engineering
mechanics

First Engineering Mechanics Symposium

23 - 24 November 1998
Rolduc, Kerkrade

Graduate School Engineering Mechanics
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Preface

The National Research School on Engineering Mechanics, a joint initiative of the Eindhoven and Delft Universities of Technology and the University of Twente, organizes on an annual basis a two-day Engineering Mechanics Symposium. The aim of this symposium is to stimulate the communication and the exchange of information with respect to ongoing research in the field of Engineering Mechanics. To achieve this goal the program offers a broad range of activities with keynote lectures by leading experts in the field, topic sessions in relation to the selected research program of the Graduate School, poster presentations of actual research projects by PhD- and Twaio-students and a meeting of the senior academic staff.

The first Engineering Mechanics Symposium takes place on November 23rd and 24th 1998, at Rolduc - Kerkrade. In the opening session there are lectures by:

- Prof.Dr.Ir. P.J. Zandbergen, President of the Royal Netherlands Academy of Arts and Sciences (KNAW),
- Prof.Dr.-Ing. W. Schiehlen, President of the International Union of Theoretical and Applied Mechanics (IUTAM),
- Prof.Dr.Ir. D.H. van Campen, Scientific Director of the Graduate School Engineering Mechanics.

Furthermore, there are the following topic sessions:

- Mechanics of Material Nonlinearities,
  organized by Ton van den Boogaard (UT), Bert Sluys (TUD) and Marc Geers (TUE),
- Dynamics of Structures,
  organized by Bram de Kraker (TUE), Paul van Woerkom (TUD) and Henk Tijdeman (UT)
- Structural Optimization and Reliability,
  organized by Fred van Keulen (TUD) and Bert Schoofs (TUE).

Each topic session is introduced by the session organizers, focussing on activities, trends, outlooks and perspectives of the field. Subsequent contributions report on specific projects in more detail.

Additionally, there is a poster session in which 62 PhD- and Twaio-students participating in the Graduate School Engineering Mechanics present their current research project. In relation to these presentations a contest is organized in which an external jury selects the best three contributions. This years members of the jury are Dr.Ir. F.J. Klever (Shell International Exploration and Production), Ir.Drs. P.D. van der Koogh (TNO Road-Vehicles Research Institute) and Dr.Ir. B.M. Spee (National Aerospace Laboratory NLR). Winners will be announced at the evening session of the symposium on Monday, November 23rd .

On Tuesday November 24th a meeting of the senior academic staff participating in Engineering Mechanics takes place. Topics regarding a consolidation of the position of the Graduate School Engineering Mechanics and the coordination and combination of research activities of participating groups will be discussed.

This report contains more detailed information on the First Engineering Mechanics Symposium. Included are the following sections:

- **Section 1:** Detailed program of the symposium.
- **Section 2:** Abstracts of selected opening lectures and of introductions to the topic sessions.
- **Section 3:** Abstracts of presentations at the topic sessions.
- **Section 4:** Survey of poster presentations.

Individual poster presentations are collected in a separate report which will be supplied at the start of the symposium. It also can be obtained from the Secretariat of the Graduate School. Furthermore, poster presentations are available through:

http://www.em.tue.nl

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PROGRAM

This section contains the detailed program of the first Engineering Mechanics Symposium. Information on the opening lectures and introductions to the sessions are presented in section 2. Abstracts of the presentations can be found in section 3.

PROGRAM

Monday, 23 November 1998

09.45-10.30	Registration and informal get-together.	
10.30-12.25	**Session 1: Opening Session**	
10.30-11.15	Opening of the Symposium together with a Review of Some Approaches to the Exact Solution of the Soliton Problem. Prof.Dr.Ir. P.J. Zandbergen, President of the Royal Netherlands Academy of Arts and Sciences (KNAW)	Page 7
11.15-12.10	Opening lecture: Modular Simulation in Multibody System Dynamics. Prof.Dr.-Ing. W. Schiehlen, President of the International Union of Theoretical and Applied Mechanics (IUTAM)	Page 8
12.10-12.25	Perspectives of the Research School Engineering Mechanics. Prof.Dr.Ir. D.H. van Campen, Scientific Director EM	
12.30-13.30	Lunch	
13.45-16.55	**Session 2: Mechanics of Material Nonlinearities** **Session organisers: Van den Boogaard, Sluys, Geers**	Page 9
13.45-14.00	Introduction by the session organiser Marc Geers (TUE).	Page 9
14.00-14.20	Martin Tijssens (TUD): On the Numerical Simulation of Crazing in Polymers Using a Cohesive Surface Methodology.	Page 24
14.20-14.40	Joeri Lof (UT): Numerical Modeling of Aluminium Extrusion.	Page 19
14.40-14.55	Introduction by the Session Organiser Ton van den Boogaard (UT).	Page 9
14.55-15.15	Dirk Brokken (TUE): Modelling of the Metal Blanking Process - Tackling the Crack Numerically.	Page 14
15.15-15.45	Break	
15.45-16.05	Ad Goijaerts (TUE): Modelling of the Metal Blanking Process - How to Predict Ductile Fracture.	Page 16
16.05-16.20	Introduction by the Session Organiser Bert Sluys (TUD).	Page 9
16.20-16.40	Bert Rietman (UT): Finite Elements for Beter Understanding of Compression Tests.	Page 20
16.40-17.00	Akke Suiker (TUD): Derivation of a Second-Gradient Micro-Polar Constitutive Theory Using a Micro-Structural Approach.	Page 23
17.00-18.00	Informal reception	
18.00-19.30	Dinner	
19.30-21.30	**Poster Session:** **Presentation of current research projects, carried out by PhD- and Twaio-students participating in Engineering Mechanics.** **Announcement of winning contributions in the poster contest.**	
21.30-01.00	Bar “De Verloren Zoon”	

Tuesday, 24 November 1998

08.00-09.00	Breakfast	
09.00-12.10	**Session 3: Dynamics of Structures** **Session organisers: De Kraker, van Woerkom, Tijdeman**	Page 10
09.00-09.40	Introduction by the Session Organisers: Dynamics of Structures: Outline and Perspectives.	Page 10
09.40-10.00	Rogier Wolfert (TUD): Wave Effects in One-Dimensional Elastic Systems Interacting with Moving Objects - Theory and Applications for High Speed Trains.	Page 26
10.00-10.20	Frits van der Eerden (UT): Acoustics of a Sound Absorbing Wall.	Page 15
10.20-10.50	Break	
10.50-11.10	Arend Schwab (TUD): Dynamics of Flexible Multibody Systems with Joint Clearance.	Page 21
11.10-11.30	Nathan van de Wouw (TUE): Steady-State Behaviour of Stochastically Excited Nonlinear Dynamic Systems.	Page 27
11.30-11.50	Jeroen Wensing (UT): The Dynamic Behaviour of Ball-Bearings.	Page 25
11.50-12.10	Remco Leine (TUE): Stick-Slip Vibrations.	Page 18
12.20-13.20	Lunch	
13.30-15.00	**Session 4: Structural Optimization and Reliability** **Session Organisers: v. Keulen, Schoofs**	Page 11
13.30-14.00	Introduction by Session Organisers: Numerical Design Optimization: Achievements and Challenges.	Page 11
14.00-14.20	Arjan Stam (TUD): Reliability of Buckling Sensitive Structures.	Page 22
14.20-14.40	Rien van Houten (TUE): Function Approximation Concepts for Multidisciplinary Design Optimization.	Page 17
14.40-15.00	Henk de Boer (TUD): Accurate Semi-Analytical Design Sensitivities.	Page 13
15.00-15.10	Closure	
15.10-15.40	Break	
15.40-16.40	Assembly of Project Leaders EM	

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OPENING LECTURES

and

INTRODUCTIONS TO THE SESSIONS

This section contains abstracts of the opening lectures by Pieter Zandbergen, president KNAW, and Werner Schiehlen, president IUTAM, and of the introductions to the sessions by the session organizers. Abstracts are ordered according to the program of the symposium, as presented in section 1.

Opening of the Symposium

together with

A Review of Some Approaches to the Exact Solution of the Soliton Problem

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There has been ever since the work of Korteweg and De Vries a vivid interest in obtaining the soliton of highest wave height. A number of years ago Douwe Dijkstra and I developed an approach based on generating a sequence of successively higher order ordinary differential equations. The results are interesting but also disappointing. Only rather recently we found some of the hidden roots of this work going back to Benjamin and Lighthill. This leads to an interesting view on the different approaches developed.

Keynote lecture:

Modular Simulation in Multibody System Dynamics

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Modeling and simulation of complex multibody systems may be relieved by a modular approach in which the global system is divided into subsystems. Advantages raise from independent and parallel modeling of subsystems over easy exchange of the resulting modules to the use of different multibody dynamics software for each module.

Each subsystem may be simulated independently and in parallel with adapted numerical integration methods and adjusted step sizes. Data exchange between subsystems takes place only at discrete time instants with variable communication intervals. Two methods of simulator coupling are investigated and it will be shown that stability is guaranteed only for iterative simulator coupling schemes.

The lecture is devoted to the theoretical aspects of simulator coupling for multibody systems. The modular description is introduced on the mathematical model description level which is the basis for modular simulation. Each subsystem is set up by a general state-space formulation, the global system is then formed by interconnections between the inputs and the outputs of these subsystems. Time discretization of the subsystems including input and output variables is described. On this basis an analysis of zero-stability of the modular numerical integration is treated. It will be shown that convergence is only guaranteed if algebraic loops do not exist between the subsystems. Two methods of simulator coupling are presented. On the one hand it will be shown that stability of the modular simulation is always guaranteed for iterative simulator coupling schemes. On the other hand elimination of algebraic loops within the global system by introduction of filters will be discussed. The theoretical results are illustrated by an example from multibody system dynamics. Numerical results of this example will also be used to compare the efficiency of both methods of simulator coupling.

Session 2:

New Trends in the Modelling of Material Nonlinearities

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The modelling of the mechanics of material nonlinearities has made a significant progress in recent years. Yet, many problems are still unsolved or insufficiently understood. The current headlines in the research on material nonlinearities can be sketched on the three-level model of a material: micro-meso-macro. Material science covers both the micro-level, which is the molecular or atomic level, and the meso-level, which is the scale of the microstructure (e.g. polycrystals in metals). Within this field, the underlying mechanisms which govern the behaviour of the microstructure are intensively studied (e.g. dislocation dynamics, crystal plasticity, micro-cracking). The adequate modelling of the microstructure has become an important subject, since many observed nonlinearities originate from this level. As a result of the ongoing miniaturization, ever thinner and smaller materials are used, which brings the applications on the scale of the microstructure, where classical theories fail to describe the observed mechanical behaviour. Modern material engineering now overlaps the meso-level and the macro-level. On the macro-level, many physical nonlinearities like damage and plasticity, cannot be analysed efficiently without the inclusion of a microstructural-dependent state variable, e.g. an intrinsic length scale. Evidently, these phenomena take place at the scale of microstructure which then becomes dominant. New higher-order theories are emerging to bridge this gap between the macro-level and the underlying microstructure. Complete microstructures are nowadays modelled and used in a multi-level finite element code as a substitute for classical constitutive models. These new approaches will provide us a better insight in the micro-macro relation. If links can be established between geometrical and mechanical properties of the microstructure and the macroscopically observed properties, material design is no longer illusory. A second major headline concerns the necessity for advanced macroscopic constitutive models for geometrical nonlinearities. The numerical analyses with these models are still cumbersome and difficult to deal with, especially if they are combined with physical nonlinearities or thermo-mechanically coupled. Forming processes in metals, large deformations in polymers are typical examples.

These new trends in the modelling of material nonlinearities are directly or indirectly the subject of most research projects in this field. An overview of the running and planned projects in the Netherlands will be given. Soils, concrete, metals, polymers, composites are being investigated with a variety of techniques. Emphasis will be given on the different approaches and the experimental facilities that are currently available in the country.

Session 3:

Dynamics of Structures; Outlook and Perspectives

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In the field of research concerning Dynamics of Structures three important topics might be distinguished (see for example the keynote lecture of U. Emborg of SAAB AB-Sweden at the latest ISMA-conference [1] and the working-group themes of the Cost-F3-action: Structural Dynamics [2]):

- Fluid-Structure interaction and Acoustics
- Structural nonlinearities
- Interaction between Dynamics and Control

The introduction part of session nr. 3 of the EM-symposium will contain two separate contributions. In the first contribution the emphasis will lay upon Fluid-Structure interaction and Acoustics.

In the second contribution the global trends in nonlinear structural dynamics (especially realistic structural elements and non-deterministic excitations) will be discussed.

References

[1] ISMA 23; International Conference on NOISE and VIBRATION Engineering, September 16-18, 1998, Leuven.
[2] EEG COST-Action F3: STRUCTURAL DYNAMICS (1997-2000)

Session 4:

Numerical Design Optimization: Achievements and Challenges

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Numerical design optimization is quite mature as applied to linear static or dynamic structural design problems, described by continuous and deterministic design parameters and system behaviour. Here efficient sensitivity analysis methods are available so that most powerful optimization algorithms can be used. The time consuming character of numerical analysis of the system behaviour by means of, for instance, finite element methods can be tackled by deriving efficient approximate but explicit analysis models based on a limited number of full numerical analyses. For such applications commercial integrated software packages for analysis and optimization are becoming available. They enable the designer to define the design problem in a flexible way, and to choose an efficient optimization strategy.

Research challenges appear when we go beyond the problem characteristics mentioned above. System behaviour can become non-linear, discontinuous and/or time dependent, resulting in considerably increased computer time for analyses. Both discrete design parameters and multidisciplinary problems regarding multiple design objectives require larger numbers of full numerical analyses, whereas development of approximate analysis models is much more complex. Furthermore, the design problem may get a stochastic character, due to uncertain system parameters, input signals or the system behaviour. In such cases local sensitivities cannot be used anymore to speed up the optimization process. Last but not least is the challenge to integrate software packages coming from multidisciplinary research areas, in which the ideas of optimal design are much less elaborate than in structural optimization.

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ABSTRACTS OF PRESENTATIONS

This section contains abstracts of presentations at the first Engineering Mechanics Symposium. Abstracts are in alphabetic order on the (first) author. Abstracts of the keynote lectore and of the introductions to the sessions are presented in section 2.

Accurate Semi-Analytical Design Sensitivities

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Problem formulation

Efficient structural optimization routines require availability of gradient information. Semi-Analytical (SA) design sensitivities are rather popular, as they combine ease of implementation with computational efficiency. Their main drawback however, is their well-known inaccuracy problem. Studies revealed, that inaccuracies become more pronounced for slender structures and when FE meshes are refined. Later the observed complications were understood more thoroughly and have been associated with both the finite differences used at element level and the rigid body *rotations* of the individual elements. For linear statics the authors have proposed Refined Semi-Analytical (RSA) design sensitivities. The underlying idea is to identify the rigid body modes of the individual finite elements. These rigid body modes can easily be differentiated with respect to the design variables. Several advantages of the RSA method can be mentioned. Firstly, it is easy to implement. Secondly, the associated computational effort is limited and, finally, the RSA method can be combined straightforwardly with every finite difference scheme. The objective of the present paper is to present RSA design sensitivities in a unified and sound formulation. Its application will be focused on geometrically nonlinear, limit point, linear and linearized buckling analyses.

Example

A deployable structure, namely a petal which is fully clamped at the circular hub, is investigated. Eight of such petals in deployed configuration form a spherical cap. The location of point A is controlled by the design variable ϕ. Design sensitivities for the displacement of point A in x-direction (u) are considered. The results shown in Fig. 1, demonstrate the supremacy of RSA over SA design sensitivities.

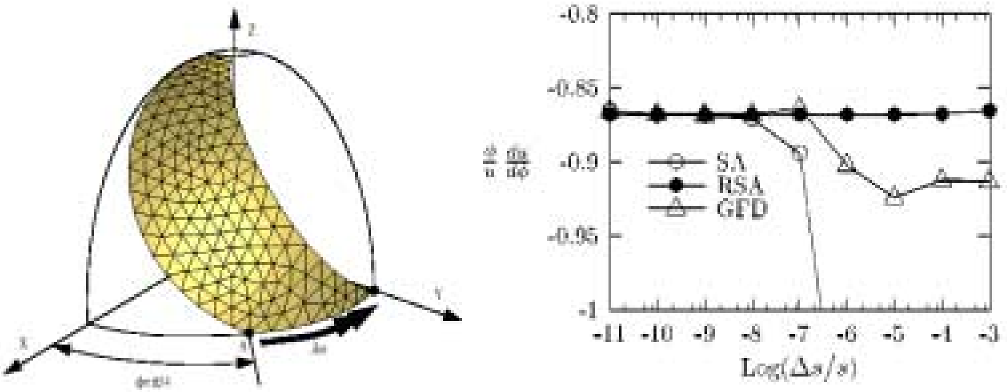

Figure 1: Logarithmic design sensitivities for displacement of point A of the petal. The angle ϕ is taken as the design variable.

Concluding remark

It is concluded that refined SA methods possess the advantages of traditional SA methods, while they do not exhibit unacceptable inaccuracies. It is therefore advocated to use always a RSA formulation in favor of a SA formulation, as better or equally good results are obtained, at the cost of minor additional effort for implementation and computing.

Modelling of the Metal Blanking Process - Tackling the Crack Numerically

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Introduction

The design and realisation of a sheet metal blanking process are currently mainly an empirical effort. Some analytical models are known, but none can fully capture all the phenomena involved. This obstructs process innovation and leads to lengthy trial and error during process evaluation. The objective of the present research is to construct a finite element model which can accurately predict the shape and residual stress state of the product.

Mesh preservation

To robustly simulate the occurring large deformation, an Operator Split version of the Arbitrary Lagrange Euler method is applied, combined with full remeshing. In this algorithm the calculation of the deformation and stress state are uncoupled from the mesh adaptation part. After an Updated Lagrange step, the mesh is adapted by shifting the nodes, and the state variables are transported to the new mesh in a transport step. Bi-linear displacement-oriented elements are used, causing the state variables to be discontinuous across element boundaries. Transport is achieved without smoothing, by solving the transport equation using the Discontinuous Galerkin method. After full remeshing the transport of state variables is achieved by a mapping technique based on smoothing.

Ductile fracture

Material failure essentially determines the shape of a blanked product. Ductile fracture is modelled by a discrete crack approach, which requires continuous remeshing. Generation of highly refined, quadrilateral meshes over strongly non-convex, fractured domains has been accomplished by converting triangular meshes to quadrilateral ones. Classical fracture mechanics approaches break down when faced with large scale plasticity, so an alternative approach based on local ductile fracture criteria will be presented to control the fracture.

Results, Conclusions

The results of a number of blanking simulations will be presented. Although the model predicts the shape of the product, certain trends in these shapes are unrealistic, due to shortcomings of the applied fracture criterion.

Future

To gain fundamental knowledge about the ductile fracture process and an appropriate criterion, simulations are performed on a micro-structural scale, where the governing physical phenomena take place. The deformation history from a simulation is applied to a model of the micro-structure, showing void growth phenomena.

Acoustics of a Sound Absorbing Wall

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Let us consider a sound absorbing wall or panel in a noisy environment. Then it is difficult to predict the sound level or the amount of sound absorption. The main reason for this is that an accurate description of the behaviour of sound absorbing material is not an easy task. Therefore the subject of this study is the modeling and experimental validation of the behaviour of sound absorbing material.

Roughly there are two ways to describe a sound absorbing material: via a boundary condition at the surface or as a volume. Both methods are well suited for implementation in a Finite Element Formulation. The surface method is usually applied in the form of a normal impedance condition. It provides a fast numerical method. However, measurements are needed to determine the normal impedance values as a function of the frequency. In the volume method there is an interaction between the frame and the fluid inside the sound absorbing material. A distinction can be made in increasing order of complexity: the ‘Rigid’ theory treats the frame as infinitely stiff, the ‘Limp’ theory treats the frame without stiffness and the ‘Biot’ theory includes the stiffness of the frame and the acousto-elastic coupling. Although the Biot theory is the most complete the computational effort and the variety of parameters to describe the material are drawbacks.

Another way of describing sound absorbing material, slightly similar to Biot, is a description of the behaviour of the fluid in the cylindrical pores. In such a pore viscous, thermal and mass effects are present. The model is validated with experiments in an impedance tube and the results show a good agreement for the complete frequency range. Variations of the radius, the length and the surface porosity are investigated. Also a combination of pores is examined. As a next step, oblique incident sound will be investigated as well as an elastic frame to account for the acousto-elastic coupling.

Modelling of the Metal Blanking Process
How to Predict Ductile Fracture

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The metal blanking process is an industrially important process. In critical applications, a trial-and-error situation can occur that could possibly be prevented with a proper model of the process. One great problem in modelling this process, is the prediction of initiation and growth of cracks. This is, because the crack path determines the eventual product shape (shear-zone and fracture zone) and thus product quality.

From literature it is known that it is essential to capture the stress and strain history to model ductile fracture (Clift et al., 1990). Therefore, a plane strain FEM-model of the blanking process, developed by Brokken et al.(1997), is validated in earlier publications (Stegeman et al., 1998, Goijaerts et al., 1998), using not only process-forces but also deformation-fields from an experimental planar blanking set-up. This validated model can capture the stress and strain history of material points in the metal blanking process.

With this tool present, we have been working on the characterisation of ductile fracture in the metal blanking process. Because of the numerical model available, we chose to apply only local ductile fracture criteria, which do not have any influence on the material behaviour. A category of such criteria can be written as an integral over plastic strain of a function of stress: $\int_{\varepsilon_0}^{\varepsilon_f} f(\sigma) d\varepsilon = C$. If this integral reaches a critical value C during the process, ductile fracture will initiate.

To get some experimental results on ductile fracture, an axi-symmetrical set-up was developed. In this set-up we chose to vary the clearance, because this parameter is known to have a great influence on the shape of the product (shear-zone and fracture-zone) and thus on the ductile fracture initiation. We used five different clearances (over a range from 1% to 15% of the sheet-thickness), which gave us five different experiments with different ductile fracture initiations.

Firstly, a number of known ductile fracture criteria are evaluated. This was done by determining the C in one experiment and then trying to predict ductile fracture in the others. None of the criteria was found to describe ductile fracture initiation over this range of clearances properly.

Secondly, a closer look at the state variables in the simulations showed that triaxiality (hydrostatic stress over equivalent Von Mises stress) is a very dominating parameter in the blanking process.

Finally, in two fracture criteria (Rice & Tracey, 1969 and Oyane et al., 1980) the influence of the triaxiality is modified and then they were found to describe ductile fracture initiation over the mentioned range of clearances.

References

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Function Approximation Concepts for Multidisciplinary Design Optimization

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In the definition of an optimization problem an objective to be reached must be formulated. To reach this objective, changes to the design parameters or variables defining the design can be made. Usually limitations or constraints are posed on the design variables and other physical properties of the design. Using numerical analysis tools, the values of the objective and constraints can be evaluated for every change in the design variables. Applying numerical optimization algorithms, an optimum design can be found in an automated way.

The interfacing of analysis tools and optimization algorithms, however, is a major difficulty in the optimization process. Firstly, a programming difficulty arises as analysis tools are usually not directly available as source codes. Extracting the values of objective and constraints from within these codes is therefore not always possible. Besides the programming difficulties, optimization of industrial designs often requires extensive computational efforts as optimization algorithms require many evaluations of the objective and constraint functions.

To overcome both difficulties, numerical design optimization tools usually apply some kind of interface as a coupling between analysis software and the optimization algorithm. By employing function approximation techniques, part or the entirety of the design space is modelled using data from a set of analyses. Optimization algorithms are then applied on these explicit approximate problem functions, which can be evaluated at very low costs. These costs are considerably lower than for a direct evaluation of the design.

The first part of the investigation presented here is focused on the development and implementation of such function approximation methods. This investigation was part of the European Brite-Euram II project ”OPTIM - A Shape Optimization Tool for Multidisciplinary Industrial Design”. The objective of the OPTIM-project was the development of a software package with tools for optimal design problems, applicable to a wide range of design applications and allowing multidisciplinary simultaneous optimization of a design.

The selection and evaluation of appropriate approximation functions to replace the real implicit response functions is an essential step to ensure the optimization procedure is solved efficiently. So-called local, global and mid-range function approximation concepts can be distinguished, depending on the size of the design space in which the approximation is valid. Local function approximations are most commonly applied in structural optimization. They are based upon the function values and sensitivities in a single point of the design space. The approximate objective function and constraints then define an optimization sub-problem. Since local approximations are only valid in a limited area of the design space, a new cycle of approximation and optimization can be started at the optimum of the sub-problem, discarding the results from previous analyses. This procedure is repeated until an acceptable optimum is achieved, resulting in a sequential approximate optimization process. To complement the local methods, only global and mid-range methods are considered for inclusion in the software architecture.

To validate and demonstrate the usefulness of the developed function approximation methods to engineering optimum de-sign, in the second part various optimization problems are solved. This includes a two-bar truss for minimum weight design, an aerofoil for minimum drag design, a plate with a hole for minimum weight design and the minimization of noise radiated from an air inlet of an engine. As a multidisciplinary problem the combined structural and acoustic optimization of bells is considered. For some of the problems an analysis tool was written for calculating response values. In addition, an interface between the analysis codes and approximation and optimization algorithms was made.

From the optimization examples solved it can be concluded that the developed function approximation tools can be applied to optimization problems in many fields. Application of the methods however requires knowledge of the possibilities of the methods. Applied in a correct way, they provide useful tools to the designer to optimize his products in a fast and systematic way.

Stick-Slip Vibrations

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The presence of stick-slip vibrations can be highly detrimental to the performance of mechanical systems. The first step to reduce or avoid these vibrations is to create a representative numerical model that can be used to evaluate all possible phenomena and can be incorporated in a control system. The study of stick-slip vibrations is faced with difficulties, as during the stick-slip motion two different mechanisms take place. The modeling of the static friction mechanism and that of the kinetic friction mechanism yield a set of differential equations with discontinuous right-hand side.

A standard method to solve discontinuous differential equations consists of applying a smoothing method (also called normalization method). The smoothing method replaces the discontinuous system by a smooth adjoint system. The smoothing method yields a system of ordinary but stiff differential equations and consequently leads to large computational times.

The problems of the smoothing method led to the development of models which switch between different sets of equations, the so-called ”alternate friction models” or ”switch models”. The classical approach to integrate the switch model starts from an initial state with a set of differential equations. After each timestep the state vector is inspected on a possible event within this timestep (e.g. slip to stick transition). If an event happened, the integration process is halted and an iteration procedure is started to find the switching point (within a certain range of accuracy). Having thus evaluated the switching point, a new integration process is started with a modified set of differential equations and initial conditions identical to the state at the switching point. The need to halt the integration process, determine the discontinuity with an iteration process and restart the integration again is undesirable from a numerical point of view. Standard integration methods integrate a set of differential equations over a specified time interval. So, if the integration needs to be halted at the discontinuity, standard integration methods cannot be applied.

A simple and efficient switch model is presented to simulate stick-slip vibrations. The specific switch model presented here consists of a set of ordinary non-stiff differential equations. This has the advantage that the system can be integrated with any standard ODE-solver available in mathematical packages (MATLAB,MATHEMATICA, MAPLE) or ODE-solvers of existing software libraries (NAG). The system is thus integrated without the need to halt which minimizes start-up costs.

Shooting methods as periodic solution solvers in combination with switch models have not been addressed in the past. A method to combine shooting with the proposed switch model, without the use of normalization, is presented. The fundamental solution matrices, necessary for the application of the shooting method, are obtained with a sensitivity method where initial disturbances are tracked in orthogonal directions.

A single-degree-of-freedom model is used to introduce and evaluate the numerical methods. An important ad-vantage of the switch model is the possibility of incorporating tribological enhancements of the classical friction model. It is shown how time-dependent static friction can be incorporated in the switch model.

The switch model can also be used for systems with greater complexities. A single violin string with a bow that is moving at a constant velocity over the string is considered. The friction force between bow and string induces lateral displacement and rotation of the string (2–DOF system). This two-degree-of-freedom system can efficiently be modeled with the switch model.

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Numerical Modeling of Aluminium Extrusion

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Insight in the aluminium extrusion process can be gained with numerical simulations. This paper gives an overview of the research done to model aluminium extrusion with the Arbitrary Lagrangian Eulerian (ALE) FEM code DiekA. The ALE formulation is used to avoid mesh distortion, which is a major problem in the simulation of extrusion. The goal of this research is to increase the lifetime of extrusion dies and to decrease the number of corrections necessary to these dies.

To model the rate-dependent behaviour of hot aluminium, normally a viscoplastic material model is used. However in the bearing the material behaviour is mainly elastic. The pressure and friction in the bearing are dominant factors in the extrusion process and an accurate modelling of this area is crucial for the final results. In this paper an elasto-viscoplastic material model is derived. This models can be simplified to a very efficient model that is elasto-viscoplastic for small deformation increments and viscoplastic for large increments. With this model it is possible to model the extrusion process including the elastic behaviour in the bearing without sacrifising efficiency.

As an example the extrusion of a tube is treated. To avoid unacceptable calculation times, the simulation is split into three parts. First a detailed 2D simulation of the bearing area is made. The results of this simulation are used in a complex 3D simulation of the aluminium flow true the die. From this simulation, the loads on the die are determined. These loads are used in a stress analysis of the die. The results of these simulations give insight in the processes that occur in the aluminium and in the die.

Finite Elements for Better Understanding of Compression Tests

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Compression tests are commonly used experimental devices to obtain the mechanical behavior of a whole series of materials. The response to a prescribed deformation is measured and fitted with a material model. This is a straight forward calculation in case of a uniaxial state of compression. Usually a homogeneous deformation cannot be maintained during deformation. Finite element calculations can lead to a better understanding and possibly a higher accuracy of the obtained mechanical behavior.

Calculations show that corrections for inhomogeneity basically can lead to correct material behavior. Main problem however remains the fact that friction conditions in practice are not exactly known and may even vary during testing. It is shown that several constraints can be made to the tool and workpiece geometry.

Dynamics of Flexible Multibody Systems with Joint Clearance

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The dynamic response of multibody systems can significantly be affected by joint clearances. This can be observed by force peaks and energy dissipation. Critical in the precise prediction of the peak forces is the contact model being used. Joint clearance can be modelled as a continuous or as a discontinuous contact phenomenon. In the discontinuous case one does not predict the peak forces since the impulse or momentum change is the basis of the calculation. Usually energy dissipation is modelled by a coefficient of restitution and friction with stick-slip characteristics is included.

In this presentation a comparison is made between the continuous and the discontinuous contact model. The multibody system is modelled with rigid or flexible bodies. For the discontinuous contact model a method is presented to predict the maximum impact force given the elastic joint material properties. It will be shown that the flexibility of the system has a smoothing effect upon the impact forces. Since most of the joint clearances in mechanical engineering designs are in lubricated bearings a comparison is made between a slider crank mechanism having an unlubricated or a hydrodynamic oil film cylindrical bearing.

Reliability of buckling sensitive structures

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Failure of thin-walled structures loaded in compression does not necessarily occur at the coincidence of yielding and buckling. In general instability of structures is due to diminishing geometric stiffness. This geometric stiffness is sensitive to some key design parameters. In particular initial geometric shape imperfections could be quite influential on the global behavior of the structure.

The example problems of cylindrical shells show a quite dramatic diminishing load carrying capacity with respect to the axial loading. It is this excessive diminishing load carrying capacity that allows the exploration of the design parameter space fully with clearly distinguishable behavior.

From empirical results this behavior can be deduced from the existence of a so-called knockdown factor for design purposes. This highly conservative multiplicative factor discards any effort spent on the quality of the shell. With a probabilistic approach shell quality information will be included into the design, and eventually a higher level of efficiency of the shell can be gained.

By definition one needs a safety model for the evaluation of a probability of failure. This safety model is represented by a so-called safety function. In the context of a probabilistic analysis the safety function is built up of several failure functions. Failure for the cylindrical shell is defined as the exceedence of the limit or bifurcation point with respect to the axial loading. In case the yield stress is exceeded the accompanying load is a failure load. In order to create a safety function both criteria and additionally a loading function could be combined. This function, the limit-state function, contains the random design variables in the analysis.

It is clear that the ‘response’ needed for a probabilistic analysis is slightly different from a regular displacement response analysis. With respect to the mechanical model the ‘response’ in a probabilistic context is the value of the ‘response’ function in the limit-state with respect to the random design variables. This feature requires a more extended set of equations for the mechanical problem.

Contrary to the deterministic analysis, in a probabilistic analysis one does not use fixed values for the design parameters. The design parameters are represented by some random variable with particular statistical properties. In practice one is generally not able to generate a suitable set of samples for the input random design variables for more than one reason. Therefore, regularly one uses a type of distribution which generates for the current problem conservative solutions. The consequence of the scarcity of data will lead to prediction errors in the distribution parameters and the type of distribution to be used.

With sufficient experimental data the design procedure could be calibrated and the ‘improved’ knockdown factor would give less conservative and more realistic estimates of the conventional allowable design loads.

Derivation of a Second-Gradient Micro-Polar Constitutive Theory Using a Micro-Structural Approach

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In general, heterogeneous material behaviour occurs either via strong *time variations* in the macroscopic displacement (rotation) field, during which the generated wave lengths become of the same order of magnitude as the intrinsic material structure, or via strong *spatial variations* in the displacement (rotation) field, which appear when relatively narrow failure zones are manifested (shear bands, cracks). For granular materials, the intensity of these heterogeneities strongly depends on the material properties at the micro-scale, as governed by particle displacements and/or particle rotations. When extending the classic continuum formulation in order to incorporate the heterogeneous effects by particle displacements, one obtains a so-called high-gradient continuum, in which displacement gradients higher than the first order are considered. In this class of formulations, the second-gradient formulation has been widely used for studying localised failure behaviour. Also, for analysing elastic wave propagation this model has been utilised. On the contrary, when incorporating the effect of particle rotation, the classic continuum formulation is extended with gradients of rotation. In this class of formulations, the Cosserat continuum (or micro-polar continuum), which takes into account the first gradient of rotation, has shown a large popularity in both analysing localised failure and wave-propagation phenomena.

Most enhanced continuum formulations have been developed from phenomenological considerations at the macro-level, rather than from transforming the physical microscopic material properties to a macroscopic material model. For elastic-plastic material formulations this is inherently caused by the increased mathematical complexities that appear when capturing the microstructure within a continuum failure mechanics framework. Up to now, a small number of researchers have tried to develop continuum variables via the analysis of the elastic behaviour of the microstructure (=micro-structural approach). Along this line, by taking the effect of both particle displacement and particle rotation into account, a so-called *second-gradient micro-polar model* has been derived (1,2). The derivation procedure as well as the result will be discussed in the current presentation. Also, it will be demonstrated that this model captures more simple models as a special case, such as the linear elastic model, the second-gradient model and the Cosserat model.

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On the Numerical Simulation of Crazing in Polymers Using a Cohesive Surface Methodology

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The increasing use of polymer materials for structural applications necessitates a thorough understanding of their failure characteristics. Polymers generally fail by a combination of shear yielding and crazing. A craze is a crack-like defect in which the bulk interfaces are bridged by a network of polymer fibrils of low volume fraction. In contrast to the process of shear yielding, in which propagating shear bands result in a large energy dissipation, the crazing phenomenon is a very localized deformation mode and often the precursor to brittle fracture. Understanding the failure process involving crazing is therefore useful in either suppressing crazing or promoting massive crazing in order to produce a more ductile fracture behaviour.

To explore the initiation, growth and breakdown of crazes in polymer based composites, a micromechanically based cohesive surface model is developed in which the initiation, widening and failure of crazes is accounted for. Based on the work of Sternstein et al. [1] a criterion is used for the initiation of crazes in which the normal traction on the cohesive surface and the first stress invariant are combined. The widening of the craze material is now thought to be the result of pulling out new polymer material from the bulk-craze interface, a process that is referred to as surface drawing. Zooming in to the craze-bulk interface reveals that originally amorphous polymer material is transformed into the highly stretched and oriented fibril material. This process is governed by substantial plastic deformation of the polymer material and as such must be strongly rate dependent. Following the continuum description of rate dependent deformation of glassy polymers, a widening law is proposed similar to the plastic shear flow law that was first proposed by Argon [2]. Kramer [3] shows that breakdown of craze material is related to the presence of dust inclusions and has been found to follow a Weibull distribution with respect to the plastic strain of the craze material. Breakdown of crazes in the cohesive surface description is therefore taken according to a criterion in which the viscoplastic widening of the craze material is bounded.

The initiation of crazes around a circular hole under plane stress conditions is studied as an example to illustrate the capabilities of the cohesive surface model. Since longitudinal extension of the craze is an outcome of the analysis, the craze zone development can be studied as a function of loading rate and model parameters. Varying the model parameters with respect to initiation and widening characteristics shows that the model is able to pick up the initial elastic prediction of the craze zone. Furthermore, it is shown that the subsequent redistribution of stresses due to the crazing influences the shape of the craze zone considerably.

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The Dynamic Behaviour of Ball Bearings

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In cooperation with SKF, a research project was started on the dynamics of ball bearings. The research is motivated by the demand for silent bearings in noise sensitive applications, especially in the household appliance and automotive industry. The investigations should bring a clear understanding about the role of the bearing in the application with respect to the design, the quality and the way it is mounted.

The dynamic behaviour of a ball bearing application is studied by means of predictive modelling. The application consists of a flexible shaft supported by two deep groove ball bearings mounted in flexible housings. The housings, the shaft and the bearing outer rings are modelled with the finite element method. To solve the equations of motion by means of time integration, the large finite element models are reduced with component mode synthesis (CMS). To account for the flexibility of the bearing outer ring a new CMS method has been developed (reference [1.]). The stiffness and damping of the elastohydro-dynamically lubricated contacts between the balls and the guiding rings are modelled with spring-damper models. Their constitutive behaviour has been predicted with the help of transient contact calculations (reference [2.]).

The present work focuses on two sources of vibration. Due to the rotation of the lubricated contacts, the stiffness and damping in the bearing become time dependent, hereby generating parametric excitations. Furthermore, vibrations are generated due to form deviations of the individual bearing components. The form deviations, which are on nanometer scale, are caused by irregularities during the grinding and honing process.

The developed 3D ball bearing model has been successfully validated with measurements on a vibration test spindle. The predicted resonances and the vibrations generated by parametric excitations and form deviations of the rings and the balls agree well with the measured ones. It was found that in the audible range, most of the vibrations generated by the bearing can be related back to form deviations of the balls. It is concluded that the presented 3D model enables a fast and accurate evaluation of the influence of ball bearings on the dynamical behaviour of applications.

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Wave Effects in One-Dimensional Elastic Systems Interacting with Moving Objects

Theory and applications for high speed trains

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With the development of high speed trains it is necessary to take into account the wave processes in the track excited by the train wheels. If the velocity of the train is comparable with the velocity of surface waves in the supporting subsoil the radiation of elastic waves can consume a substantial percentage of the train engine energy. In Dutch circumstances this surface wave velocity can be in the order of 175 km/h. High speed trains have to pass this critical wave velocity or large investments have to made to improve the track subsoil so as to enlarge the critical velocity along the entire track. It may be clear that such a wave effects have also a considerable influence on the train vibrations.

In this presentation three main types of wave radiation: i.e., Vavilov-Cherenkov radiation, transition radiation [1] and radiation in non-uniform motion [2] are shortly discussed on the example of a constant load motion along a one-dimensional elastic system. With the help of the spectra of radiated energy some qualitative conclusions are drawn. Then attention is paid to resonance velocities for the uniform motion of a harmonicallly varying load. The geometrical analysis of frequencies and wavenumbers of radiated waves is presented. A new way of passing through the elastic wave barrier is considered [3,4]. The last part of this presentation is dealing with the radiation reaction on the moving object. It is shown that due to the interaction of the radiation field and the moving object the vibrations can become unstable even for a damped supporting system [5].

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Steady State Behaviour of Stochastically Excited Nonlinear Dynamic Systems

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Nonlinear systems subject to random excitations are frequently met in practice. The source of randomness can vary from surface randomness in vehicle motion, and environmental changes, such as earthquakes or wind exciting high rise buildings or wave motions at sea exciting offshore structures or ships, to electric or acoustic noise exciting mechanical structures. The research goals are, firstly, the computation (with accuracy and efficiency as important criteria) and, secondly, the investigation and thorough understanding of stochastic, nonlinear response characteristics.

The desire to compute response characteristics, like the statistical moments and the power spectral density of the response, leads to the development of methods that can be used to approximate the response. The necessity of approximation is caused by the absence of analytical solutions for general, nonlinear systems. One could classify the approximation methods as follows: numerical integration methods; linear approximation methods; and nonlinear approximation methods. When the excitation is a (Gaussian) white noise process, suitable integration schemes are based on Itô-calculus [1]. These schemes can be used to compute the response very accurately. Especially, the information in the frequency domain is essential for a thorough understanding of the system behaviour. Specifically non-linear response phenomena are non-Gaussian response, multiple resonance frequencies and, for asymmetric non-linearities, high energy content for low frequencies (outside a resonance range). However, when using numerical integration, extensive CPU-time is needed to reduce statistical errors on the estimated response characteristics.

Therefore, the development of more efficient approximation methods is desirable. The first class of approximation models, that will be discussed, are linear models. A well-known and widely used method is statistical linearization. However, a serious drawback of the method is the fact that, for strongly nonlinear systems, this method fails to predict the specifically nonlinear, frequency domain characteristics properly. Consequently, energy estimates produced by this method appear to be structurally too low. Therefore, an approximation method is developed that builds a higher order, linear model with exactly the same output power spectral density (for white noise excitation) as the original nonlinear system. The method makes use of a limited set of simulated data on the power spectral density of the response of the nonlinear system. Using the method of spectral factorization [2], a higher order, linear, stable, causal model can be constructed, which exhibits that same spectral output to white noise excitations. Such a model can then be used to estimate response characteristics of the original, nonlinear system very efficiently in case of non-white excitations. Unfortunately, due to the linearity of the model, it is only valid (for general nonlinear systems) for excitations, which have energy-levels comparable to that of the white noise process, which was used to design the model.

Therefore, one could consider accepting one extra level of modeling complexity: nonlinear models. The models that are used are Volterra systems [3]. The response characteristics for such systems can be evaluated rather efficiently compared to numerical integration. Of course, both the effort needed to construct such a model and the effort needed to compute the response characteristics increase with respect to the effort needed to construct linear models. However, the nonlinear response characteristics can be predicted more accurately. Furthermore, the systematic reduction of the original, nonlinear system to linear models or (nonlinear) Volterra systems sheds light on the root of the nonlinear, stochastic response phenomena of the original system and thus enlarges the fundamental understanding of stochastic, nonlinear, dynamic system behaviour.

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4

SURVEY of POSTER PRESENTATIONS

This section contains a survey of poster presentations of actual PhD- and Twaio-projects within the Graduate School Engineering Mechanics. Individual poster presentations are collected in a separate report which will be supplied at the start of the symposium and can be obtained from the Secretariat of the Graduate School. Furthermore, poster presentations are available through:

http://www.em.tue.nl

Survey of Poster Presentations:

Name	Univ.	Title
H. Askens	T.U.D.	Mesh Adaptivity Techniques for Strain Localization
T.G.H. Basten	U.T.	Low Frequent Sound Reduction by Thin Air Layers
H. de Boer	T.U.D.	Draping Simulation using Optimization Techniques
E.M.H. Bosboom	T.U.E.	The Aetiology of Pressure Sores
H.L.A. van den Bosch	T.U.E.	Modelling and Specifications for an Improved Helmet Design
D.W.A. Brands	T.U.E.	Modelling Brain Tissue under Impact Loading
D. Brokken	T.U.E.	Numerical Modelling of the Blanking Process
H. Brouwers	T.U.E.	Characterization of Swelling Materials
J.J.G. Buschgens	T.U.E.	Moisture Transport in Brick Walls
R. van Dijk	T.U.D.	Solubility and Pressure Effects for Closed Thin Walled Structures
C.F.J. den Doelder	T.U.E.	Modelling Melt Fracture
M. Donners	T.U.E.	Chemo-Mechanical Failure of MnZn Ferrite
W.D. Drenth	T.U.E.	Interactive Platform for Numerical Algorithms in Large Scale Scientific Computing
A.J. van Eekelen	T.U.D.	Optimization of Structures with Reliability Constraints
F.J.M. van der Eerden	U.T.	Acoustics of a Sound Absorbing Wall
A.J.H. Frijns	T.U.E.	Swelling and Shrinking of Biological Tissues
A.M. Goijaerts	T.U.E.	The Prediction of Ductile Fracture in the Metal Blanking Process
M.A. Gutiérrez	T.U.D.	Stochastic Finite Element Analysis of Localisation Phenomena
J. de Hart	T.U.E.	Fluid-Structure Interaction in Heart Valves
O.M. Heeres	T.U.D.	Finite Element Analysis of Soils
M.F. Heertjes	T.U.E.	Control Applied on a Harmonically Excited Beam with One-Sided Spring
M.J. van der Horst	T.U.E.	Head-Neck Response during Acceleration Impacts: Phase1
E. Jiménez Piqué	T.U.E.	Process Zone ThermoMechanics and Fracture
R. Kerckhoffs	T.U.E.	Dynamic Shape Changes of the Heart
P.H.L. Kessels	T.U.E.	Acoustic Noise Reduction of MRI-Scanners
M.S. Kiasat	T.U.D.	Shrinkage and Stress Build-up in a Termoset Resin during Curing
P.G.M. Kruijt	T.U.E.	Mixing Flow in a Multiflux Static Mixer
A.H.W.M. Kuijpers	T.U.E.	Making an MRI-Scanner Quiet (well almost)
K. Laevsky	T.U.E.	Modelling and Simulation of Glass Manufacturing Processes
R.I. Leine	T.U.E.	Stick-slip Vibrations in Drillstrings
B.J. van der Linden	T.U.E.	Radiative Heat Transfer in Hot Glass Melts
F.J. Lingen	T.U.D.	ScaFiEP: *the* Scalable Finite Element Package
J. Lof	U.T.	Numerical Modeling of Aluminium Extrusion
M. Maenhout	T.U.E.	Validation of a 3-D Continuum Model for Muscle Contraction
M. Mahardika	T.U.D.	On the Analysis of a Riveted Repair Patch
H.S.C. Metselaar	U.T.	Thermally Induced Wear of Ceramics
R.D. van de Moesdijk	U.T.	Predicting the Shape after Blanking
V. Nefedov	T.U.E.	Local Defect Correction for Glass Tank Model
D.E.A. van Odijck	U.T.	Lubrication: Stokes vs Reynolds
L. Ossevoort	T.U.E.	Adaptive Processes of the Heart
R.H.J. Peerlings	T.U.E.	Continuum Damage Approach to Fatigue
K. Pijnenburg	T.U.D.	On Deformation of Particles in Polymer-Rubber Blends
S. Postma	U.T.	Transient Nonlinear Finite Element Analysis of the Stall Force of a Tubular Linear Induction Motor
B.B. Prananta	T.U.D.	Physical and Numerical Aspects of Aeroelastic Simulation
L.V. Raulea	T.U.E.	Size Effects in Processing of Thin Metal Sheets
A.D. Rietman	U.T.	Compression Experiments for Parameter Identification Reviewed
J.H.A. Schipperen	T.U.D.	Failure Analysis of Laminated Fibre Reinforced Plastic Composites
E.G. Septanika	T.U.D.	Hysteresis and Time-dependent Constitutive Modeling of Filled Vulcanized Rubbers
A.F.A. Serrarens	T.U.E.	Driveline Management for CVT-based Passenger Cars
A.R. Stam	T.U.D.	Reliability of Thin-Walled Buckling Critical Structures
H.C. Stoker	U.T.	Numerical Simulation of Forming Processes with the ALE-Formulation

A. Telea	T.U.E.	A Scientific Visualization and Computational Steering System
M. Tijssens	T.U.D.	Micromechanically Motivated Cohesive Surface Modelling of Crazing in Brittle Polymers
R.S.J.M. Verhoeve	T.U.E.	Evaluation of Head Injury Criteria
J.A.P. de Visser	T.U.D.	Optimization of Composite Wing Structures under Dynamic Loads
B.L. van de Vrande	T.U.E.	Compliant Journal Bearings
B.G. Vroemen	T.U.E.	Local Controllers for Automotive Driveline Components
K. Wang	T.U.E.	BEM Simulation for the Pressing Phase in Glass-Manufacturing
G. Wells	T.U.D.	Enhanced Element Techniques for Fracture of Quasi-Brittle Materials
J.A. Wensing	U.T.	The Dynamic Behaviour of Ball Bearings
H.H. Wisselink	U.T.	FE Analysis of Sheet Metal Cutting
N. van de Wouw	T.U.E.	Steady State Behaviour of Stochastically Excited Nonlinear Dynamic Systems

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