FEA Information Co.

For the Engineering Global Community
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Issue 2001-1
Fourth Issue

Welcome to Issue 2001-1 of our newsletter. Our goal is to bring you a monthly synopsis of the additions/revisions to the FEA Information Co. web sites and special articles you may have missed on the sites during the month. When available we'll bring you information from our community of participating companies, engineers, professors, consultants, and students.

Always feel free to send us information you would like to share with the global community – publications, presentations, articles, or personal opinions/reviews for posting to the web sites, or in our monthly News Letter.

Topic D - E
Two new linear equation solver options in version 960

Each of these new solvers uses the sparse matrix storage scheme to minimize memory and floating-point operation counts. In the sparse scheme, the nonzero matrix entries are stored including those that become nonzero during the matrix inversion. The sparse method is superior in speed and memory usage to older banded and profile storage schemes.   The default solver is solver #4

Topic D: Solver #4
An optimized version of our original default solver #1.

It solves the linear system by direct inversion of the stiffness matrix. Unrolling internal loops and revising the sequence of operations have achieved better ratios of floating point operations to memory loads and stores. This solver performs from 2x to 6x faster than the old solver #1, depending on hardware platform and model size. On the SGI Origin platform, solver #4 equals the performance of SGI's vendor-supplied sparse solver.

Another important benefit of solver #4 is in the parallel performance. Solver #4 runs in both SMP and MPP parallel architectures. As shown below, SMP performance is excellent with 4 processors and diminishes as the number of processors increase to 8. MPP performance is vastly superior to SMP performance for a larger number of processors. Solver #4 is the only currently available option for MPP-DYNA implicit.

cpus	metal forming: hood inner panel, adapted mesh	artificial knee: brick elements, rigid body contact	I-beam model: fine mesh, shell elements
	timing	timing	timing
1	101	147	413
2	68	87	262
3	59	69	210
4	55	59	186
5	53	55	177
6	52	52	170
7	53	50	160
8	53	49	158

Topic E: Solver #6
The BCSLIB-EXT package from The Boeing Company.

This double precision solver makes extremely efficient use of out-of-core disk space, allowing it to solve huge problems. Systems with over 1,000,000 degrees of freedom are routinely solved with BCSLIB-EXT.

In addition, a new matrix reordering option has been added to both solvers. Matrix reordering is similar to the bandwidth minimization procedure used in older profile solvers, where rows and columns of the matrix are exchanged to minimize storage and operation count during factorization. The old MMD reordering option is very fast. The METIS option can be much slower, but can also produce more efficient reordering, reducing factorization time by 2x or more. By default, LS-DYNA selects the reordering scheme based on the matrix characteristics. There is no guarantee that the default is optimal.

Below are the new input options for the *CONTROL_IMPLICIT_LINEAR keyword:

```
$
*CONTROL_IMPLICIT_LINEAR
$  lsolvr  prntflg  negeig   order
      0      0      0      0
$
$ lsolvr = linear equation solver
$  eq. 1: sparse direct auto out-of-core
$  eq. 2: sparse direct incore
$  eq. 3: sparse direct double precision
$  eq. 4: new sparse direct single - auto out-of-core (DEFAULT)
$  eq. 5: new sparse direct double - auto out-of-core
$  eq. 6: BCSLIB-EXT double - auto out-of-core
$  eq.11: iterative, Conjugate Gradient
$  eq.12: iterative, C.G. with Jacobi
$  eq.13: iterative, C.G. with Inc. Choleski
$  eq.14: iterative, Lanczos
$  eq.15: iterative, Lanczos with Jacobi
$  eq.16: iterative, Lanczos with Inc. Choleski
$
$ prntflg = print flag
$    eq.0: no printed information concerning linear solver
$    eq.1: summary information:  memory, cpu
$    eq.2: linear solver statistics
$    eq.3: debug level information and checking
$
$ order = sparse ordering option
$    eq.1: ordering chosen by LS-DYNA
$    eq.2: order with Multiple Minimum Degree
$    eq.3: order with METIS
$
```

Air Bag Thermodynamics
Livermore Software Technology © 2000

Presented is the detailed development of the thermodynamic equations used in LS-Dyna to model airbags. The air bag thermodynamic model includes:

1. inlet flow from an inflator
2. outlet flow through vents and fabric leakage
3. heat transfer from the hot gases in the airbag to the cooler environment
4. PdV work due to an expanding airbag
5. gas mixtures
6. gas thermodynamic properties a function of temperature

The 1st Law of Thermodynamics provides an equation to calculate the change in energy (or temperature, see eq. 9) of the gas in an airbag over a time step in the LS-Dyna analysis. Then, at the end of the time step, the temperature can be updated and the pressure determined by an equation of state (e.g., ideal gas law). This work follows previously published developments by J.T. Wang [1,2] and Wenyu Lian [3] of GM. We appreciate the time and effort of J.T. Wang and Wenyu Lian in reviewing this work while it was under development, helping us understand airbag physics, and correcting errors.

Nomenclature

$\vec{A}$	[m^2] area vector, positive in outward normal direction
$\bar{c}_p$	[J / mol K] molar heat capacity at constant pressure
c_p	[J / kg K] heat capacity at constant pressure
c_v	[J / kg K] heat capacity at constant volume
f_i	[dimensionless] mass fraction of gas species I
$\Delta H_{f,298}$	[J / kg] standard heat of formation at 298K
h	[J / kg] specific enthalpy
M	[kg / mol] molecular weight
m	[kg] mass
$\dot{m}$	[kg / sec] mass flow rate
P	[N / m^2] pressure
$\dot{Q}$	[W] rate of heat transfer, positive when heat is added to the system
$\bar{R}$	8.31434 [N m / mole K] universal gas constant
$R = \bar{R}/M$	[N m / kg K] gas constant for a gas with molecular weight M
T	[K] temperature
t	[sec] time
u	[J / kg] specific internal energy
$\vec{V}$	[m / sec] velocity vector, positive in outward normal direction
V	[m^3] volume
$\dot{W}$	[W] rate of work, positive when work is done by the system on its surroundings
ρ	[kg / m^3] density
v	[m^3 / kg] specific volume

1.0 The First Law of Thermodynamics

In the following development, the control volume, defined by the subscript (cv), represents the airbag or fixed volume tank in a tank test. The inflow stream, defined by the subscript (in), represents gas flow into the control volume from the inflator. The outflow stream, defined by the subscript (out), represents gas flow out of the control volume due to vents and fabric leakage. The work term, $\dot{W}$, represents PdV work due to an expanding airbag. The term $\dot{Q}$ represents heat transfer from the hot gases in the airbag to the cooler surroundings.

1.1 Control Volume Formulation of the 1st Law

Neglecting kinetic and potential energy, the rate dependent first law formulation for a control volume is (eq. 4.45 in [4])

$$\frac{d}{dt}\iiint\limits_{cv} u\rho dV + \iint\limits_{cs} h\rho\vec{V}\cdot d\vec{A} = \dot{Q} - \dot{W} \tag{1}$$

The first term on the left side of equation 1 represents the change in energy in the control volume (cv). The second term on the left side of equation 1 represents energy transport by mass flow across the control surface (cs). The rate of heat transfer, $\dot{Q}$, is taken as positive when heat is added to the control volume from the surroundings. The rate of work done, $\dot{W}$, is taken as positive when work is done by the control volume on its surroundings.

1.2 Evaluating the Rate of Change of Energy in the Control Volume

The first term on the left side of equation 1 represents the change in energy in the control volume. After performing the integration and then the differentiation, this term becomes

$$\frac{d}{dt}\iiint\limits_{cv} u\rho dV = \frac{d}{dt}\left(u_{cv}m_{cv}\right) = u_{cv}\frac{dm_{cv}}{dt} + m_{cv}\frac{du_{cv}}{dt} \tag{2}$$

The term m_{cv} can be evaluated from a mass balance

$$m_{cv} = m_{in} - m_{out}$$

Then,

$$\frac{dm_{cv}}{dt} = \dot{m}_{cv} = \dot{m}_{in} - \dot{m}_{out} \tag{3}$$

The term $\dfrac{du_{cv}}{dt}$ can be evaluated as

$$\frac{du_{cv}}{dt} = \frac{du_{cv}}{dT}\frac{dT}{dt} = c_{v,cv}\frac{dT}{dt} \tag{4}$$

5

The rate of change of energy in the control volume can be evaluated by substituting equations 3 and 4 into equation 2.

$$\frac{d}{dt}\iiint\limits_{cv} u\rho dV = \dot{m}_{in}u_{cv} - \dot{m}_{out}u_{cv} + m_{cv}c_{v,cv}\frac{dT}{dt} \tag{5}$$

1.3 Evaluating Energy Transport by Mass Flow Across the Control Surface

The second term on the left side of equation 1 represents energy transport by mass flow across the control surface. This term can be evaluated as

$$\iint\limits_{cs} h\rho\vec{V}\cdot d\vec{A} = \dot{m}_{out}h_{cv} - \dot{m}_{in}h_{in} \tag{6}$$

Note that for mass flow entering the control volume, the velocity vector and area vector point in opposite directions resulting in a negative dot product. For outflow, both vectors point in the same direction resulting in a positive dot product.

1.4 The 1st Law Rearranged to Give the Rate of Change of Temperature

The rate of temperature change in the control volume can be evaluated by substituting equations 5 and 6 into equation 1 and rearranging terms.

$$\frac{dT}{dt} = \frac{\dot{m}_{in}\left(h_{in} - u_{cv}\right) - \dot{m}_{out}\left(h_{cv} - u_{cv}\right) + \dot{Q} - \dot{W}}{m_{cv}c_{v,cv}} \tag{7}$$

A further simplification can be achieved by using the definition $h_{cv} - u_{cv} = Pv\big|_{cv}$ and assuming ideal gas behavior $Pv\big|_{cv} = RT_{cv}$.

$$\frac{dT}{dt} = \frac{\dot{m}_{in}\left(h_{in} - u_{cv}\right) - \dot{m}_{out}RT_{cv} + \dot{Q} - \dot{W}}{m_{cv}c_{v,cv}} \tag{8}$$

2.0 Gas Mixtures - Single Inlet Stream With Multiple Gas Species

Equation 8 can be modified for gas mixtures

$$\frac{dT}{dt} = \frac{\sum\limits_{i=1}^{n}\dot{m}_{in}f_{i,in}\left(h_{i,in} - u_{i,cv}\right) - \sum\limits_{j=1}^{m}\dot{m}_{out}f_{j,cv}R_jT_{cv} + \dot{Q} - \dot{W}}{\sum\limits_{j=1}^{m}f_{j,cv}m_{cv}c_{v,cv}} \tag{9}$$

6

The first summation in the numerator on the right hand side, from i=1,n, is over the number of gas species entering the control volume from the inflator. Equation 9 is for a single inflator with the mass fraction of each gas species, $f_{i,in}$, defined by

$$f_{i,in} = \frac{m_{i,in}}{\sum\limits_{i=1}^{n} m_{i,in}} \qquad i=1,n \qquad (10)$$

The second summation in the numerator and the summation in the denominator, from j=1,m, is over the number of gas species in the control volume. The number of gas species, m, in the control volume is usually greater than n, because air (i.e., N_2, O_2) is initially present in the control volume. This mass fraction is defined by

$$f_{j,cv} = \frac{m_{j,cv}}{\sum\limits_{j=1}^{m} m_{j,cv}} \qquad j=1,m \qquad (11)$$

Assuming that the gas mixture in the control volume is homogeneous, the mass fraction of each gas species in the exit stream is also defined by equation 11.

Equation 9 can be easily extended to multiple inflators and multiple vents (e.g., fabric leakage) by including the appropriate summations over all these streams.

3.0 Evaluation of Heat Capacity, Enthalpy, and Internal Energy

The definition of enthalpy is

$$dh = c_p(T)dT \qquad (12)$$

with $c_p(T)$ being a function of temperature. This equation can be integrated to determine the value of enthalpy, h, for use in equations 8 or 9.

$$\int\limits_{h_{ref}}^{h} dh = \int\limits_{T_{ref}}^{T} c_p dT \qquad (13)$$

An appropriate energy zero (i.e., lower integration limit, reference temperature) must be chosen. However, an absolute scale of enthalpy does not exist. There is no pressure and temperature combination at which we can unambiguously state that the enthalpy of the particular gas is zero. Recourse must, therefore, be made to defined scales with defined zeros.

> Warning – There is a proliferation of a number of different scales, all having different zeros. It is not advisable to mix data from different reference books [5].

An accepted method is to chose h=0 at T=25C (298.15 K). Employing this definition, the National Institute of Standards (NIST) [6] uses the Shomate equation to define

$$c_p = a + bT + cT^2 + dT^3 + \frac{e}{T^2} \tag{14}$$

and

$$h = aT + \frac{bT^2}{2} + \frac{cT^3}{3} + \frac{dT^4}{4} - \frac{e}{T} + f - \Delta H_{f,298} \tag{15}$$

The curve fit constants (a,b,c,d,e,f) and $\Delta H_{f,298}$ for many gases can be found in the NIST Chemistry WebBook (http://webbook.nist.gov/chemistry/).

Note that

$$f - \Delta H_{f,298} = -\left(a*298 + \frac{b*298^2}{2} + \frac{c*298^3}{3} + \frac{d*298^4}{4} - \frac{e}{298} \right) \tag{16}$$

The heat capacity at constant volume can then be calculated from

$$c_v = c_p - R \tag{17}$$

and the internal energy from

$$u = h - RT \tag{18}$$

References

1. J.T. Wang, An Analytical Model for an Airbag with a Hybrid Inflator, GM rept. R&D-8332, April, 1995.
2. J. Kang and J.T. Wang, ISP – An Airbag Inflator Simulation Program, GM rept. R&D-8763, January, 1998.
3. W. Lian and G. Narwani, Effect of Gas Thermodynamics on the Agressiveness of Airbag Inflator, SAE Technical Paper Series #982323, 1998.
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5. K.E. Bett, et. al., Thermodynamics for Chemical Engineers, MIT Press, 1975, ISBN 0-262-02119-6, chapter 8.5.
6. National Institute of Standards Web Based Chemical Data, http://webbook.nist.gov/chemistry/

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Month of December additions and revisions to the FEA Information web sites

Site:	Additions/Revisions
www.feainformation.com	News Pages 1,2 and 3 have been added to bring you monthly postings of interest
News Page 1	Book review by Dr. David Benson on The Finite Element Method, Volume 1, Volume 2, and Volume 3 – The Basics, 5th edition by O.C. Zienkiewicz and Robert Taylor
News Page 2	Article: Linux Makes Sense For Blind Users –Charles E. Hallenbeck, Ph.D (also in this news issue)

Publications showcased during the month of December. If you missed any visit our News Page on News Page #3 - they are being posted for a month in pdf format.

- **ALE and Fluid-Structure Interaction Capabilities in LS-DYNA** – Lars Olovsson (LSTC) and M'hamed Souli (Universite d'Artois)
- **Effects of Initial Geometrical Imperfection on Square Tube Collapse** – Liang Xue, Zhongqin Lin, Zhengxu Jiang (Shanghai Jiao Tong University)
- **Simulating the Motion of Heart Valves Under Fluid Flows Induced by Cardiac Contraction** – Eann A. Patterson, C.J. Carmody, Ian C. Howard (University of Sheffield)

Sites under review to open in 2001:

Auto Meshing	Underwater Shock Analysis	Linear Structural Analysis
Explicit FEA	Fluid-Structure Interaction	FEA Magazine
Implicit FEA	Virtual Prototype Testing	CAE Information

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Personal Opinion/Review:
Linux Makes Sense For Blind Users (c) Charles E. Hallenbeck, Ph.D.
Contact: chuckh@mhonline.net for comments on this article

As Linux matures and finds a home in the desktop PC, blind users are discovering that it is easy to gain access to this system with speech or braille displays. This article summarizes how such access is achieved.

Background. The first personal computer to be used widely by the blind was the Apple II and II-E dating from the late 1970's. With an inexpensive speech synthesizer plugged into one of its slots, a number of useful programs were written with their output directed to that slot. Programs included word processors, simple data base engines, text to braille translators, and modem/comm programs. What else could a blind person ask for? The modem program especially opened the way to local BBS's and from there to university and commercial time-sharing systems and to the rest of the world of computing. The downside was that each application carried its own unique access solutions, and blind users ended up using - forgive the expression - "separate but equal" applications, and of course separate was not equal then either. Blind users and sighted users did not use the same applications and software development rapidly stagnated for blind users.

Then came DOS and the IBM compatible PC. (I am omitting the CP/M story). On a DOS machine the solution for the blind to achieve speech access was much more satisfactory. A special screen access program could be run at bootup as a TSR (Terminate and Stay Resident) designed to steal a copy of each keystroke and each character sent to screen memory, and direct those copies to a speech synthesizer. The text on the screen at any given moment was stored in memory as ASCII character codes and could conveniently be re-referenced or reviewed by the screen access software. Once such a TSR program was run, all subsequent applications would automatically become accessible to blind users, who would hear each key say its name as it was pressed and hear all information sent to the screen. The application need not be modified in any way. Blind users used the same applications as everyone else. Liberation! Long live WordStar, Kermit, and Lotus 123!

Then came Windows. The GUI (Graphical User Interface) presented blind users, or rather designers of screen access software for the blind, with a very serious challenge. There were no characters sent to screen memory. In fact screen memory contained no ASCII character codes at all; it contained only pixels whose patterns sometimes looked like letters and numbers, but sometimes looked like paperclips, smiley faces, wastebaskets, hourglasses, or whatever. The preferred mode of input was by mouse droppings, and eye-hand coordination was the supreme skill. Windows designers boasted that there were "no complicated commands" to learn, such as "DIR," "COPY," or "DEL" I suppose. Visual intuition and the "point and click" reflex response sufficed. At the present time GUI screen access software for Windows exists, but it is expensive, functions imperfectly, and is never as current as the most recent Windows releases. Users rely on keystroke equivalents of mouse commands, and so those "complicated commands" have crept back in, at least for blind users.

Linux at last. With the advent of Linux for the desktop PC, several access solutions for blind users have been proposed. The simplest is so obvious it hardly needs mentioning. Connect the Linux machine by a serial null modem cable to a second PC which is already accessible, and dial into the Linux box from there. The second machine could be an Apple with a "talking COMM" program, or a DOS box with a

standard modem program such as Procomm, Kermit, or Telix. I used that method happily for a couple of years until something better came along. It is very much like having a shell account on your own machine, and it is not a bad solution at all.

Emacs and Emacspeak. Richard Stallman and the Free Software Foundation will long be remembered for the GPL concept, for the GNU C/C++ compiler GCC, and for the gonzo editor Emacs. Emacs is more than an editor; its enthusiasts regard it as an IDE (Integrated Development Environment) and boast that one can perform any computing task one desires without ever leaving Emacs. While there is a steep and daunting learning curve, the payoff at the top is said to be substantial for mastering its conventions. And as far as blind users are concerned, such an integrated environment is perfect as a means of gaining access. T.V. Raman has developed a set of Lisp macros to render Emacs functions accessible in speech, and the package (called Emacspeak) is in widespread use. Its author vigorously pursues its development, and an active email discussion lists exists to support users. Emacspeak can even be used without a hardware voice synthesizer, since it supports the IBM ViaVoice software synthesizer. The downside of this solution is that one must bring the system up, log into a user account, and run Emacs with the Emacspeak macros before having access to the screen. In addition, if for any reason you cannot do it in Emacs, it cannot be done.

Speakup. Have you noticed that I saved the best for last? Kirk Reiser at the University of Western Ontario has developed an acvcess solution called "Speakup" which takes a very different path. Speakup is a set of kernel patches applied to the source code for the Linux kernel. With the Speakup patches applied and the kernel recompiled and reinstalled, the same powerful solution that made DOS so "blind friendly" now exists for Linux. In particular, all screen output is spoken right from the start - including those sometimes all important bootup messages. Each key says its name when pressed, and every application speaks its output as well as placing it on the screen. With Speakup, the numeric keypad is dedicated to review functions; i.e., moving an imaginary cursor around the current screen to review its contents a line at a time, a word at a time, or character by character. Recompiling and installing a kernel patched with Speakup is not as difficult a task as it sounds, and the payoff is a totally accessible desktop PC running a world class operating system.

Many developers of access technology are themselves blind, including both Raman and Reiser. There is a clear sense of self-help at work here. In addition to the usual support structures for all Linux users, blind persons using Linux have available several specialized support lists dealing with access issues. Blind plus Linux equals BLINUX, a term often appearing in the names of email lists on this subject. Two examples are blinux-list@redhat.com and blinux-newbie@braille.uwo.ca . You should also visit http://www.linux-speakup.org for the best information and the latest developments.

Unsolved problems. A handful of minor problems remain, and a few rather major ones. The smaller problems have to do with those as yet unfinished features of Speakup, which time and diligence will surely fix. Speakup has a principal author, but it is offered as an Open Source project and has an impressive number of very talented lieutenants providing Kirk Reiser with very capable assistance. One major problem is that Speakup requires a hardware speech synthesizer at the present time. A software synthesizer would either increase the kernel size unreasonably or would be designed as a kernel module. In the latter case, it would not be able to execute until after Linux has completed loading and configuring itself, and so much important early information would be lost to the blind user. Fortunately hardware synthesizers are not terribly expensive.

Another major problem is that neither Emacspeak nor Speakup provide access to the Linux GUI, the X windowing system. Unlike Windows, where the GUI is the only interface offered, Linux makes its GUI

a user choice, and so in its character mode the full power of Linux is available for the blind to enjoy. However, when running X, Linux is no longer an accessible environment for the blind. There are a few X applications that blind users might like to use, including Netscape and WordPerfect, although there are text based alternatives that are very useful tools. I myself rely on Lynx and Pine in the Linux character environment. Quite recently a text based interface for Realplayer by Matt Campbell, called "trplayer," has made audio streams and Realaudio files accessible without resort to a GUI context. Linux is not Unix of course, but the differences are legal and economic rather than real. As such its conventions and its style date from the early 1970's and anticipate DOS by a decade and Windows by two. It is based on open standards and flourishes under Open Source. It makes a great choice for any serious PC user, and especially for those who must rely on speech access to the digital world.

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1st Quarter 2000

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