and client implementations of this protocol are available for free as part of the SaMBa suite of software. The SAMBA software is an outstanding example of freeware available for UNIX® , Linux and Microsoft® Windows that allows Linux users to share any folder, drive, or printer with users of Microsoft® Windows. In fact, Linux users can dependably share files and printers with any machine running UNIX® , Linux, Windows or MacOS.

A Linux system running SAMBA can perform nearly every function of a Microsoft® Windows machine, except that a Linux system cannot be used as a primary domain controller for NT®--such a controller must contain Microsoft® licensed domain code in it. The NT® domain is a complex labyrinth of message passing adhering to no published standards, the details of which are a closely guarded secret. If someone does manage to decipher the message passing protocol, then there is a provision in the service packs to completely change the protocol. SAMBA servers are starting to support some of the NT® domain functions, but they are still most useful as file and print servers.

Among the companies supporting and/or developing Linux are HP and COMPAQ, SGI® , MSC.Software

HP has announced a partnership with RedHat Linux to offer fully-integrated Linux on Intel® Itanium®-2 based systems and on its AlphaServers. All HP ProLiant, blade servers and Itanium®-2 systems will be available with certified RedHat Linux Advanced Server.

HP has contributed graphical system administration tools, HP-certified printer drivers for Linux, optimizations for the Itanium®-2 system which it co-developed with Intel® , and several other optimizations related to parallel computing.

SGI® is seriously committed in the direction of the Linux OS offering several high-performance graphics clusters and workstations that run Linux, and they have ported most of their popular graphics tools to their Linux systems. SGI® offers Linux for its Itanium®-2 graphics workstations. SGI® 's alliance with Nvidia has been one of the most significant contributions to the Linux world, offering hardware-accelerated OpenGL graphics for Linux and bringing a new generation of graphics technology to the PC at the same time. SGI® has significantly improved the Linux kernel for fast, reliable scalability. They have contributed kernel profiling tools, software that allows the user to specify the CPU's on which a software application can run, enhancements to the raw I/O system, Posix compliant kernel asynchronous I/O, and better resource synchronization. SGI® 's robust and efficient XFS filesystem is now part of the standard Linux OS as well.

MSC.Linux is the definitive cluster distribution designed for the most demanding computational environments in engineering and life sciences.

What makes MSC.Linux distribution so good is the focus on the challenges faced by an administrator of a Beowulf cluster and putting the tools in one convenient location. An Administrator will immediately appreciate the intuitive and easy to use web based installation and administration tool, Webmin. The premier cluster tool is OSCAR (Open Source Cluster Application Resources), developed by the Open Cluster Group. MSC.Software, a founding member of the team, is the technical lead for the programming and installation environment. For complete information on MSC.Linux visit **www.msclinux.com**

If you have information to share on Linux for a future article please send it to mv@feainformation.com

For space consideration the full 54 pages are posted on the FEA Information Inc. Website in pdf format. Chapters 1 through 3 are posted.

CLASSIFICATION OF MATERIALS FOR NUMERICAL SIMULATION

Main decisions:

- is the structure 2D or 3D?
- is the material reversible or irreversible?

	Reversible	Irreversible (permanent deformations)
	Elastic ML Viscoelastic ML	Elastoplastic ML
2D (Shell)	Tissue (Bag-Belt) Plastic (Polymers)	Mild steel High strength steel Aluminium Magnesium Plastic (Polymers)
3D (Solid)	Rubber (Elastomers) Soft foams Confor foam EPF (EPP,EPS...) EA-PU	Honeycomb Aluminium foam Crushable PU

Sometimes the choice is hard since part of the deformation is reversible and part is permanent, i.e., plastics.

MEASURES OF STRESS IN SOLIDS

We consider Cauchy stresses (force over current area), and we will write the stress tensor as:

$$\underline{\vec{\sigma}} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{pmatrix} = \vec{\sigma}^T$$

Since the stress tensor is symmetric, we can always find a proper orthogonal matrix (rigid body rotation) that diagonalizes it:

$$\vec{R}^T \vec{\sigma} \vec{R} = \begin{pmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{pmatrix}$$

The diagonal components are the principal stresses and allow a 3D representation of the state of stress in a point of a continuum

INVARIANTS

The state of stress in a point is determined by the invariants of the stress tensor , the three invariants are:

$$\underline{p} = -\frac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3}$$

$$\underline{\sigma}_{vm} = \sqrt{\frac{3}{2}\left((\sigma_{xx} + p)^2 + (\sigma_{yy} + p)^2 + (\sigma_{zz} + p)^2 + 2\sigma_{xy}^2 + 2\sigma_{yz}^2 + 2\sigma_{xz}^2\right)}$$

$$\left|\underline{\ddot{\sigma}}\right|$$

The first and second invariants are called pressure and von Mises stress, respectively. By invariance, we mean invariance under a proper orthogonal transformation:

$$\underline{\ddot{\sigma}} = \ddot{R}^T \ddot{\sigma}_0 \ddot{R}$$

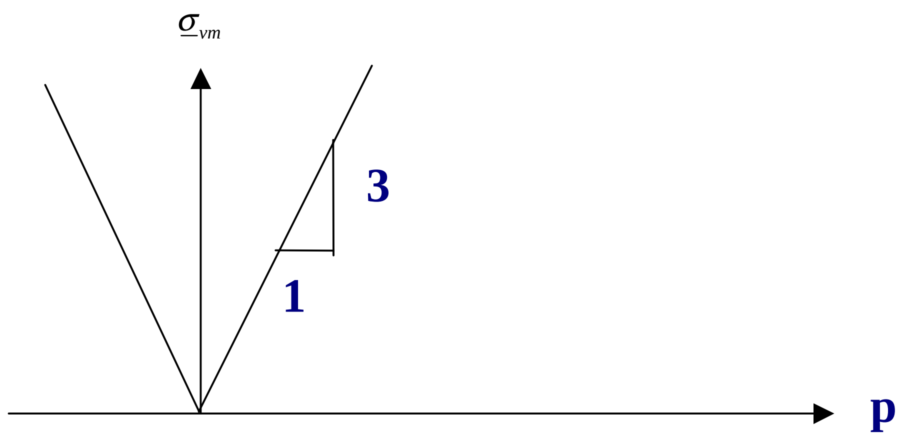
$$\underline{p} = p_0$$

$$\underline{\sigma}_{vm} = \sigma_{vm0}$$

$$\left|\underline{\ddot{\sigma}}\right| = \left|\underline{\ddot{\sigma}}_0\right|$$

INVARIANT SPACE:

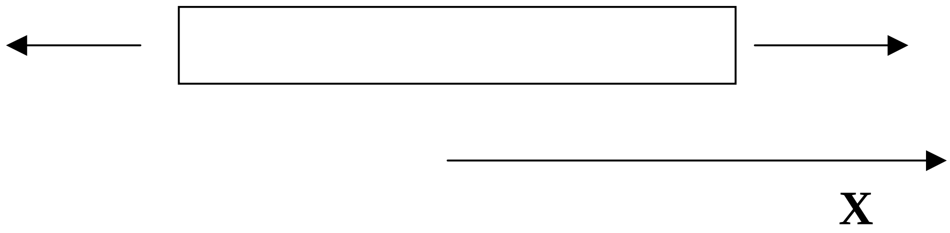
For an isotropic material, the plasticity law will depend upon the stress invariants only, if we further restrict to the first 2 invariants, we can represent the material law in a 2D plane:



Here:

- the horizontal axis corresponds to a hydrostatic loading path
- the vertical axis is pure shear
- the line with tangent 1/3 is uniaxial compression
- the line with tangent -1/3 is uniaxial tension
- a line of constant von Mises stress is horizontal
- etc...

UNIAXIAL STATE-OF-STRESS



$$\overleftrightarrow{\sigma} = \begin{pmatrix} \sigma_{xx} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$p = -\frac{\sigma_{xx}}{3}$$

$$\sigma_{vm} = \sqrt{\frac{3}{2}\left(\left(\frac{2\sigma_{xx}}{3}\right)^2 + 2\left(-\frac{\sigma_{xx}}{3}\right)^2\right)} = |\sigma_{xx}| \geq 0$$

$$\begin{cases} \sigma_{vm} = 3p \quad (compression) \\ \sigma_{vm} = -3p \quad (tension) \end{cases}$$

DEVIATORIC STRESSES

The pressure or first invariant is related to the change in volume of the solid, the 'deviation' from a hydrostatic state of stress is linked to the change in shape.

The stress deviator is defined as:

$$\underline{\overleftrightarrow{s}} = \overleftrightarrow{\sigma} + p\overleftrightarrow{I}$$

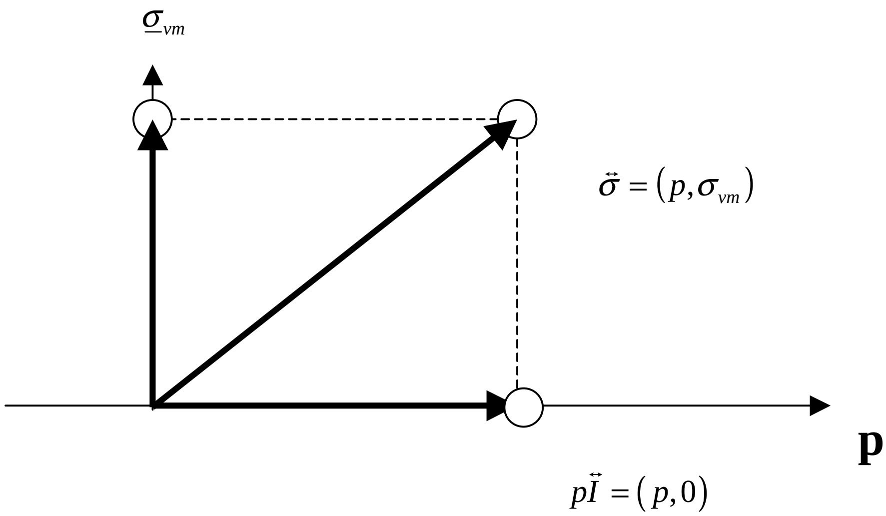
$$\begin{pmatrix} s_{xx} & s_{xy} & s_{xz} \\ s_{yx} & s_{yy} & s_{yz} \\ s_{zx} & s_{zy} & s_{zz} \end{pmatrix} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{pmatrix} + \begin{pmatrix} p & 0 & 0 \\ 0 & p & 0 \\ 0 & 0 & p \end{pmatrix}$$

The second invariant in terms of stress deviators becomes:

$$\underline{\sigma}_{vm} = \sqrt{\frac{3}{2}\left(s_{xx}^2 + s_{yy}^2 + s_{zz}^2 + 2s_{xy}^2 + 2s_{xz}^2 + 2s_{yz}^2\right)}$$

A surface of constant von Mises stress in deviatoric space (9D) or in principal deviatoric space (3D) is thus a sphere

REPRESENTATION IN THE INVARIANT PLANE



REMARKS

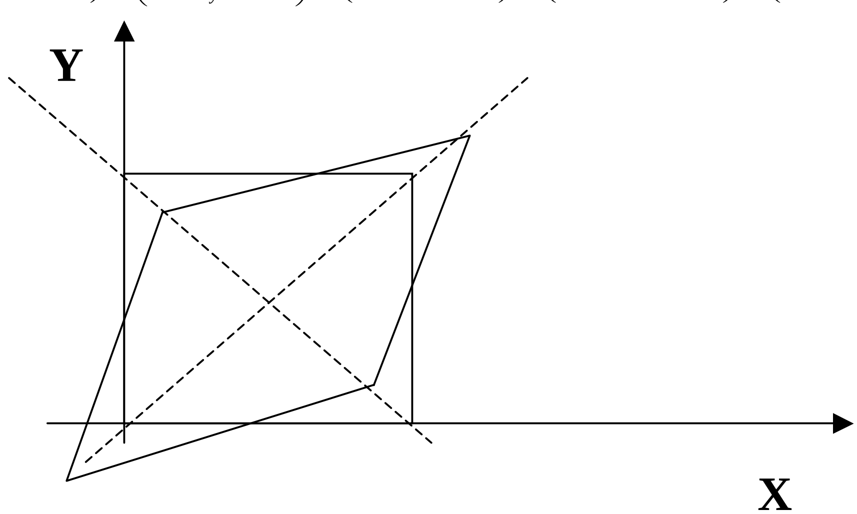
A hydrostatic state of stress is the kind that can exist in a liquid or a gas. It has such a high degree of symmetry that the corresponding deformation can only be a change of size, without change of shape (cube remains cube, sphere remains sphere etc...), as long as the material is isotropic.

Similarly the deviatoric stresses can produce only shear deformation changing the angle between 2 faces of a block or between 2 of its diagonal planes. Indeed the deviatoric stresses have a zero trace (volumetric component) and can thus be represented as the superposition of 5 simple shear-stress systems:

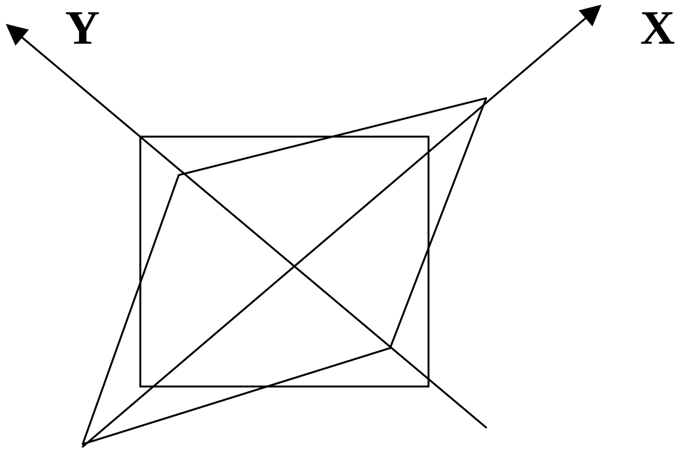
$$s_{xx} + s_{yy} + s_{zz} \equiv 0.$$

thus :

$$\vec{s} = \begin{pmatrix} 0 & s_{xy} & 0 \\ s_{xy} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & s_{yz} \\ 0 & s_{yz} & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & s_{xz} \\ 0 & 0 & 0 \\ s_{xz} & 0 & 0 \end{pmatrix} + \begin{pmatrix} s_{xx} & 0 & 0 \\ 0 & -s_{xx} & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & -s_{zz} & 0 \\ 0 & 0 & s_{zz} \end{pmatrix}$$



$$\sigma_{xy} = \sigma_{yx} \neq 0$$



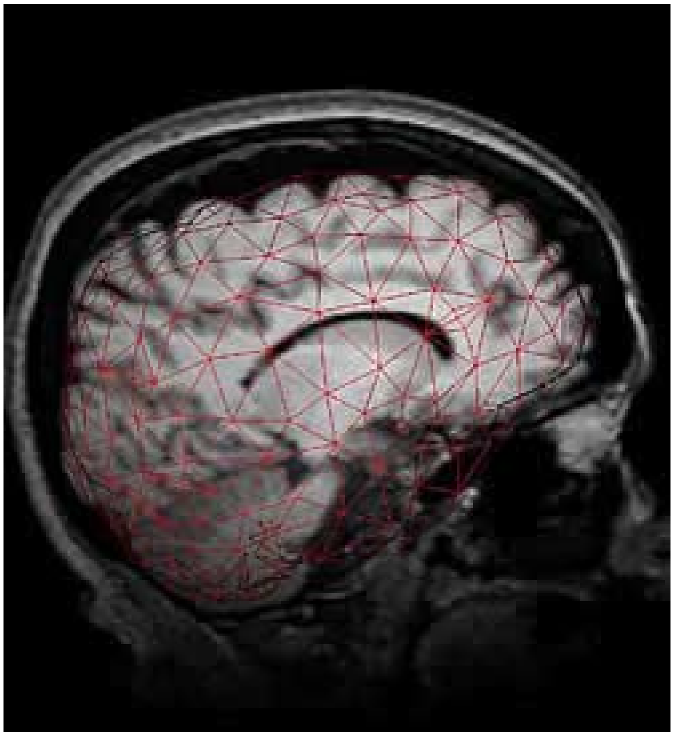
$$\sigma_{yy} = -\sigma_{xx} < 0$$

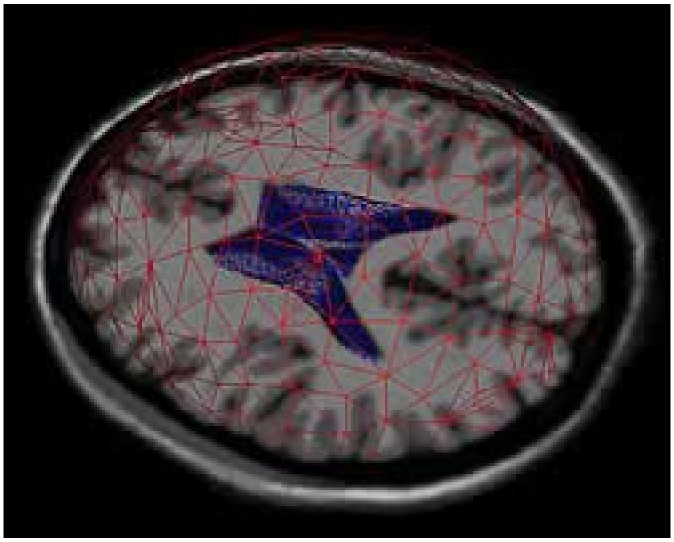
Ansys Saves U.K. and U.S. Researchers Time and Money Constructing Patient-Specific Brain Models © Copyright, 2002 SAS IP Inc. All Rights Reserved

Excerpt from the above article – the article with enlarged graphics can be located on the website www.ansys.com/customer_stories/case_studies/biomedical_kings.htm

Introduction

With advanced technology providing so many advantages to manufacturing, it may come as a surprise to some that many of the tools used daily by engineers are also extensively used within the medical field. There have been many documented examples of 3-D modeling and rapid prototyping having been used in a medical environment, but perhaps even more surprising may be the fact that computer-aided engineering is also in use-particularly in the field of brain surgery.





Human Brain With Mesh

A case in point is the work recently carried out by a team comprising of members of the Computational Imaging Sciences Group at King's College (Strand, London, England, U.K.), the Clinical Sciences departments at the University of Sheffield (Western Bank, Sheffield, U.K.) and the University of Minnesota (St. Paul, Minnesota, U.S.A.). Using ANSYS®-distributed by ANSYS Inc. (Canonsburg, Pennsylvania, U.S.A.), a global innovator of CAE solutions-the group is currently working on a state of the art system, allowing surgeons to garner a much greater understanding of the results of invasive brain surgery, long before the patient has donned an open-backed smock.

Challenge

The problem revolves around the natural pressure within the human skull. More specifically, the deformation of the brain caused by breaching the cranium during surgery, which releases that pressure as the fluid surrounding the organ escapes. For sometime, it's been possible to extract data from a MRI scan and construct a three-dimensional model of the brain 'in-situ.'

The dilemma that the team set out to solve is that this 3-D model does not accurately represent the form of the brain during surgery. In other words, the team needed to develop a system that provides surgeons with a more accurate understanding of the brain during surgery than has traditionally been possible.

Solution

To accomplish this, the multi-skilled team worked to develop an experimental suite of software that takes MRI scan data from a patient and creates a 3-D model of the brain, performs an FEA-based analysis of the procedure allowing the user to gauge the effects of surgery. The team has been using ANSYS as the major analysis engine for the entire process.

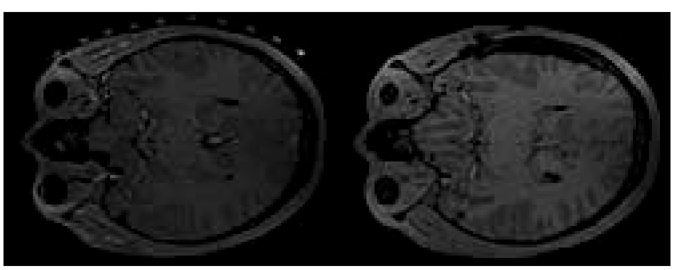
Alongside the fundamental problem, there are other bottlenecks in the process that the team had to overcome if the system is ever to make it into production. Perhaps the most critical element in the system's development is the time required to build an accurate element mesh, which not only represents the three most critical sections of the brain (Grey matter, White matter and Cerebral Spinal Fluid) but can be tailored to each individual patient. Rather than requiring that a model be built from scratch for each patient, it was decided that the system would use a single 'Atlas' model as the basis for all subsequent projects, which represents a standard model of the brain, including the various sub-sections of matter.

This Atlas model is then processed in each case using a custom developed mesh-warping application. The process of warping the Atlas model uses standard registration processes to match the 'Atlas' model to that the individual patient using the data captured from the MRI Scan as a basis, obviously saving a great deal of work for each case.

The registration process is fully automatic, and involves manipulating a 3-D grid of B-spline control points regularly spaced throughout the image volume while optimizing the normalized mutual information between patient brain and atlas brain. The team believes that this particular form of registration "has not been used before and has great potential for allowing patient specific FEM models to be constructed in a clinically relevant timescale."

Obviously, when using any form of analysis system (particularly those incorporating any degree of automation) it is essential that the quality checks be conducted on the resultant mesh. This is done to ensure that the results are appropriate, reliable and free from any of the potential problems associated with creating any form of element-based mesh, such as folded and badly shaped elements. With this in mind, the team has incorporated the standard mesh checking functions in ANSYS.

Initially, this will identify any such problems then allow the user to manually correct them, although the team are looking to incorporate some form of automatic correction tools. To test the system, the team piloted it using data captured from four patients at the University of Minnesota, both pre and post their operations. The system was used to analyze the effects of the surgery, and then these experimental results were compared to the actual effects recorded. From the initial trial runs it would appear that the ANSYS-driven system is proving to be just as accurate as the team had expected.



Benefit

While the system is far from ready to roll out to hospitals around the world, the team is looking to take advantage of both the results available from this initial work, the rapidly advancing world of CAE simulation and the technology it brings to build a system which not only better informs the surgeon prior to operations, but could eventually save lives. As strange as it may seem, the FEA system provided by ANSYS is destined to become an integral part of not only design and engineering, but to the field of surgery and medicine.

Computer simulation or computer-aided engineering technology within the product development and manufacturing industry has rapidly become widespread, as have the benefits its use brings to both the design team and to the end customer. The ability to accurately simulate the behavior of a product according to real-world operating conditions has been a driving factor behind the shift from physical prototype testing to the use of virtual models. This brings massive savings in terms of both money and perhaps more critically in these days of reduced development cycles - time.

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06/03	LSTC	Conference Review
	SGI	SGI® workstations
	ETA	eta/FEMB27-PC
	GissETA	Distributor in India
06/10	OASYS	D3PLOT
	HP	HP's rack optimized servers
	Flotrend	Distributor in Taiwan
06/17	EASi	EASi-SEAL
	Fujitsu	PRIMEPOWER Family
	STRELA	Distributor in Russia
06/24	LMS	LMS Virtual.Lab
	CEI	EnSight
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EVENTS – see events on www.feainformation.com for details

2002		
Sept 16 – 17	Sweden	Nordic LS-DYNA Users' Conference
Sept. 18 & 19	USA	LMS Conference for Physical and Virtual Prototyping
Sept. 19&20	Germany	DYNAmore – German LS-DYNA Forum
Oct. 03-04	Italy	Engin Soft Conference and User's Meeting
Oct. 08	UK	OASYS LS-DYNA Update Meeting
Oct. 09-11	Germany	CAD-FEM Users Meeting - Germany
Oct. 10-13	USA	10th Foresight Institute Conference on Molecular Nanotechnology
Oct. 24 – 25	Japan	Japanese LS-DYNA & JMAG Users Conference
Oct. 28	Korea	Korean LS-DYNA Users Conference
Nov. 28 & 29	Germany	LMS Conference for Physical and Virtual Prototyping
Dec 18 – 21	India	HiPC 2002
2003		
May 19-21	USA	BETECH2003
May 22-23	Germany	4th European LS-DYNA Conference
June 17-20	USA	The Second M.I.T Conference on Computational Fluid and Solid Mechanics

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