Recent Advances in Model Reduction of Vibrating Substructures

Dan Givoli
Faculty of Aerospace Engineering, Technion, Israel

In structural dynamics, one often wishes to approximate a given discrete model of a structure by another model which involves a much smaller number of degrees of freedom. There is a very large volume of literature on the subject, often called "model order reduction." One of the oldest and most popular model reduction method in structural dynamics is Standard Modal Reduction (SMR), which is based on the "low frequency rule." According to this rule, reduction of the model is achieved by retaining only the modes associated with low frequencies, while discarding the modes associated with high frequencies. In this talk, the subject will be briefly reviewed. Then the special problem of substructure reduction will be considered. A recent method, called Optimal Modal Reduction (OMR) will be presented. A numerical example will be used to demonstrate the performance of OMR and compare it to SMR.

Israel Association for Computational Methods in Mechanics - IACMM-21
Ben-Gurion University, Oct. 19, 2006

The Discontinuous Enrichment Method for the Helmholtz Equation: 3-D Elements

Eran Grosu (grosu@eng.tau.ac.il), Isaac Harari (harari@eng.tau.ac.il)
web page: http://www.eng.tau.ac.il/~harari

Department of Solid Mechanics, Materials, and Systems
Tel Aviv University

Boundary-value problems governed by the Helmholtz equation arise in a variety of physical phenomena such as acoustic, elastic and electromagnetic time-harmonic wave propagation. For the Helmholtz operator, the accuracy of standard finite element method solutions deteriorates rapidly with increasing wave number. This is related to the pollution effect, caused by accumulation of spurious dispersion. In practical terms, this leads to a considerable increase in the cost of finite element analysis at higher wave numbers.

In the discontinuous enrichment method (DEM) [1], the standard finite element polynomial field within each element is enriched by free-space solutions of the governing homogeneous, constant-coefficient, partial differential equation. In this manner, features of the differential equation are included in the approximation. The enrichment field is not continuous across element boundaries, and continuity is enforced weakly by Lagrange multipliers. Thus, the enrichment can be eliminated at the element level by static condensation, which simplifies the method and improves matrix conditioning.

DEM was originally implemented using quadrilateral elements [1, 2] and has recently been extended to hexahedral elements [3]. However, due to practical considerations of three-dimensional mesh generation, tetrahedral meshes are usually used. Triangular DEM elements are developed as a prelude to the formulation of tetrahedral elements. Dispersion properties of different configurations of plane waves in the enrichment and approximations of Lagrange multipliers provide preliminary information on their performance. Numerical tests then assess conditioning and accuracy, indicating preferred element configurations. This procedure is then extended to tetrahedral elements. Numerical results show that the proposed configurations for tetrahedral DEM elements become more competitive as we enhance the enrichment and Lagrange multipliers.

1. C. Farhat, I. Harari, L. P. Franca, “The discontinuous enrichment method”, Comp. Meth. App. Mech. Eng., 190(48), 6455-6479, 2001.

2. C. Farhat, R. Tezaur, P. Wiedemann-Goiran, “Higher-order extensions of a discontinuous Galerkin method for mid-frequency Helmholtz problems”, Wave Mot., 39(4), 307-317, 2004.

3. R. Tezaur, C. Farhat, “Three-dimensional discontinuous Galerkin elements with plane waves and Lagrange multipliers for the solution of mid-frequency Helmholtz problems”, Int. J. Numer. Meth. Eng., 63(5), 796-815, 2006.

Failure initiation at a V-notch tip subject to mixed mode loading: *p*-FEA and validation by experiments[1]

E. Priel & Z.Yosibash

Dept. of Mechanical Engineering, Ben-Gurion University of the Negev, Beer-Sheva

Brittle structural components containing V-notches may fail suddenly at significantly lower loads than suggested by apparent material strength. Several works propose failure laws to predict failure in components having a V-notched tip under *mode I* loading but few address the more complicated and realistic case of *mixed mode* (*I* and *II*) loading.

We enhanced a mode I failure law to the case of mixed-mode loading. This enhancement is based on matched asymptotic solutions and requires the solution of an auxiliary problem in an infinite domain, obtained by p-FEA. In addition, the generalized stress intensity factors at the notch tip are also extracted by p-FEA.

In order to validate the proposed failure criterion, experiments were preformed on PMMA and MACOR (Glass Ceramic) V-notched specimens. The validity of the extended failure criterion was demonstrated by comparing the predicted failure loads and crack initiation angles to ones obtained by experimental observation [1].

This talk presents the extended failure criterion, p-FEAs required for computing the required information to apply it, and its validity (by comparing the predicted failure load and crack initiation angle for a wide range of V-notch opening angles and mode mixity ratios to experimental observations).

References

[1] Yosibash Z., Priel E. and Leguillon, D., ``A Failure Criterion for Brittle Elastic Materials under Mixed-mode Loading'', *International Journal of Fracture*, in press.

[1] Work sponsored by the Kamag-Vatat grant and performed in collaboration with Prof. Dominique Leguillon from Laboratoire de Modélisation en Mécanique -,Univ. of Paris 6, Paris, France, and Dr. Arie Bussiba from Kamag.

Crack Detection using a Genetic Algorithm

Daniel Rabinovich and Dan Givoli
Faculty of Aerospace Engineering, Technion

A robust computational tool is developed for the accurate detection and identification of cracks (and other flaws) in two-dimensional structures. This tool is to be used in conjunction with non-destructive testing of specimens, as is commonly done, for example, for aircraft structures. It is based on the solution of an inverse problem. Based on some measurements that describe the response of the structure to vibration in a chosen frequency, or a combination of frequencies, typically along part of the boundary of the structure, the goal is first to estimate whether the structure contains a crack, and if so, to find the location and shape of the crack that produces a response closest to the given measurement data in some chosen norm. The crack may be either internal or edge-reaching and may possibly be curved. The measurements may be noisy, and the success of accurate identification depends, of course, on the level of noise. The inverse problem is solved using a Genetic Algorithm (GA), sometimes with the aid of regularization to overcome ill-posedness difficulties. The GA optimizing process requires the solution of a very large amount of direct problems. The latter are solved via the eXtended Finite Element Method (XFEM). This enables one to employ the same regular mesh for all the direct problems. In fact, the problem becomes tractable mainly owing to this capability of the XFEM. Performance of the method will be demonstrated via a number of numerical examples involving a cracked membrane and a thin cracked elastic plate under plane stress conditions. Various computational aspects of the method will be discussed.

CFD elliptic analysis of anisotropic flow in the wake of a wind turbine

Y. Feldman & A. Herszage
Dept. of Development of Energy Technologies,
Israel Electric, Haifa, 31000, Israel
amiel@iec.co.il

Abstract

A continuing demand for electric energy and the environmental implications of conventional power generation methods motivates the active search for renewable clean energy sources. Wind energy is, under suitable conditions, one of the most effective ways of environmental friendly power production. In this case wind turbines are used to convert the flowing air kinetic energy into electrical energy. Extraction of the air flow energy, leads to significant modifications of the air flow field downstream the turbine rotor, resulting in a wake characterized by reduced mean velocity and static pressure. A main turbulent momentum transfer mechanism from the fast external flow to the resulting slow flow downstream the rotor, is responsible for the wake structure and therefore for velocity recovery in the wind direction. Blade tip vortices created by blade motion in the viscous surrounding media, are shed downstream. They roll up in a short distance and move farther in helical trajectories [1]. This behavior can be approximated by a cylindrical shear layer, which separates the slow moving fluid in the wake from the fast moving fluid outside [2]. Momentum diffusion from this layer inwards in the downstream direction, results in wake diameter decrease with the consequent velocity recovery and turbulent energy transfer. The above issue is of cardinal importance regarding wind farm design. An ideal arrangement of wind turbines should exclude their mutual interaction, since downstream turbines are influenced by the wakes from the upstream rotors, which result in velocity deficits and increased levels of incident turbulence. These effects lead to significant reduction in the downstream turbines power production and unsteady loads increase. Unfortunately, the areas suitable for wind energy production are limited and in order for wind power generation to be economically attractive, the wind turbines have to be assembled in arrays, inevitably leading to mutual wake interactions. In this respect significant energy losses have been measured in arrays characterized by spacing smaller than seven turbine diameters [3]. As a result, optimization of wind turbines layout in wind farms has been the subject of extensive study over the recent three decades. Experimental findings within this large group of investigations have provided the main motivation for the present work. These experimental observations concern turbines arranged in line [4, 5]. According to them, while the first turbine produces full power, there is a significant decrease of power in the second turbine, with practically no further loss in successive machines. On this basis, it is proposed to use a straightforward approach, using a commercial finite volume code [6] for the numerical solution of the turbulent anisotropic flow field, including direct rotor modeling. In terms of reasonable computational resources available today, the full modeling of the flow field around a small number of turbines is not out of reach. As a first step towards this goal, it is necessary to validate and fully understand the limitations of the above described approach for a single turbine, which are presented in this work.

A CFD elliptic analysis of anisotropic flow in the wake of wind turbine was carried out, using a Reynolds Stress model for the closure of the averaged Navier Stokes equations. Special attention was paid to grid refinement techniques, in order to provide adequate pressure and velocity distributions in the vicinity of the turbine blades and to prove the overall convergence and stability of the numerical solution. An acceptable qualitative agreement with previous numerical and experimental studies was found. The proposed model implementation needs no extra features than those available in a commercial CFD code and may be a powerful instrument for wind turbine engineers.

[1] R. Gomez-Elvira, A. Crespo, E. Migoya, F. Manuel, J. Hernandez, Anisotropy of turbulence in wind turbine wakes, J. Wind Eng. Ind. Aerodyn. 93 (2005) 797-814.

[2] J. N. Sorensen, W. Z. Shen, Numerical Modeling of Wind Turbine Wakes, J Fluids Eng. 124 (2) (2002) 393-399.

[3] A. Crespo, J. Hernandez, S. Frandsen, Survey of Modeling Methods for Wind Turbine Wakes and Wind Farms, Wind Energy 2 (1999) 1-24.

[4] L. J. Vermeer, J. N. SØrensen, A. Crespo, Wind Turbine Wake Aerodynamics, Prog. Aero Space Sci. 39 (2003) 467- 510.

[5] J. van Leuven, and D. Stevens, The wind farm of Zeebrugge: experimental set-up, J. Wind Eng. Ind. Aerodyn. 27 (1988) 39-144.

[6] Fluent 6 User's Guide, Fluent Inc., Lebanon- NH, USA, 2005.

NUMERICAL MODEL FOR
BOILING LIQUID VAPOR EXPLOSION (BLEVE)

G.A. Pinhasi [a], A. Dayan [b] and A. Ullmann [b]

[a)] Department of Chemical Engineering and Biotechnology- Faculty of Engineering
The college of Judea and Samaria– Ariel 44837, Israel
[b)] Department of Fluid Mechanics and Heat Transfer- Faculty of Engineering
Tel-Aviv University, Israel
gadip@yosh.ac.il

Abstract

The depressurization of a vessel containing saturated or subcooled liquid may occur in a variety of industrial processes and often poses a potentially hazardous situation. A numerical model was developed for estimating the thermodynamic and the dynamic state of the boiling liquid during a boiling liquid vapor explosion (BLEVE) event. The model allows calculation of bubble nucleation and growth processes in the liquid at the superheat-limit state, the front velocity of the expending liquid and the shock wave pressure formed by the liquid expansion through the air. Conditions of shock formation were found to be normally associated with high initial temperatures that can bring the liquid to its superheat-limit state during the initial depressurization. Furthermore, the high initial temperature also induces a generation of higher vapor pressures that forces a rapid mixture expansion.