Engineering Mechanics
Annual Report 2004
Colophon:

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   2.1

3. Materials Technology
   3.1

4. Analysis Scientific Computing and Applications (CASA)
   4.1

5. Engineering Mechanics (1)
   5.1

6. Aerospace Structures
   6.1

7. Structural Optimization and Computational Mechanics
   7.1

8. Engineering Mechanics (2)
   8.1

9. Computational Mechanics, Structural Mechanics and Dynamics
   9.1

10. Applied Mechanics
    10.1

11. Surface Technology and Tribology
    11.1

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    12.1

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    13.1
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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, herewith presents its Annual Report 2004. It covers 2004, the third year of the second period of operation, 2002-2007. There was a continuation of ongoing research in the field of Engineering Mechanics and of the structural activities of the Research School, such as the programme of EM-graduate courses and the yearly Engineering Mechanics Symposium. Details on these activities are described and documented in this Annual Report 2004.

The first chapter contains general and aggregated information on the Graduate School Engineering Mechanics. Outlined are the Engineering Mechanics' field of research as well as the organizational structure and the participating groups in the Research School. Furthermore, the selected research themes and the educational programme are presented. Finally, there is a description of developments in 2004, a survey of the aggregated input and output for 2004 and an overview of the input and output per participating group for 2004.

In the subsequent chapters, the research documentation for 2004 is given in more detail per group, participating in the Research School. More specifically there is information on research programmes related to the Research School Engineering Mechanics and on group members involved. Furthermore, there is a survey of refereed scientific papers, dissertations completed, memberships of both editorial boards and international scientific committees, keynote lectures, awards and patents. Each chapter concludes with an overview of research input and output for 2004 and with a summary of projects that take place in co-operation with other EM-groups.

Finally, the appendices contain additional information on ongoing research and addresses of the research groups involved. Appendix A contains the summaries of the dissertations that were completed in 2004 within the context of the Research School Engineering Mechanics, whereas Appendix B summarizes information per research theme. Appendix C gives an overview of actual addresses of participating research groups and their staff.
1. GENERAL INFORMATION

1.1 Introduction

In the Netherlands, graduate schools have been founded for a variety of scientific disciplines. Normally, several Dutch universities participate in such a graduate school, which is laid down in a formal agreement between the Executive Boards of the participating universities. One of the universities is responsible for the administration of the graduate school, e.g., the organization of various scientific activities and the preparation of an annual report. These activities are conducted under the responsibility of a scientific director, often, but not necessarily, one of the professors of the university that is in charge of the administration.

The primary aims of graduate schools are to provide additional education and training for PhD students of the participating institutions and to foster scientific contacts and collaboration. For the graduate school Engineering Mechanics the aims have been particularized in the Mission Statement, presented in section 1.2.

Graduate schools can be accredited by the Royal Netherlands Academy of Arts and Sciences (KNAW), which gives a sign of quality. The accreditation is given on the basis of a proposal in which a coherent educational programme for PhD students is described as well as coherence in terms of research between the participating teams. Accreditation is given for five-year periods. After such a period an application for renewal of the accreditation can be filed at the KNAW, which consists of a self-assessment over the past period together with a peer review based on this self-assessment.

The graduate school Engineering Mechanics was founded in 1996 and received a five-year accreditation of the KNAW directly at the first application in 1997. It embraces all research groups that are active in the field at the Eindhoven University of Technology, the Delft University of Technology and the University of Twente, with the Eindhoven University of Technology acting as the commissioner, locating the secretariat. In 2001 a peer review of the activities of the Graduate School over this first period of operation by an international review panel took place and in 2002 the ECOS/KNAW-accreditation of the Graduate School Engineering Mechanics was renewed.

The graduate school Engineering Mechanics represents the internationally important groups of the Dutch universities in the area of engineering mechanics. Because the EM-school also co-ordinates and tunes the research activities in the participating groups, whereas it has developed a series of high-quality graduate courses, it can be considered to be the representative scientific platform in the Netherlands in the engineering mechanics field. This platform sets the major directions of future research in the Netherlands in the engineering mechanics field, whereas it is responsible for the quality of future generations of PhD’s, who are the primary determinants of the quality of future activities in this area in the Dutch industries and universities.

In the graduate school Engineering Mechanics the individual research groups remain responsible for their research programmes. However, on basis of consensus the graduate school stimulates certain focal areas of research. More importantly, it exercises a quality control on the level of research, since it has adopted a lower bound for the quality of the participating groups, which derives from the research assessments that are commissioned by the Netherlands Society of Universities (VSNU).
1.2 Mission statement

The Netherlands Graduate School on Engineering Mechanics has been established with the aim to strengthen research and education in the field of engineering mechanics in The Netherlands. The Graduate School EM intends to be a platform that, on the basis of a number of selected research themes, fosters long-term knowledge and skills in the engineering mechanics field. Although operating primarily at a national level, it intends to stimulate international collaborative research projects within the research themes.

Within the foregoing global objectives the following more specific objectives can be formulated:

• Training of PhD-students to become qualified independent researchers in the field of engineering mechanics according to international standards. To this end, a series of high-quality graduate courses is developed on specific subjects.
• Co-ordination and tuning of the engineering mechanics research activities in the participating groups. Furthermore, the Graduate School aims at strengthening the available infrastructure for research in engineering mechanics. It can be stated that the present infrastructure meets high international standards.
• Selection of the main research themes in engineering mechanics carried out within the Graduate School EM. These research themes are being characterized by a strong international position of the research in the Netherlands, while at the same time they are of importance for Dutch industry and society.
• Strengthening of the international scientific position and the international visibility of The Netherlands in the engineering mechanics field.
• Guarding the standards of undergraduate education in the engineering mechanics area at the Dutch universities. This is done in particular by influencing policies with respect to the appointment of professors and other senior staff in this area.

1.3 Outline of the field of Engineering Mechanics

Engineering mechanics is concerned with the description, analysis and optimization of the static and dynamic behavior of materials, products and processes. Solid mechanics is at the heart of engineering mechanics, but is not necessarily identical with it. Traditionally, engineering mechanics is one of the fundamental cores of engineering sciences such as Civil Engineering, Aerospace Engineering, Mechanical Engineering and Marine Technology.

The advent of modern computers provided completely new challenges and perspectives for the engineering mechanics field. Contemporary developments of engineering mechanics include the following major directions:

• Prediction of structural mechanical behaviour from material mechanics and establishment of structure-property relations for engineering materials, including the ultimate failure of the material. The ultimate aim is to bridge the gap between science and technology in the area of materials processing and design, via computational modeling and experimental analysis of the full thermo-mechanical history of material (elements) during their formation, processing and final design, in order to be able to quantitatively predict product properties.
• Prediction of the dynamic behavior of engineering systems with full account of nonlinearities. This area is of crucial importance in many practical dynamical systems where friction, contact and other nonlinearities have a substantial effect on the dynamic behavior.
• Optimization of products, processes and systems by means of computer simulations to tailor their mechanical behavior for the particular application. Here, it is assumed
that the simulation of the mechanical behavior can be carried out in a sufficiently accurate way, while the optimal design is traced numerically.

As a consequence of the above developments the traditional boundaries between solid and fluid mechanics are sometimes fading. This happens, for example, in the field of mechanics of materials and in the area of acoustic radiation of structures. In addition, the interactions with other areas of engineering sciences, such as materials technology, thermodynamics and systems and control, become of increasing importance. Finally, it is noted that the successful implementation of the above-mentioned developments in practical applications relies on prior experimental validation of the developed simulation tools and physical models. This requires an increasing interaction between computational modeling and experimental analysis.

1.4 Organization

The organizational structure of the Graduate School Engineering Mechanics is summarized in the following organization chart:

The Scientific Director is in charge of the day-to-day management of the Graduate School. Local Directors from the participating Universities assist him in this. Eindhoven as commissioner supplies extra support for general management and secretariat. Altogether they form the Management Team.

The Governing Board establishes the annual plans on research, education and finances of the Graduate School. They are advised on this by the Advisory Board, which consists of representatives from industry and applied research institutes.
The composition of the Governing Board and the Advisory Board is as follows:

<table>
<thead>
<tr>
<th>Governing Board</th>
<th>Advisory Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Dr. Ir. D.H. van Campen (chairman)</td>
<td>Dr. Ir. P. van den Berg</td>
</tr>
<tr>
<td>TU Eindhoven</td>
<td>Delft Geotechnics</td>
</tr>
<tr>
<td>Prof. Dr. J. Arbocz</td>
<td>Ir. G. Callis</td>
</tr>
<tr>
<td>TU Delft</td>
<td>Stork N.V., Naarden</td>
</tr>
<tr>
<td>Prof. Dr. Ir. M.G.D. Geers</td>
<td>Dr. Ir. S. Hoekstra</td>
</tr>
<tr>
<td>TU Eindhoven</td>
<td>NIMR</td>
</tr>
<tr>
<td>Prof. Dr. Ir. J. Huëtink</td>
<td>Ir. F. Holwerda</td>
</tr>
<tr>
<td>UT Twente</td>
<td>NLR, Amsterdam</td>
</tr>
<tr>
<td>Ir. Drs. P.D. van der Koogh</td>
<td>Dr. Ir. F.J. Klever</td>
</tr>
<tr>
<td>TNO Automotive, Delft</td>
<td>Shell Int. Exploration and Production B.V., Rijswijk</td>
</tr>
<tr>
<td>Prof. Dr. Ir. D.J. Rixen</td>
<td>Ir. D.Ph. Schmidt</td>
</tr>
<tr>
<td>TU Delft</td>
<td>TNO-TPD, Delft</td>
</tr>
</tbody>
</table>

The Board of AIOs represents the PhD-students within the Graduate School towards the Management Team. They are involved in the evaluation and organization of the EM-symposium and initiate activities for fellow PhD-students. Members are:

<table>
<thead>
<tr>
<th>Board of AIOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ir. R. Loendersloot</td>
</tr>
<tr>
<td>UT Twente, Department of Mechanical Engineering.</td>
</tr>
<tr>
<td>Ir. J.J.C. Remmers</td>
</tr>
<tr>
<td>TU Delft, Department of Aerospace Engineering.</td>
</tr>
<tr>
<td>Ir. M.J. v.d. Bosch</td>
</tr>
<tr>
<td>TU Eindhoven, Department of Mechanical Engineering.</td>
</tr>
</tbody>
</table>

1.5 Participants

The Graduate School ‘Engineering Mechanics’ was founded as an interuniversitary Graduate School by the Eindhoven and Delft Universities of Technology and the University of Twente. The Eindhoven University of Technology acts as the commissioner, locating the secretariat. Co-operation takes place through three local institutes:

- The Stevin Centre for Computational and Experimental Engineering Science at the Eindhoven University of Technology (TU/e),
- The Koiter Institute Delft at the Delft University of Technology (TUD),
- The Twente Institute of Mechanics at the University of Twente (UT).
Each of them invokes the contributions of specific research groups, twelve altogether:

<table>
<thead>
<tr>
<th>University</th>
<th>Department</th>
<th>Group, Groupdirector(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TU(e)</td>
<td>Mechanical Engineering</td>
<td>Systems, Dynamics and Control&lt;br&gt;Prof.Dr. H. Nijmeijer, Prof.Dr.Ir. J.E.Rooda, Prof.Dr.Ir. M. Steinbuch&lt;br&gt;Materials Technology, Prof.Dr.Ir. F.P.T. Baaijens, Prof.Dr.Ir. M.G.D. Geers</td>
</tr>
<tr>
<td></td>
<td>Mathematics and Computing Science</td>
<td>Analysis Scientific Computing and Applications (CASA)&lt;br&gt;Prof.Dr.Ir. J. de Graaf, Prof.Dr. R.M.M. Mattheij</td>
</tr>
<tr>
<td>TUD</td>
<td>Aerospace Engineering</td>
<td>Engineering Mechanics (1)&lt;br&gt;Prof.Dr.Ir. R. de Borst&lt;br&gt;Aerospace Structures&lt;br&gt;Prof.Dr. Z. Güdäl</td>
</tr>
<tr>
<td></td>
<td>Design, Engineering and Production</td>
<td>Structural Optimization and Computational Mechanics&lt;br&gt;Prof.Dr.Ir. F. van Keulen&lt;br&gt;Engineering Mechanics (2)&lt;br&gt;Prof.Dr.Ir. L. J. Ernst</td>
</tr>
<tr>
<td></td>
<td>Civil Engineering</td>
<td>Computational Mechanics, Structural Mechanics and Dynamics&lt;br&gt;Dr.Ir. L.J. Sluys</td>
</tr>
<tr>
<td>UT</td>
<td>Mechanical Engineering</td>
<td>Applied Mechanics&lt;br&gt;Prof.Dr.Ir. A. de Boer, Prof.Dr.Ir. J. Huêltink, Prof.Dr.Ir. H. Tijdeman&lt;br&gt;Surface Technology and Tribology&lt;br&gt;Prof.Dr.Ir. D.J. Schipper&lt;br&gt;Mechanical Automation&lt;br&gt;Prof.Dr.Ir. J.B. Jonker&lt;br&gt;Production Technology&lt;br&gt;Prof.Dr.Ir. R. Akkerman</td>
</tr>
</tbody>
</table>

On an annual basis contributions from Eindhoven (TU(e)), Delft (TUD) and Twente (UT) amount to:

<table>
<thead>
<tr>
<th></th>
<th>TU(e) (fte)</th>
<th>TUD (fte)</th>
<th>UT (fte)</th>
<th>Total (fte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior academic staff</td>
<td>8.6</td>
<td>10.0</td>
<td>4.2</td>
<td>22.8</td>
</tr>
<tr>
<td>PhD*</td>
<td>36.8</td>
<td>35.2</td>
<td>29.6</td>
<td>101.6</td>
</tr>
<tr>
<td>Postdocs</td>
<td>5.0</td>
<td>3.2</td>
<td>4.1</td>
<td>12.3</td>
</tr>
<tr>
<td>Total</td>
<td>50.4</td>
<td>48.4</td>
<td>37.9</td>
<td>136.7</td>
</tr>
</tbody>
</table>

* Research input per PhD per year: 0.8 fte

More detailed information on the participating groups can be found in subsequent chapters of this Annual Report 2004.

1.6 Research themes

An important goal of the Graduate School Engineering Mechanics is the co-ordination and combination of research activities of participating groups. In accordance to this it was decided to group the research activities into four research themes:

1. **Computational Mechanics**
   This research theme is related to the potential of modern computing hardware for solving problems in mechanics. Much attention is paid to optimal numerical procedures and to large-scale computing. Important applications are in the field of crash simulation of vehicle systems, simulation of production processes, in particular forming processes, as well as complex structures in civil engineering and aerospace engineering.
2. **Mechanics of Materials**
   This research theme is related to the prediction of the material behaviour in engineering structures from the internal structure of the material. This includes the prediction of collapse. The interchange between numerical and experimental techniques is of major importance. Important applications are in the field of biomedical technology, concrete structures, ceramic materials and polymer technology.

3. **Structural Dynamics and Control**
   This research theme is related to the dynamic behaviour of engineering structures. Particular attention is paid to nonlinear dynamics and fluid-structure-interaction. Also of importance is the interaction with control. Important applications are in the field of rotating machinery, noise reduction and drive systems.

4. **Structural Mechanics**
   This research theme is related to the development of design procedures based on reliability, as well as to structural optimization with respect to mechanical behaviour. Important applications are in the fields of biomedical technology (e.g. heart valves) and in the field of thin-walled structures.

These research themes fit well with the major directions in contemporary engineering mechanics as described in Section 1.3. Furthermore, they are characterized by a strong international position of the research in the Netherlands, while at the same time they are of importance for Dutch industry and society.

Point of departure in all research themes is the development of models based upon the principles of engineering mechanics. These models necessitate and motivate the development of contemporary numerical and experimental tools for solving engineering mechanics problems. The application of these tools in computer-aided design and production processes results in a decrease in the development time of advanced products, for instance due to a reduction in the required amount of prototypes. Also, an increase in product quality and a reduction in costs are worth mentioning. The optimal use of the possibilities of computers for complex numerical simulations as well as the incorporation of nonlinear phenomena in the modeling are common to all four themes.

Research groups participate, depending upon their expertise and affinity, in several themes:

<table>
<thead>
<tr>
<th>Group</th>
<th>Computational Mechanics</th>
<th>Mechanics of Materials</th>
<th>Structural Dynamics and Control</th>
<th>Structural Mechanics</th>
</tr>
</thead>
<tbody>
<tr>
<td>TU/e</td>
<td>Systems, Dynamics and Control</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Materials Technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analysis Scientific Computing and Applications (CASA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TUD</td>
<td>Engineering Mechanics (1)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Aerospace Structures</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Structural Optimization and Computational Mechanics</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Engineering Mechanics (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computational Mechanics, Structural Mechanics and Dynamics</td>
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<tr>
<td>UT</td>
<td>Applied Mechanics</td>
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<td></td>
<td>Surface Technology and Tribology</td>
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<tr>
<td></td>
<td>Mechanical Automation</td>
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<td></td>
<td>Production Technology</td>
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</table>

1.7 Education

The most important goal of the Graduate School Engineering Mechanics is the formation and education of graduate students to become independent researchers in the field of Engineering Mechanics. In accordance with this, the Graduate School offers a national four years training programme for PhD-students in the field of Engineering Mechanics. It consists of a programmatic part and a PhD-research project, accompanied by a personal plan of education and supervision per PhD-student.

The programmatic part of the training programme covers about 20% of the four years training’s programme. The heart of it is formed by a joint series of EM-graduate courses, in close connection with the selected research themes. PhD-students are required to take part in at least 50% of the courses, providing the opportunity to keep track with developments in the field of engineering mechanics outside their own focus of research.

EM-graduate courses all follow a general framework, which consists of two three-day clusters of lecturing, alternated with (computer) exercises to obtain hands-on experience. In principle, staff members of the participating universities teach the courses, inviting (international) experts in the field as guest lecturers where relevant. The programme successfully started in 1998 with a first series of joint courses, as summarized in the next table:

<table>
<thead>
<tr>
<th>Title</th>
<th>Date; Location</th>
<th>Lecturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability and collapse of thin-walled structures</td>
<td>March 23-25 and March 30-April 1, 1998; TUD</td>
<td>Arbocz, Riks</td>
</tr>
<tr>
<td>Computational methods for material nonlinearities</td>
<td>November 9-11 and November 16-18, 1998; TUD</td>
<td>De Borst, Sluys, Geers</td>
</tr>
<tr>
<td>Structural optimization and reliability</td>
<td>October 25-27 and November 1-3, 1999; TU/e</td>
<td>Etman, Van Keulen, Rijpkema, Sigmund, Schoofs, Schuëller</td>
</tr>
<tr>
<td>Micromechanics of materials</td>
<td>October 2-6, 2000; Ameland</td>
<td>Van der Giessen, Van Mier, Oomens, Onck</td>
</tr>
<tr>
<td>Advanced dynamics of structures</td>
<td>May 6-9 and May 14-16, 2001; UT and TU/e</td>
<td>de Boer, Tijdeman, Nijmeijer, Van Campen, Leine, Broer</td>
</tr>
</tbody>
</table>

All courses are evaluated systematically and results are discussed with lecturers and Governing Board. In general, participants are very content with the courses, appreciating their relevance and the new knowledge and information offered. Furthermore, courses enabled a fast and effective interaction between research and education.

On the basis of the evaluation of the first series of graduate courses it was decided to continue with a second series of courses, following the same general framework. However, to keep the connection with the selected research themes actual and up-to-date the contents of individual courses were carefully reconsidered. This resulted in a second series of joint courses, as summarized in the next table. Although considered relevant, a course on Stochastic Mechanics has been postponed until completion of this second series, when research in this field within the Graduate School is expected to have been crystallized.
### Computational methods for material and structural instabilities

- **Title:** Computational methods for material and structural instabilities
- **Date, Location:** May 27-29 and June 3-5, 2002; TUD
- **Lecturers:** Askes, Arbocz, Peerlings, Sluys
- **Contents:**

### Multibody dynamics

- **Title:** Multibody dynamics
- **Date, Location:** October 28-30, 2002; TUD and November 4-6, 2002; UT
- **Lecturers:** Jonker, Rixen, Schwab, Van Woerkom, Van de Wouw
- **Contents:**

### Engineering optimization

- **Title:** Engineering optimization
- **Date, Location:** June 4-6 and June 11-13, 2003; TU/e
- **Lecturers:** Etman, Van Keulen, Rijpkema
- **Contents:**

### Mechanics of forming processes

- **Title:** Mechanics of forming processes
- **Date, Location:** November 10-12 and November 17-19, 2003; UT
- **Lecturers:** Akkerman, Brekelmans, Van den Boogaard, Geijselaers, Hüetink, Meinders, Peerlings, De Rooij, Schipper.
- **Contents:**

### Advanced dynamics and control of structures

- **Title:** Advanced dynamics and control of structures
- **Date, Location:** June 2-4, 2004; UT and June 9-11, 2004; TU/e
- **Lecturers:** De Boer, Steinbuch, Rixen.
- **Contents:**
  - Introduction: Linear systems; damping; reduction techniques; solution methods. Structural acoustics: Physical principles and foundations; numerical methods for the analysis of complex acoustic problems. Active damping: Active vibration isolation and suppression; control strategies; sensor and actuator placement; stability; reduction techniques.

### Micromechanics

- **Title:** Micromechanics
- **Date, Location:** November 2-4 and November 8-10, 2004; TU/e
- **Lecturers:** Brekelmans, Geers, Van der Giessen, Van Mier, Peerlings
- **Contents:**

### Nonlinear dynamics and control

- **Title:** Nonlinear dynamics and control
- **Date, Location:** Spring 2005; TU/e
- **Lecturers:** Nijmeijer, Rixen, Van der Hoogt
- **Contents:**

On the basis of an evaluation of the second series of graduate courses, it was decided that in spring 2006 the Graduate School will start with the third series of joint graduate courses, as summarized in the next table.

### Engineering Optimization

- **Title:** Engineering Optimization
- **Date, Location:** Spring 2006; TUD
- **Lecturers:** Van Keulen, Etman, Gürdal

### Computational Methods for Material and Structural Instabilities

- **Title:** Computational Methods for Material and Structural Instabilities
- **Date, Location:** Autumn 2006; TUD
- **Lecturers:** De Borst, Peerlings
In addition to these joint courses the programmatic part contains an individual course programme, with initial and post-initial courses selected from the programmes offered at participating groups. Furthermore, participation in workshops and summer schools under guidance of foreign visiting lecturers forms part of it even as practical work at foreign top-institutes.

The PhD-research project covers about 80% of the four-years training programme. Research topics are in connection with the research programme of the Graduate School. As the research approach within the Graduate School is thematically oriented, research students get the opportunity both to deepen their knowledge in the context of their own project and to broaden their vision on the research field as a whole.

### 1.8 General description of developments in 2004

2004 was another successful year for the graduate school EM. Like in the previous years priority was laid on the continuation of the research activities in the field of Engineering Mechanics. This resulted in the following overall output for 2004:

<table>
<thead>
<tr>
<th>Category</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific publications: refereed journals</td>
<td>110+4*</td>
</tr>
<tr>
<td>Scientific publications: books, chapters in book</td>
<td>17</td>
</tr>
<tr>
<td>Scientific publications: refereed proceedings</td>
<td>190+2*</td>
</tr>
<tr>
<td>PhD theses</td>
<td>16</td>
</tr>
</tbody>
</table>

* Publications in co-operation between different EM-groups

This output is documented in more detail in subsequent chapters of this Annual Report, whereas appendix A contains summaries of the dissertations completed.

To stimulate the exchange of information on ongoing research within the Graduate School, the yearly Engineering Mechanics Symposium took place on November 22nd and 23rd, 2004 in Rolduc, Kerkrade. One hundred fifteen members of the senior academic staff and PhD-students participating within the Graduate School Engineering Mechanics attended the meeting.

Prof. Alan Grodzinsky from MIT, USA, presented a keynote lecture, entitled ‘Chondrocyte Mechanobiology: Links to Molecular Mechanics and Cartilage Tissue Engineering’. At the 2002 EM Symposium the format of the oral presentation sessions was changed to that of workshops that partly run plenary and partly run in parallel. The topics of the Workshops at the 2004 EM Symposium were “Biomechanics”, “Micromechanics (numerical and experimental)”, “Computational & Experimental Mechanics” and “Dynamics”. Each of the workshops started with a Plenary Introduction by the Workshop Organizers. Next, two of the actual Workshops were scheduled to run in parallel on the first Symposium day, whereas the other two were scheduled to run in parallel on the second Symposium day. Each Workshop consisted of two parts, separated by a break. Each part consisted of two presentations by AIOs/Postdocs.
were plenary presentations of the trends and conclusions of the Workshops by the Workshop Organizers.

In conjunction to the oral presentations there was an AIO presentation contest, awarding a prize for the best AIO presentation at each of the Symposium Workshops. Members of the jury were the Workshop Organizers. Winners were: R. van Loon (TU/e) with a contribution entitled “A CFD method for fluid-structure interaction of the aortic heart valve”, P. Janssen (TU/e) with a contribution entitled “Mechanical behaviour of thin sheet metal with only a few grains in thickness”, I.E.M. Severens (TU/e) with a contribution entitled “DEM simulations of toner behavior in the development nip of the Oce Direct Imaging print process” and R.P.H. Faassen (TU/e) with a contribution entitled “Modelling the milling process for chatter prediction”.

In two poster sessions 59 PhD-students of the graduate school Engineering Mechanics presented their current research project. This resulted in stimulating discussions on running projects. In conjunction to the poster sessions a poster contest was organized in which a jury selected the best three contributions. The jury consisted of the following members Prof. R. Akkerman (UT), Ir. G. Calis (Stork NV), Prof. R. Gürdal (TUD) and Dr. R. Peerlings (TU/e). Winners were: R. Pedersen (TUD) with the poster “Computational study of impact fracture of concrete structures”, M. v.d. Bosch (TU/e) with the poster “A combined numerical-experimental approach to characterize delamination in polymer copated steel” and M. Hannink (UT) with the poster “Experimental validation of an optimised resonator configuration for sound absorption”.


In the framework of the three years’ programme of EM-graduate courses two courses were organized.

The course “Advanced Dynamics and Control of Structures” took place on June 2-4 and June 9-11, 2004 and partly hosted at the University of Twente and at Eindhoven University of Technology. The lecturers were Prof. Dr. Ir. A. de Boer (UT), Ir. O.H. Bosgra (TU/e), Dr. Ir. M.H.H. Oude Nijhuis (UT), Prof. Dr. Ir. D. Rixen (TUD), Prof. Ir. M.G.E. Schneider, (TU/e), Ir. R.M.E.J. Spiering (UT), Prof. Dr. Ir. M. Steinbuch (TU/e) and Dr. Ir. Y.H. Wijnant (UT). There were 26 participants from all three Universities involved in Engineering Mechanics.

The course “Micromechanics” was organized from November 2-4 and November 8-10, 2004 and was hosted at Eindhoven University of Technology. The lecturers were W.A.M. Brekelmans (TU/e), I. Doghri (UCL, Louvain-la-Neuve), J.A.W. van Dommelen (TU/e), M.G.D. Geers (TU/e), E. van der Giessen (RuG), J.M.R.J. Huyghe (TU/e), V.G. Kouznetsova (NIMR, TU/e), J.G.M. van Mier (ETH, Zürich), P.R. Onck (RuG), R.H.J. Peerlings (TU/e), P.J.G. Schreurs (TU/e) and J.M.J. den Toonder (Philips, TU/e). There were 34 participants from all three Universities involved in Engineering Mechanics, 12 participants of the Belgium Graduate School GrasMech and 4 participants from other affiliations.

Both courses were evaluated systematically and results were discussed with lecturers and Governing Board.

Furthermore, the following details for 2004 are worth mentioning:

- In 2004 there were two meetings of the Advisory Board of the Graduate School Engineering Mechanics. The first meeting was held on June 23rd at the Delft University of Technology. The second meeting took place after the Seventh Engineering Mechanics Symposium. At the second meeting Dr.lr. S. Hoekstra, Director of the Netherlands Institute of Metals Research (NIMR) was welcomed as a new member of the Advisory Board, whereas Drs. M. Thijssen left in view of retirement. At both meetings the future strategy and directions of the Graduate School were discussed. Particular attention was paid to the value and identification of characteristic input and output numbers for the Graduate School.
• There was a meeting of the board of project leaders, on November 23rd, 2004 in which the Seventh Engineering Mechanics Symposium was evaluated and plans for the Eighth Engineering Mechanics Symposium, to be held November 21-22, 2004 in De Werelt in Lunteren, were discussed. Furthermore, there was a debate on strategical issues within the Graduate School.

• In co-operation with representatives from the J.M. Burgerscentrum, Research School for fluid dynamics, and the Royal Institution of Engineers in the Netherlands, KIVI, Department of Mechanics, the Netherlands Mechanics Committee (NMC) was founded in April 2004. As its major mission the NMC will function as the representative body in The Netherlands for contacts with international organizations. Soon after its foundation, the NMC was recognized as the representative body in the Netherlands by the International Union of Theoretical and Applied Mechanics (IUTAM) and by the International Association for Computational Mechanics (IACM).

• The Annual Report 2003, with information on participating research groups, was published in May 2004. It was distributed among participants and relations of the Graduate School. In addition, there was a continuous effort to keep the information on the Internet site of Engineering Mechanics (http://www.em.tue.nl) up-to-date. Preparations were started for the development of a new Internet site.
1.9 Aggregated input and output for 2004

1.9.1 Input related to EM, 2004

For 2004 the input, aggregated over all participating groups, amounts to:

<table>
<thead>
<tr>
<th>Sources of financing</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>number</th>
<th>fte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior academic staff</td>
<td>84.0</td>
<td>3.0</td>
<td>1.0</td>
<td>88.0</td>
<td>22.8</td>
</tr>
<tr>
<td>Supporting staff</td>
<td>22.0</td>
<td>2.0</td>
<td>-</td>
<td>24.0</td>
<td>-</td>
</tr>
<tr>
<td>PhD</td>
<td>32.0</td>
<td>33.5</td>
<td>61.5</td>
<td>127.0</td>
<td>101.6</td>
</tr>
<tr>
<td>Postdocs</td>
<td>9.0</td>
<td>1.0</td>
<td>9.0</td>
<td>19.0</td>
<td>12.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>147.0</td>
<td>39.5</td>
<td>71.5</td>
<td>258.0</td>
<td>136.7</td>
</tr>
</tbody>
</table>

Sources of financing:
1: University;
2: STW, SON, NWO, FOM;
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI, etc.

No research input involved for supporting staff.

Research input per PhD per year: 0.8 fte

A subdivision of the input in fte over the participating Universities gives the following results:

<table>
<thead>
<tr>
<th>TU/e (fte)</th>
<th>TUD (fte)</th>
<th>UT (fte)</th>
<th>Total (fte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior academic staff</td>
<td>8.6</td>
<td>10.0</td>
<td>4.2</td>
</tr>
<tr>
<td>PhD*</td>
<td>36.8</td>
<td>35.2</td>
<td>29.6</td>
</tr>
<tr>
<td>Postdocs</td>
<td>5.0</td>
<td>3.2</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>50.4</td>
<td>48.4</td>
<td>37.9</td>
</tr>
</tbody>
</table>

* Research input per PhD per year: 0.8 fte

A subdivision of the PhD-projects per December 2004 over the four selected research themes results in the following:

<table>
<thead>
<tr>
<th>EM research theme</th>
<th>Number of PhD-projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Mechanics</td>
<td>41.5</td>
</tr>
<tr>
<td>Mechanics of Materials</td>
<td>35.0</td>
</tr>
<tr>
<td>Structural Dynamics and Control</td>
<td>39.0</td>
</tr>
<tr>
<td>Structural Mechanics</td>
<td>11.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>127.0</td>
</tr>
</tbody>
</table>

Appendix B contains a summary of the actual PhD-projects per research theme.
1.9.2 Output related to EM, 2004

For 2004 the output, aggregated over all participating groups, amounts to:

<table>
<thead>
<tr>
<th>Publication Type</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific publications: refereed journals</td>
<td>110+4*</td>
</tr>
<tr>
<td>Scientific publications: books, chapters in book</td>
<td>17</td>
</tr>
<tr>
<td>Scientific publications: refereed proceedings</td>
<td>190+2*</td>
</tr>
<tr>
<td>PhD theses</td>
<td>16</td>
</tr>
</tbody>
</table>

*Publications in co-operation between different EM-groups

A subdivision of the output over the participating Universities gives the following results:

<table>
<thead>
<tr>
<th>Publication Type</th>
<th>TU/e</th>
<th>TUD</th>
<th>UT</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific publications: refereed journals</td>
<td>44</td>
<td>56+4*</td>
<td>10</td>
<td>110+4*</td>
</tr>
<tr>
<td>Scientific publications: books, chapters in book</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Scientific publications: refereed proceedings</td>
<td>70</td>
<td>78+2*</td>
<td>42</td>
<td>190+2*</td>
</tr>
<tr>
<td>PhD theses</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>16</td>
</tr>
</tbody>
</table>

*Publications in co-operation between different EM-groups are equally divided over participating groups

1.10 Overview of input and output per participating group, 2004

In this section the 2004-input and the 2004-output per participating group are summarized. Further details can be found in the description of individual groups in subsequent chapters. Aggregated results are reported in the preceding paragraph.

1.10.1 Input related to EM, 2004
1.10.2 Output related to EM, 2004

<table>
<thead>
<tr>
<th>Group</th>
<th>Ref. journals</th>
<th>Books, chapters in book</th>
<th>Ref. proceedings</th>
<th>PhD-theses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TU/e</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systems, Dynamics and Control</td>
<td>16</td>
<td>4</td>
<td>33</td>
<td>2</td>
</tr>
<tr>
<td>Materials Technology</td>
<td>21</td>
<td>-</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Analysis Scientific Computing and Applications (CASA)</td>
<td>7</td>
<td>1</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td><strong>TUD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Mechanics (1)</td>
<td>10+1*</td>
<td>3</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Aerospace Structures and Computational Mechanics</td>
<td>9+1*</td>
<td>1</td>
<td>19+1*</td>
<td>1</td>
</tr>
<tr>
<td>Structural Optimization and Computational Mechanics</td>
<td>11+1*</td>
<td>2</td>
<td>8+1*</td>
<td>-</td>
</tr>
<tr>
<td>Engineering Mechanics (2)</td>
<td>12</td>
<td>1</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Computational Mechanics, Structural Mechanics and Dynamics</td>
<td>14+1*</td>
<td>-</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td><strong>UT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Mechanics</td>
<td>3</td>
<td>-</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Surface Technology and Tribology</td>
<td>6</td>
<td>1</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Mechanical Automation</td>
<td>-</td>
<td>-</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Production Technology</td>
<td>-</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

*In co-operation with other EM-groups.

1.11 Overview of co-operation

1.11.1 Internal co-operation

With reference to its mission statement the Graduate School Engineering Mechanics fosters the co-operation between participating research groups. This has resulted in an increasing number of joint research projects that received substantial input from different EM-groups. Joint projects for 2004 are summarized in the following table.

<table>
<thead>
<tr>
<th>Project</th>
<th>Participating groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADOPT: Sequential Approximate Design Optimization including uncertainties, discontinuities and discrete design variables</td>
<td>Systems, Dynamics and Control (TU/e)</td>
</tr>
<tr>
<td></td>
<td>Aerospace Structures and Computational Mechanics (TUD)</td>
</tr>
<tr>
<td></td>
<td>Structural Optimization and Computational Mechanics (TUD)</td>
</tr>
<tr>
<td></td>
<td>Structural Optimization and Computational Mechanics (TUD)</td>
</tr>
<tr>
<td></td>
<td>Materials Technology (TU/e)</td>
</tr>
<tr>
<td>Lubrication, Acoustics and Vibrations of Roller Bearings</td>
<td>Applied Mechanics (UT)</td>
</tr>
<tr>
<td></td>
<td>Surface Technology and Tribology (UT)</td>
</tr>
<tr>
<td>Hybrid Isolation of Construction Noise (HIC)</td>
<td>Applied Mechanics (UT)</td>
</tr>
<tr>
<td></td>
<td>Mechanical Automation (UT)</td>
</tr>
<tr>
<td>Friction and Roughness Transfer in Rolling and Metal Forming Processes</td>
<td>Applied Mechanics (UT)</td>
</tr>
<tr>
<td></td>
<td>Surface Technology and Tribology (UT)</td>
</tr>
<tr>
<td>NIMR-project MC1.03158, Strain path dependent materials models for forming and crush</td>
<td>Applied Mechanics (UT)</td>
</tr>
<tr>
<td></td>
<td>Materials Technology (TU/e)</td>
</tr>
</tbody>
</table>

Furthermore, co-operation between members from different participating groups resulted in a total of 6 joint publications in refereed journals and proceedings.
1.11.2 External co-operation

Within the field of mechanics of materials, the graduate school Engineering Mechanics strongly co-operates with NIMR, the leading technological institute for metals. The EM-projects in these institutes form a coherent programme that concentrates on the fundamental understanding and the predictive analysis of a number of carefully selected generic industrial problems in metal forming. Most engineering problems for these materials emerge from the physics and the mechanics of the underlying microstructure. Establishing micro-macro structure-property relations for metals and polymers, with a particular emphasis on the improvement of materials, permits to set up a knowledge database supported through appropriate and predictive numerical frameworks. The scientific work in these institutes directly supports the long-term strategy of the industrial partners involved (Akzo Nobel, Boal, Corus, DAF, Dow, DSM, GE Plastics, Impress Metal Packaging, Montell, Interturbine, Koninklijke Schelde Groep, Océ, Philips, Polynorm, Reynolds Aluminium, Shell, SKF, Stork, TNO) by acquiring fundamental insight that leads to improved metals and polymers. At the same time, the investigated applications in several projects are fine-tuned to a particular industrial request, which provides direct answers to specific engineering questions in industry. The graduate school Engineering Mechanics participates in these leading technological institutes with 10 research projects. In 2004, the graduate school Engineering Mechanics co-operated with the Belgian Graduate School in Mechanics, GrasMech, in such that members of both Graduate Schools participated in each others courses.
2. RESEARCH DOCUMENTATION OF THE GROUP
SYSTEMS, DYNAMICS AND CONTROL\(^1\)

1. University/Department
Eindhoven University of Technology
Department of Mechanical Engineering

2. Subprogrammes related to research school EM
2.1 Non-linear Dynamics of Mechanical Systems
2.2 Structural Acoustics and Noise Control
2.3 Structural Optimization
2.4 Advanced Motion Systems
2.5 Automotive Technology
2.6 Systems Design Optimization
2.7 Control of Manufacturing Systems
2.8 Nonlinear and Hybrid Dynamics

3. Group directors
Prof.Dr. H. Nijmeijer
Prof.Dr.Ir. J.E. Rooda
Prof.Dr.Ir. M. Steinbuch

4. Senior academic staff: name, position, research input in fte related to research school EM

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Research Input in FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Besselink, Dr.Ir. J.J.M.</td>
<td>UD (0.4) main position at TNO-TPD</td>
<td>0.2</td>
</tr>
<tr>
<td>Campen, Prof.Dr.Ir. D.H. van</td>
<td>Full Professor (PM) main position Dean TU/e-W</td>
<td>p.m.</td>
</tr>
<tr>
<td>Etman, Dr. Ir. L.F.P.</td>
<td>UD</td>
<td>0.4</td>
</tr>
<tr>
<td>Fey, Dr.Ir. R.H.B.</td>
<td>UD</td>
<td>0.2</td>
</tr>
<tr>
<td>Groenwold, Prof. Dr. A.A.</td>
<td>Visiting professor (May 1th- Nov 1th 2004)</td>
<td>0.2</td>
</tr>
<tr>
<td>Kok, Prof.Dr.Ir. J.J.</td>
<td>Full Professor (0.4)</td>
<td>0.1</td>
</tr>
<tr>
<td>Kraker, Dr.Ir. A. de</td>
<td>Part-time UHD (0.3) main position Dir.</td>
<td>p.m.</td>
</tr>
<tr>
<td>Lefeber, Dr. Ir. E.</td>
<td>UD</td>
<td>0.4</td>
</tr>
<tr>
<td>Liebrand, Prof.Ir. N.J.J.</td>
<td>Part-time Prof. (0.4)</td>
<td>0.2</td>
</tr>
<tr>
<td>Lopez, Dr.Ir. I.</td>
<td>UD</td>
<td>0.1</td>
</tr>
<tr>
<td>Nijmeijer, Prof.Dr. H.</td>
<td>Full Professor</td>
<td>0.2</td>
</tr>
<tr>
<td>Nuji, Ir. P.W.J.M.</td>
<td>UD</td>
<td>0.2</td>
</tr>
<tr>
<td>Pogromsky, Dr. A.Y.</td>
<td>UD</td>
<td>0.4</td>
</tr>
<tr>
<td>Post, Dr.Ir. W.J.A.E.M.</td>
<td>UD</td>
<td>0.2</td>
</tr>
<tr>
<td>Rijpkema, Dr. J.J.M.</td>
<td>UD, General Manager Research School EM</td>
<td>0.1</td>
</tr>
<tr>
<td>Rooda, Prof.Dr.Ir. J.E.</td>
<td>Full Professor</td>
<td>0.2</td>
</tr>
<tr>
<td>Roozen, Prof.Dr.Ir. N.B.</td>
<td>Part-time Prof. (0.2) main position at Philips</td>
<td>0.1</td>
</tr>
<tr>
<td>Steinbuch, Prof.Dr.Ir. M.</td>
<td>Full Professor</td>
<td>0.1</td>
</tr>
<tr>
<td>Veenhuizen, Dr. P.A.</td>
<td>UD</td>
<td>0.2</td>
</tr>
</tbody>
</table>

\(^1\) Per 2002 the activities of the previous EM groups “TU/e – Dynamics and Control Technology” and “TU/e – Systems Engineering” are combined within the new EM group “TU/e – Systems, Dynamics and Control”.

Annual Report Engineering Mechanics 2004 2.1
5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1 Nonlinear Dynamics of Mechanical Systems
Faassen, Ir. R.P.H. (PhD 3) Chatter in high-speed Milling StDy
Mihajlovic, M.Sc. N. (PhD 1) Limit cycling in mechanical systems StDy
Mallon, Ir. N.J. (PhD 2) Dynamic stability of thin walled structures StDy
Veggel, Ir. A.A. van (PhD 3) Design of a metrology system for GAIA StDy

5.2 Structural Acoustics and Noise Control
Debiesme, M.Sc. F.X. (PhD 3) Design tools for low noise products with uncertain parameters StDy
Dijkhof, Ir. W.J. (PhD 3) Analysis methods for low noise products with uncertain parameters StDy
Scholte, Ir. R. (PhD 2) Acoustic holography StDy

5.4 Advanced Motion Systems
Hamelink, Ir. R.F.M.M. (PhD 3) Adaptive Optics StDy
Henselmans, Ir. R. (PhD 3) Fee-form optics measurement instrument StDy
Werner, Ir. C. (PhD 3) Large stroke AFM StDy

5.5 Automotive Technology
Bonsen, Ir. B. (PhD 3) Modelling and control of slip in a push-belt StDy
Hofman, Ir. T. (PhD 2) Hybrid Vehicle Topology StDy
Meerakker, Ir. K.G.O. vd (PhD 3) Alternative variator actuation StDy

5.6 Systems Design Optimization
Tosserams, Ir. S. (PhD 1) Analytical Target Cascading (start 1 Sept 2004) StMe
Kock, Ir. A.A.A. (PhD 2) Effective Process Time (start 1 June 2004) StDy

5.7 Control of Manufacturing Systems
Eekelen van, Ir. J.A.W.M. (PhD 1) Modeling of Manufacturing Systems for Control StDy

5.8 Nonlinear and Hybrid Dynamics
Berg van de, Ir. R. (PhD 1) Performance based design of hybrid systems (start 1 August 2004) StDy

6. Postdocs: name, country, project title, subprogramme, research theme EM and period of stay

Dr.Ir. R.M. v. Druten NL Power train design 5.5 StDy
2002 – 2007
Dr.Ir. A.J.C. Schmeitz NL Vehicle dynamics & tyres 5.5 StDy
May 2004 – May 2005
7. Short description of subprogrammes related to research school EM

7.1 Non-linear dynamics of mechanical systems
Within this theme, the following research topics are investigated:

7.1.1 Numerical and experimental study of non-smooth mechanical systems, like systems with friction, impacts, or constraints. The research on these phenomena is highly relevant in many engineering applications (friction in high performance/high precision systems, drill-strings, hybrid control systems etc.). Numerical aspects are notably difficult, but with increasing computer power, become more and more feasible. Interesting and important results involve the study of bifurcations in non-smooth systems. Together with Remco Leine (ETH, Zürich) a monograph on this subject was completed in 2004. A further development along the line of non-smooth systems consists of the study of active control of non-smooth mechanical systems. This is part of the EU sponsored project, SICONOS and is linked with the European Network of Excellence HYCON. Additionally, possibilities for passive control of piecewise linear systems are studied.

7.1.2 Development of accessible (numerical) procedures for the steady-state response under periodic excitation. In particular, a non-linear dynamics toolbox with time-discretization and shooting methods and a path-following procedure has been integrated in the commercial finite element package DIANA and in the general-purpose package MATLAB. Non-linear dynamics phenomena such as bifurcations have been studied both at an experimental and numerical level. Related to research theme “Structural Dynamics and Control”.

7.2 (Structural) acoustics and noise control
The research topic involving two PhD students is the modelling of and optimization of ‘uncertainty’ in structural vibrations and the associated sound radiation. Important examples for low-noise design are road vehicles, railway carriages, aircraft, ships and MRI-scanners. With respect to structural-acoustic modelling, these examples have two characteristic problems in common. These are the enormous size of numerical models needed to describe their physics correctly and their ‘uncertainty’ behaviour. The first topic refers to the frequency range in which structural wavelengths are small compared to the characteristic geometrical dimensions. The latter characteristic means that nominally identical structures show a large and rather unpredictable scatter in acoustic behaviour. This is true for new products and may even increase after some years of use. Therefore, much interest is shown in improving predictive capabilities and in optimization for ‘robust designs’, i.e. designs which do not deteriorate easily during their life cycle. TNO-Institute of Applied Physics participates significantly in this long-term research. The research topic “Tyre-road noise” currently focuses on modeling the acoustically relevant structural vibrations of rolling tyres. A graduation student has recently finished his MSc. thesis and a second student has continued in this direction. On the subject “Acoustic holography” an STW-project proposal is awarded on the subject of improved capabilities of the inverse acoustic holography method. Related to research theme “Structural Dynamics and Control”.

7.3 Structural optimization
The research in this area concerns the development of tools for the optimization of the dynamic behaviour of constructions, where the engineering optimization problem is considered as an interrelated combination of an Optimal Design Problem (ODP) and an Optimal Control Problem (OCP). Particular attention is paid to the development and utilization of both approximation concepts in the optimization process and of strategies for the combination, integration and coordination of effective approaches for (uncertain) ODP and OCP. In co-operation with the Systems Engineering section and the Structural Optimization and Computational Mechanics group from TUD an inter-university research
project ‘ADOPT: Sequential Approximate Design Optimization including uncertainties, discontinuities and discrete design variables’, sponsored by the Technology Foundation STW, is running. The aim of the project is to develop design optimization tools for problems exhibiting simultaneously discrete design variables, uncertainties, and discontinuous response functions. Applications are foreseen in the design of (automotive) multibody systems, composite structures and manufacturing systems. In particular, the Automatic Balancing Unit (ABU) donated by Philips CFT is used as an experimental carrier in this project.
Related to research theme “Structural Dynamics and Control”.

7.4 Advanced Motion Systems

7.4.1 Advanced Motion System Design
Various projects address mechatronics research questions. With Océ a project is running on the design of a new accurate printhead. Furthermore, there is a project on the complete design of a measurement machine with nanometer accuracy for aspheric objects. Also a project on adaptive optics is running, addressing the complexity question as well as design issues. This is done together with TNO/TPD and the Technische Universiteit Delft (TUD).
New activities, together with the Department of BioMedical Engineering, concentrate on medical robotics, in particular on surgical robotic systems. These activities capture haptic feedback in tele-operation, as well as instrumentation and control design for a ‘plasma needle’.

7.4.2 Hydraulic Servo Systems
With the help of ir. Piet Teerhuis (TUD) a start has been made to consolidate and extend the hydraulic (i.e. Fluid Power) servo technology know-how as formerly present at the TUD. This should lead to a new and active research area, in which our capabilities in advanced motion control are combined with our hydraulic knowledge and lab facilities. A new servo hydraulic mechanism is built and used for education and research. A second, non-linear, multivariable set-up is under construction.
Two extensive activities, related to the automotive research in the group, have been performed in the Fluid Power laboratory: (i) building a hydraulic test-rig for driving and loading of a CVT (‘continuously variable transmission’) to measure the CVT efficiency and (ii) building a hydraulic test-rig to generate rapidly changing torques for a dynamical CVT test-rig.

7.4.3 Mobile robot structures
This research line in the Dynamics & Control Technology Laboratory has been initiated in 2000. Mobile, autonomous, structures are very attractive for numerous application areas (space travelling, mail delivery, cleaning, inspections in hazardous environments etc.). Apart from mechanical design issues, these systems exhibit specific control challenges, especially because the systems are often under actuated and not enough accurate measurement information is available. The aims for this research line are:
(i) development of an experimental set-up for validation of (theoretical) non-linear control concepts, (ii) development and validation of non-linear models, controllers, and observers, (iii) development of a representative demonstration object for mobile and under actuated mechanical structures. (iv) development of a test environment of autonomous guided vehicles (AGVs).
Upcoming activities in this direction are the participation in Robocup and embedded autonomous robots.
Related to research theme “Structural Dynamics and Control”.

2.4 Annual Report Engineering Mechanics 2004
7.5 **Automotive Technology**

7.5.1 **Advanced Power Trains**
A large project concentrates on servomotor based actuation systems. New transmissions, like the CVT and the double clutch transmission, still rely on hydraulic actuation, leading to compromised transmission efficiencies and requiring a complex and expensive hydraulic unit. The reduction in the costs of permanent magnet materials and the increase in magnetic field strength now make a further penetration of electric servomotors for actuation purposes possible. The application and control of these servomotors and the consequences of their integration in vehicular transmissions are subject of study. Slip control of CVTs is a new and very promising line of research.

The second project focuses on validation and test facility development. Power train components are being developed and tested on the available test facilities. New facilities will be developed whenever needed. Newly developed components are preferably demonstrated in state-of-the-art test vehicles, using modern controllers, so they can be validated under real life conditions.

7.5.2 **Vehicle Dynamics and Tyres**
The MSc course "Advanced Vehicle Dynamics" has been given for the first time in 2004 and was attended by 30 almost students, which gave a very positive feedback on this course. It was developed in cooperation with DAF Trucks. In the AES lab the flat plank tyre tester was used for various experiments (e.g. relaxation length measurements, parking behaviour, cleat tests) and valuable experience was gained by the laboratory personnel. In 2004, amongst others, measurements on the overturning moment and motorcycle tyre behaviour at large camber angles are done, combined with activities to model the measured tyre response. Also a start was made with research on tyre noise (see research area 2) and a number of student projects were done in the field of vehicle control.

Related to research theme “Structural Dynamics and Control”.

7.6 **Systems Design Optimization**
Optimization methods to support systematic design and improvement of complex engineering systems are investigated. We concentrate on computational design optimization in the context of manufacturing system networks, manufacturing machines, and micro-mechanical systems. Optimization methods and tools are being developed that can deal with typical governing characteristics such as: one or more computationally expensive computer simulation models in the loop, a mix of continuous and discrete design variables, stochastic design variables and responses, and dynamic response behavior. The development of techniques for approximation, meta-modelling, and lumped-parameter modelling that can be utilized in the optimization plays a central role in our research work. Furthermore, methods for design optimization of multidisciplinary and multi-level decomposed systems have our special interest.

Related to research themes "Structural Mechanics" and "Structural Dynamics and Control".

7.7 **Control of Manufacturing Systems**
In this subprogramme two main streams can be considered.

The first stream considers a class of manufacturing systems that can be approximately modelled by means of a continuous time fluid or flow model. For this approximate model, standard techniques from control theory can often be used to design controllers. As the manufacturing system has a discrete-event nature, a connection between the discrete event plant and the continuous time controller has to be developed. Continuous time signals have to be converted to discrete-events and measurements of discrete states need to be filtered for a better control performance.
The second stream tries to bridge the gap between flow models that often ignore variability and queuing theory that often considers only steady state behavior. For that purpose new (mathematical) models need to be developed that include both variability and dynamics. It is clear that preferably these models should be suited for applying standard control theory in order to control these systems.

Related to research theme “Structural Dynamics and Control”.

7.8 Nonlinear and hybrid dynamics

In this subprogram two main directions can be considered.

First, general questions of nonlinear dynamics and control of mechanical systems including switched (hybrid) systems are studied. In recent years hybrid systems attracted a considerable attention due to possible applications in various fields of science and technology. The theory of hybrid systems is far from its completeness. Therefore it is of interest to further develop methods of analysis and design for such systems. In this research particular attention is drawn to the following two questions: analysis of oscillations in hybrid systems and formalization of some mathematical models of hybrid systems using the formal languages approach. The formal language used is Chi developed in the Systems Engineering group.

The second direction of the research is to study applications for the theoretical results in the framework of systems engineering. Nowadays complex manufacturing machines constitutes of discrete-event and continuous-time parts with interactions between the components. These interactions can result in nonlinear dynamical phenomena that should be taken into account during design and real-time control of the machine. This research theme has a strong relation with the topic Embedded Systems (within the Institute for Programming and Algorithmic).

Related to research theme “Structural Dynamics and Control”.

8. Refereed scientific publications related to research school EM

8.1 Refereed journals


Kieft, I.E., E.P. van der Laan, E. Stoffels-Adamowicz, Electrical and Optical Characterization of the Plasma Needle, NJP, 6(149), 1-14, 2004

Lizarraga, D.A., N.P.I. Aneke, H. Nijmeijer, Robust point stabilization of underactuated mechanical systems via the extended chained form, SIAM J Control Optimization, 42(6), 2172-2199, 2004


Respondek, W.; Pogromsky, A.Y.; Nijmeijer, H.: Time scaling for observer design with linearizable observer dynamics, Automatica, 40(2), 277-285, 2004
De Ron, A.J.; Rooda, J.E.: Equipment Effectiveness: OEE revisited, IEEE Transactions on Semiconductor Manufacturing, 17, 100-107, 2004


8.2 Books, chapters in book


Leine, R.I., B. Brogliato, H. Nijmeijer, Periodic Motion Induced by the Painleve Paradox, in Advanced dynamics and control of structures and machines; Editors: Hans Irischik, Kurt Schlacher, 169-194, Springer Wien New York, Book Chapter ISBN 3-211-22867-5, 2004


8.3 Refereed proceedings

Beek, D.A. van; Pogromsky, A.Y.; Nijmeijer, H.; Rooda, J.E.: Convex Equations and Differential Inclusions in Hybrid Systems, in 43rd IEEE Conference on Decision and Control; Nassau, Bahamas, 6pp, 2004


Druten, R.M. van, B.G. Vroemen, M.F.M. Pesgens, Performance Analysis of the Impulse Shift Transmission,
in VDI 2004 Congress Innovative Powertrain Systems; Editors: Koepf (ZF), Dresden, Germany, 12, 2004

Druten, R.M. van, B.G. Vroemen, Performance Analysis of the Impulse Shift CVT, in 2004 International Continuously Variable and Hybrid Transmission Congress; Editors: Frank, Davis, United States, 6, 2004


Hamelinck, R.F.M.M., P.C.J.N. Rosielle, J.P. Kappelhof, B. Snijders, M. Steinbuch, Large adaptive deformable membrane mirror with high actuator density, in Astronomical Telescopes and instrumentation; Glasgow, United Kingdom, 8, 2004


Hofman, T., R.M. van Druten, Research Overview: Design Specifications for Hybrid Vehicles, in European ELE-DRIVE Transportation; Editors: AVERE, Lissabon, Portugal, CDROM, 2004


Lopez, I., J.M. Busturia, H. Nijmeijer, Friction dampers, the positive side of friction, in ISMA2004 Noise and Vibration Engineering; Editors: P.Sas, M. De Munck, Leuven, Belgium, 569-601, 2004

Meerakker, K.G.O. van de, P.C.J.N. Rosielle, B. Bonsen, T.W.G.L. Klaassen, Design of an electromechanical ratio and clamping force actuator for a metal V-belt type CVT, in CVT 2004 congress; Davis, United States, , 2004


Pogromsky, A.Y.; Nijmeijer, H.; Rooda, J.E.: A negative Bendixson's-like criterion for a class of hybrid systems, in Proceedings of the MTNS; Leuven, Belgium, 6pp., 2004

Rademakers, N.G.M., R. Akkeliawati, R. Hill, C. Bil, H. Nijmeijer, Modelling and Gain Scheduled Control of a Tailless Fighter, in ASCC04 ; Editors: ASCC04, Melbourne, Australia, 9 pages, 2004

Sciarretta, A., L. Guzzella, J. van Baalen, Fuel optimal trajectories of a fuel cell vehicle, in Int. Conference on Advances in Vehicle Control and Safety (AVCS2004); Editors: IFAC, Genua, Italy, CDROM, 2004


Vael, G.E.M., I. Lopez, P. Achten, Reducing flow pulsation with the floating cup pump: theoretical analysis, in Bath Workshop on Power Transmission and Motion Control; Editors: C.R. Burrows, K.A. Edge and D.N. Johnston, Bath, United Kingdom, 123-141, 2004

Veenhuizen, P.A., S. Cools, Servo hydraulic control of a continuously variable transmission, in 7th International Symposium on Advanced Vehicle Control (AVEC’04); Editors: J. Pauwelussen, M. Steinbuch, Arhem, Netherlands, 117-123, 2004


Wouw, N. van de, N.J. Mallon, H. Nijmeijer, Friction Compensation in a controlled one-link robot using a reduced-order observer, in Proc. of 6th IFAC Symp. on Nonlinear Control Systems (NOLCOS); Editors: F. Allgower, Stuttgart, Germany, 1163-1168, 2004

9. Dissertations: related to research school EM: name, title, university, date and advisors

Name: R.J. Hesseling
Title: Active Restraint Systems - Feedback Control of Occupant Motion, 2004, TU/e
Advisor: M. Steinbuch, P.P.J. v. d. Bosch
Co-advisor: F.E. Veldpaus
Current position: Employee Takata, Berlin

Name: J.H. Jacobs
Title: Performance quantification and simulation optimization of manufacturing flow lines, TU/e, 13 September 2004
Advisors: Prof.dr.ir. J.E. Rooda (TU/e), Prof.dr.ir. F. van Keulen (TUD),
Co-advisor: Dr.ir. L.F.P. Etman (TU/e)
Current position: Employee ASML

10. Membership editorial boards international journals

Prof.Dr.Ir. D.H. van Campen:
  • Contributing Editor Multibody Systems Dynamics
  • Member Advisory Board Nonlinear Dynamics

Dr.Ir A.G. de Jager
  • Associate Editor IEEE Trans. On Control Systems Technology

Prof.Dr. H. Nijmeijer:
  • Editor in Chief Journal of Applied Mathematics
  • Associate editor AUTOMATICA
• Corresponding editor SIAM J Control Optimization
• Subject editor International J. of Robust and Nonlinear Control
• Member Editorial Board J. of Applied Mathematics Computer Science
• Member Editorial Board J. of Dynamical Control Systems
• Member Editorial Board International J. of Control
• Member Editorial Board J. of Stability and Control
• Member Editorial Board European Journal of Control

Prof.Dr.Ir. J.E. Rooda:
• Member Editorial Board Advanced Manufacturing Technology

Prof.Dr.Ir. M. Steinbuch:
• Editor-at-Large European Journal of Control

Prof.Dr.Ir. J.W. Verheij:
• Member Editorial Board Int. Journal of Acoustics and Vibration
• Member Editorial Board of E-mail Noise and Vibration Digest
• Member Editorial Board Handbook of Noise and Vibration Control (to be published by John Wiley & Sons, New York)

11. Keynote lectures and seminars

Dr. P.A. Veenhuizen:

12. Membership international scientific committees

Prof.Dr.Ir. D.H. van Campen:
• Secretary-General of the International Union on Theoretical and Applied Mechanics (IUTAM) since November 2000.
• Chairman EUROMECH Nonlinear Oscillation Conference Committee.
• Chairman Fifth EUROMECH Nonlinear Dynamics Conference, The Netherlands, August 2005
• IUTAM Representative on Scientific Committee of IUTAM Symposium on Elastodynamics and Microelastodynamics, Cardiff, UK, 1-3 September 2004.

Dr.Ir. L.F.P. Etman:
• Member scientific committee of 2004 IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop, 4-6 May, Boston.

Prof.Dr. H. Nijmeijer:
• Member EU Marie Curie Network ‘Control Training Site’
• Member EU Marie Curie Network ‘MASTER’
• Member EU project HYCON (Hybrid Control)

Prof.Dr.Ir. J.E. Rooda:
• Member scientific committee of 2004 IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop, 4-6 May, Boston.
Prof. Dr. Ir. M. Steinbuch:
• Chairman of the Danish Research Programme WAVES (2001-2005).
• Chairman of the Scientific Committee AVEC 04
• Member Board of the European Association of Control

Dr. ir. F.E. Veldpaus:
• Member of the Scientific Committee AVEC 04

Prof. Dr. Ir. J.W. Verheij:
• Secretary of the International Institute of Acoustics and Vibration

Dr. P.A. Veenhuizen:
• Member of the Scientific Committee AVEC 04

13. Awards and patents

Awards:
• Ir. A.A.A. Kock has received the Corus Young Talents Prize awarded by the Koninklijke Hollandse Maatschappij der Wetenschappen for the best Mechanical Engineering M.Sc. thesis over the year 2003 (awarded in 2004).
• ‘Spykerprijs’, Award for G. van der Zalm, for the best MSc thesis in the Netherlands, within the area of Automotive Engineering, 2004.

Patents:

14. Overview of research input and output

14.1 Input “Systems, Dynamics and Control” related to EM, 2004

<table>
<thead>
<tr>
<th>Sources of financing</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Senior academic staff</td>
<td>21</td>
</tr>
<tr>
<td>Supporting staff</td>
<td>8</td>
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<tr>
<td>PhD</td>
<td>4</td>
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<tr>
<td>Postdocs</td>
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<tr>
<td>Total</td>
<td>35</td>
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</table>

Sources of financing: 1: University
2: STW, SON, NWO, FOM, EM
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, etc.

2 No research input involved for supporting staff.
3 Research input per PhD per year: 0.8 fte
14.2 Output “Systems, Dynamics and Control” related to EM, 2004

<table>
<thead>
<tr>
<th>Scientific publications: refereed journals</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Scientific publications: books, chapters in book</td>
<td>16</td>
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<tr>
<td>Scientific publications: refereed proceedings</td>
<td>33</td>
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<tr>
<td>PhD theses</td>
<td>2</td>
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</table>

* In cooperation with other EM-groups.

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

Project Title: ADOPT: Sequential Approximate Design Optimization including uncertainties, discontinuities and discrete design variables.
Participating Groups: Systems, Dynamics and Control (TU/e)
Structural Optimization and Computational Mechanics (TUD)
Aerospace Structures and Computational Mechanics (TUD)
Participants: Dr. Ir. L.F.P. Etman (TU/e), Ir. S.P. Gurav (TUD),
Ir. J.H. Jacobs (TU/e), Prof. Dr. Ir. A. van Keulen (TUD),
Dr. J.J.M. Rijpkema (TU/e), Ir. R.A. van Rooij (TU/e),
Prof. Dr. H. Nijmeijer (TU/e), Ir. K. Vervenne (TUD).
Research Input in fte: 2.4

Project Title: STW project TW 6618, Inverse Acoustics
Participating Groups: Applied Mechanics (UT), Dynamics and Control (TUe)
Participants: Prof. Dr. Ir. A. de Boer (UT), Dr. Ir. Y.H. Wijnant (UT), Vacancy (UT), Prof. Dr. Ir. N.B. Roozen (TUe), Dr. I. Lopez (TUe),
Ir. R. Scholte (TUe)
Research Input in fte: 2.0
3. RESEARCH DOCUMENTATION OF THE GROUP
MATERIALS TECHNOLOGY

1. University/Department

Eindhoven University of Technology
Department of Mechanical Engineering
Department of Biomedical Engineering

2. Subprogrammes related to research school EM

2.1 Structure-Property relations and Constitutive Modelling
2.2 Microscopic Aspect of Deformation
2.3 Micromechanics of Functional Devices
2.4 Multi-scale Mechanics, Damage and Fracture in Metals
2.5 Impact Protection and Injury Biomechanics
2.6 Biomechanics

3. Group directors

Prof.Dr.Ir. F.P.T. Baaijens
Prof.Dr.Ir. M.G.D. Geers

4. Senior academic staff: name, position, research input in fte related to research school EM

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Research Input in FTE</th>
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<tbody>
<tr>
<td>Baaijens, Prof.Dr.Ir. F.P.T.</td>
<td>Full Professor</td>
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<tr>
<td>Brekelmans, Dr.Ir. W.A.M.</td>
<td>UHD</td>
<td>0.4</td>
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<tr>
<td>Dietzel, Prof.Dr. A.H.</td>
<td>Full Professor</td>
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</tr>
<tr>
<td>Dommelen, Dr.Ir. J.A.W.</td>
<td>UD</td>
<td>0.4</td>
</tr>
<tr>
<td>Geers, Prof.Dr.Ir. M.G.D.</td>
<td>Full Professor</td>
<td>0.4</td>
</tr>
<tr>
<td>Huyghe, Dr.Ir. J.M.R.J.</td>
<td>UHD</td>
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<tr>
<td>Kouznetsova, Dr.Ir. V.G.</td>
<td>NIMR-fellow</td>
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<tr>
<td>Oomens, Dr.Ir. C.W.J.</td>
<td>UHD</td>
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<td>Peerlings, Dr.Ir. R.H.J.</td>
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<td>Vellinga, Dr.Ir. W.P.</td>
<td>UD</td>
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<td>Wismans, Prof.Dr.Ir. J.S.H.M.</td>
<td>Part-time Professor</td>
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<tr>
<td>Witteman, Dr.Ir. W.J.</td>
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<tr>
<td>Zhang, Prof.Dr.Ir. G.Q.</td>
<td>Part-time Professor</td>
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Total fte: 3.0
5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1 Structure-Property Relations and Constitutive Modelling

<table>
<thead>
<tr>
<th>Name</th>
<th>Source of Financing</th>
<th>Project Title</th>
<th>Research Theme EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aydemir, Ir. A.</td>
<td>(PhD 3)</td>
<td>Multi-scale mechanics of thin structures</td>
<td>CoMe/ StMe</td>
</tr>
<tr>
<td>Boers, Ir. S.H.A.</td>
<td>(PhD 1)</td>
<td>Discrete multi-path forming</td>
<td>StMe</td>
</tr>
<tr>
<td>Bosch, Ir. M.J. v. d.</td>
<td>(PhD 3)</td>
<td>Deformation limits of polymer coated metal sheets</td>
<td>CoMe/ MeMa</td>
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</table>

5.2 Microscopic Aspect of Deformation

<table>
<thead>
<tr>
<th>Name</th>
<th>Source of Financing</th>
<th>Project Title</th>
<th>Research Theme EM</th>
</tr>
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<tbody>
<tr>
<td>Janssen, Ir. P.J.M.</td>
<td>(PhD 3)</td>
<td>Miniaturisation and forming micro-parts</td>
<td>MeMa</td>
</tr>
<tr>
<td>Viatkina, Ir. E.M.</td>
<td>(PhD 3)</td>
<td>Strain path effects and forming limits</td>
<td>CoMe</td>
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5.3 Micromechanics of Functional Devices

<table>
<thead>
<tr>
<th>Name</th>
<th>Source of Financing</th>
<th>Project Title</th>
<th>Research Theme EM</th>
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<tbody>
<tr>
<td>Erinç, M.Sc. M.</td>
<td>(PhD 2)</td>
<td>Solder joint fatigue</td>
<td>MeMa</td>
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<tr>
<td>Matin, Ir. M.A.</td>
<td>(PhD 2)</td>
<td>Experimental assessment of solder Joint reliability</td>
<td>MeMa</td>
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<tr>
<td>Ubachs, Ir. R.L.J.M.</td>
<td>(PhD 2)</td>
<td>Thermomechanical integrity of solder joints</td>
<td>MeMa/ CoMe</td>
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</table>

5.4 Multi-scale Mechanics, Damage and Fracture in Metals

<table>
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<th>Name</th>
<th>Source of Financing</th>
<th>Project Title</th>
<th>Research Theme EM</th>
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<tbody>
<tr>
<td>Engelen, Ir. R.A.B.</td>
<td>(PhD 3)</td>
<td>CDM-gradient plasticity</td>
<td>CoMe</td>
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<tr>
<td>Kasyanyuk, Ir. Y.</td>
<td>(PhD 3)</td>
<td>Fatigue damage in metals</td>
<td>CoMe/ MeMa</td>
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<tr>
<td>Mediavilla, Ir. J.</td>
<td>(PhD 3)</td>
<td>Ductile damage to fracture modelling</td>
<td>CoMe</td>
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5.5 Impact Protection and Injury Biomechanics

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<th>Name</th>
<th>Source of Financing</th>
<th>Project Title</th>
<th>Research Theme EM</th>
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<tbody>
<tr>
<td>Hrapko, Ir. M.</td>
<td>(PhD 1)</td>
<td>Determination of the mech. behaviour of brain tissue for impact conditions</td>
<td>MeMa</td>
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5.6 Biomechanics

<table>
<thead>
<tr>
<th>Name</th>
<th>Source of Financing</th>
<th>Project Title</th>
<th>Research Theme EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driessen, Ir. N.J.B.</td>
<td>(PhD 1)</td>
<td>Heart valve tissue differentiation</td>
<td>CoMe</td>
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<tr>
<td>Hendriks, Ir. F.M.</td>
<td>(PhD 3)</td>
<td>Mechanics of skin</td>
<td>MeMa</td>
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<tr>
<td>Peeters, Ir. E.A.G.</td>
<td>(PhD 1)</td>
<td>Cell-mechanics</td>
<td>MeMa</td>
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<tr>
<td>Roos, Ir. R.W.</td>
<td>(PhD 3)</td>
<td>Mechanics of hydrogels</td>
<td>MeMa</td>
</tr>
<tr>
<td>Schroeder, Dipl.Ing. Y.</td>
<td>(PhD 3)</td>
<td>Degeneration of the intervertebral disc</td>
<td>MeMa</td>
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</table>
6. Postdocs: name, country, project title, subprogramme, research theme EM and period of stay

<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
<th>Project Title</th>
<th>Subprogramme</th>
<th>Research Theme</th>
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<tr>
<td>Chen, Dr.Ir. S.</td>
<td>China</td>
<td>Micromechanics of TRIP steel</td>
<td>2.1</td>
<td>CoMe/MeMa</td>
</tr>
<tr>
<td>Bayley, Dr.C.</td>
<td>Canada</td>
<td>Micro-forming of metals, since 6-2004</td>
<td>2.1</td>
<td>CoMe/MeMa</td>
</tr>
</tbody>
</table>

7. Short description of subprogrammes related to research school EM

7.1 Structure-Property Relations and Constitutive Modelling
This subprogramme focuses on the mechanical behaviour of solids, with a particular emphasis on micromechanics, where the microstructural morphology is of major influence. Typical topics addressed are (poly-)crystalline structures, dislocation networks in metals, structured single crystal alloys (turbine blades), structured ceramics, complex structured polymer-metal geometries (flexible displays), (semi-)crystalline polymers with various inclusions. The ultimate goal is to arrive at a physically based constitutive description, which can be numerically implemented, enabling an accurate analysis of engineering products or product manufacturing processes.
Related to research themes “Computational Mechanics” and “Mechanics of Materials”.

7.2 Microscopic Aspects of Deformation
This subprogramme aims to provide a sound experimental basis for the computational efforts in the group, by trying to take into account a hierarchy of interacting length scales. Research topics are mainly concerned with the analysis of microscopic aspects of deformation and adhesion at interfaces (e.g. polymer-metal interfaces), multi-phase materials (e.g. micro-electronics solders), multi-layered structures (e.g. flexible displays), microsystems, etc.
Related to research themes “Computational Mechanics” and “Mechanics of Materials”.

7.3 Micromechanics of Functional Devices
This subprogramme focuses on the micromechanics of devices upon miniaturization. In miniaturized products, materials cannot be trivially considered as continua. Furthermore, boundary, surface and interface effects start to play a dominant role. Changes in deformation mechanisms and failure processes directly influence the lifetime of functional devices. Both numerical and experimental tools and techniques are being developed for the analysis of these phenomena and the influence on the performance of microsystems.
Related to research themes “Computational Mechanics” and “Mechanics of Materials”.

7.4 Multi-scale Mechanics, Damage and Fracture in Metals
This subprogramme focuses on mechanical failure as an important design criterion for metallic products and components. Both prevention and control of damage are thereby of relevance. The correct prediction of this ultimate behaviour offers many challenges, both numerically and experimentally. Non-standard continuum theories are required to deal with intense localization phenomena. The transition to discrete failure and the coupling with the underlying microstructure in a multi-scale setting is another goal pursued here.
Related to research themes “Computational Mechanics” and “Mechanics of Materials”.

7.5 Impact Protection and Injury Biomechanics for Automotive Safety
This subprogramme focuses on passive safety research for automotive applications, i.e. prevention of injuries caused by an accident. Important topics are:
- Smart vehicle structures and restraint systems
- Improvement of (impact)compatibility of different vehicles
• Use of light-weight materials
• Use of electronics in pre-crash sensing
• Characterisation of the mechanical behaviour of biological materials under impact conditions

Related to research theme “Mechanics of Materials”.

7.6 **Biomechanics**

Within the program Biomechanics and Tissue Engineering we apply principles from engineering mechanics and biology, to a variety of biomedical problems and devices. In particular, prevention, diagnosis and treatment of medical conditions and diseases of the cardio-vascular and the musculoskeletal systems are examined. Treatment may result in the engineering of living tissues and artificial implants, such as heart-valves, small diameter blood vessels, orthopaedic implants, and extracorporal systems and devices. These developments critically rely on the availability of various technologies, such as bioreactors and testing procedures, which are subjects of research. In all cases, numerical and experimental techniques offer powerful tools for biologically and clinically relevant research in these areas.

Three major themes can be discerned:
1. Soft Tissue Biomechanics & Engineering
2. Cardiovascular Biomechanics
3. Bone and Orthopaedic Biomechanics

Related to research themes “Mechanics of Materials” and “Structural Mechanics”.

8. **Refereed scientific publications**

8.1 **Refereed journals**


8.2 Books, chapters in book

8.3 Refereed proceedings

Boerboom, R.A. Peeters, ; E.A.G. ; Bouten, C.V.C. ; Baaijens, F.P.T., Mechanical properties of skeletal muscle cell nuclei, in Proceedings of the 14th European Society of Biomechanics (ESB) conference; 's Hertogenbosch, Netherlands, CD-rom, 2004

Driessen, N.J.B. ; Bouten, C.V.C. ; Baaijens, F.P.T., Mechanically induced collagen remodelling in cardiovascular tissues, in Proceedings of the 14th European Society of Biomechanics (ESB) conference; 's-Hertogenbosch, Netherlands, CD-rom, 2004


9. Dissertations related to research school EM: name, title, university, date and advisors

Name: Stijnen, J.M.A.
Title: Interaction between the mitral and aortic heart valve- an experimental and computational study
TU/e July 2004

Advisors: Prof.Dr.ir. F.N. van de Vosse
Prof.Dr.Ir. F.P.T. Baaijens
Dr.Ir. H.E.H. Meijer

Co-Advisor: Dr.Ir. P.H.M. Bovendeerd
Current position: Employee Hemolab

Name: Verver, M.M.
Title: Numerical Tools for Comfort Analyses of Automotive Seating
        TU/e 2004
Advisors: J.S.H.M. Wismans, F.P.T. Baaijens
Co-Advisor: Dr.Ir. C.W.J. Oomens
Current position: Employee TNO

10. Membership editorial boards international journals

Prof.Dr.Ir. F.P.T. Baaijens:
   • Advisory editor of Comp. Meth. Appl. & Eng.
   • Member editorial board Journal of Non-Newtonian Fluid Mechanics

Prof.dr.ir. M.G.D. Geers:
   • Editorial board International Journal for Multiscale Computational Engineering

11. Keynote lectures and seminars

   • M.G.D. Geers, L.P. Evers and W.A.M. Brekelmans, Strain gradient crystal plasticity in
    FCC microstructures, GAMM-seminar on microstructures, Stuttgart, January 9th -10th
    2004, invited lecture
   • M.G.D. Geers, L.P. Evers and W.A.M. Brekelmans, Multi-scale modelling of the crystal
    mechanics of FCC metals, Düsseldorf, March 16th 2004, invited lecture
   • M.G.D. Geers, W.A.M. Brekelmans, P.J.G. Scheurs and W.P. Vellinga, Structure-property
    modelling of the mechanics of materials across length scales, International conference on
    structure, processing and properties of materials, Dhaka, February 18th -20th 2004,
    keynote lecture

12. Membership international scientific committees

   Prof.Dr.Ir. M.G.D. Geers
   • Member CNRS Visiting Committee LASMIS, Université de Troye
   • Member of the Scientific Committee of Esaform
   • Member of the Technical Committee of EuroSime
   • Member of the Scientific Committee of SPPM2004

13. Awards and patents

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14. Overview of research input and output

14.1 Input “Materials Technology” related to EM, 2004

<table>
<thead>
<tr>
<th>Sources of financing¹</th>
<th>Total</th>
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</thead>
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<td>1</td>
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<tr>
<td>Senior academic staff</td>
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<td>Supporting staff</td>
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</tr>
<tr>
<td>PhD</td>
<td>4</td>
</tr>
<tr>
<td>Postdocs</td>
<td>-</td>
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<tr>
<td>Total</td>
<td>18</td>
</tr>
</tbody>
</table>

¹ Sources of financing: 1: University
2: STW, SON, NWO, Fom
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI etc.
² No research input involved for supporting staff
³ Research input per PhD per year: 0.8 fte

14.2 Output “Materials Technology” related to EM, 2004

<table>
<thead>
<tr>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tbody>
</table>

Scientific publications: refereed journals: 21
Scientific publications: books, chapters in book: 0
Scientific publications: refereed proceedings: 17
PhD theses: 2

* In co-operation with other EM-groups.

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

Project Title: Multiscale Methods in Computational Mechanics
Participating Groups: Engineering Mechanics (1) (TUD)
Structural Optimization and Computational Mechanics (TUD)
Materials Technology (TU/e)
Participants: Prof. Dr. Ir. R. de Borst (TUD), Prof. Dr. Ir. F. van Keulen (TUD), Dr. Ir. J.M.R.J. Huyghe (TU/e)

Project Title: NIMR-project MC1.03158, Strain path dependent materials models for forming and crash
Participating Groups: Applied Mechanics and Polymer Engineering (UT)
Materials Technology (TU/e)
Participants: Prof. Dr. Ir. J. Huëtink, Dr. Ir. A.H. van den Boogaard (UT), Prof. Dr. Ir. M.G.D. Geers, Dr. Ir. W.A.M. Brekelmans (TU/e)

Project Title: FOM-project 02EMM30, Tailoring of metastable steels
Participating Groups: Applied Mechanics (UT)
Materials Technology (TU/e)
Participants: Prof. Dr. Ir. J. Huëtink, Dr. Ir. A.H. van den Boogaard (UT), Prof. Dr. Ir. M.G.D. Geers, Dr. Ir. V.G. Kouznetsova (NIMR/TU/e)
4. RESEARCH DOCUMENTATION OF THE GROUP ANALYSIS SCIENTIFIC COMPUTING AND APPLICATIONS (CASA)

1. University/Department

Eindhoven University of Technology
Department of Mathematics and Computing Science

2. Subprogrammes related to research school EM

2.1 Scientific Computing
2.2 Applied Analysis

3. Group directors

Prof.Dr.Ir. J. de Graaf
Prof.Dr. R.M.M. Mattheij

4. Senior academic staff: name, position, research input in fte related to research school EM

Graaf, Prof.Dr.Ir. J. de Full Professor 0.2
Maten, Dr. E.J.W. ter UD, main position at Philips-Research 0.1
Mattheij, Prof.Dr. R.M.M. Full Professor 0.2
Maubach, Dr. J.M.L. UD 0.3
Morsche, Dr. H.G. ter UHD 0.2
Schilders, Prof.Dr. W.H.A. Part time Professor, main position at Philips-Research 0.1
Tijsseling, Dr.Ir. A.S. UD 0.1
Ven, Dr.Ir. A.A.F. van de UHD 0.3
Total fte: 1.5

5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1 Scientific Computing
Aa, Ir. N.P. van der (PhD 3) Field based parameter estimation for lithography CoMe
Allaart-Bruin, Drs. (PhD 3) Blowing of Glass CoMe
S.M.A.
Heres, Ir. P. (PhD 2) Codestar CoMe

1 Per 2004 the name of the previous EM-group “TU/e – Computational Science and Engineering” has been changed to “TU/e – Analysis Scientific Computing and Applications (CASA).
5.2 Applied Analysis

Dijkstra, Ir. W.  (PhD 1) Boundary Element methods  CoMe
Gramberg, Ir. H.J.J.  (PhD 1) Front instabilities in injection moulding of polymer melts  MeMa
Hagman, Ir. F.  (PhD 1) Biomechanical foot model for the kinetic analysis of locomotion  MeMa
Kraaij, Ir M.G.M.M. v. (PhD 3) Rigorous Coupled-Wave Analysis  CoMe
Kroot, Ir. J.M.B.  (PhD 3) Current distribution in a gradient coil. Simulation of eddy currents  MeMa
Patricio Dias, M.J.M., M. Sc.  (PhD2) Structural integrity  CoMe
Severens, Ir. I.E.M.  (PhD 3) Modelling of direct imaging processes in photo copiers  MeMa
Shcherbakov, E., MSc  (PhD 1/2) Model Reduction Techniques  CoMe
Verhoeven, Ir. A.  (PhD 3) Circuit Simulation  CoMe

6. Postdocs: name, country, project title, research theme EM and period of stay

<table>
<thead>
<tr>
<th>Name</th>
<th>Project Title</th>
<th>Research Theme</th>
<th>Period of Stay</th>
</tr>
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<tbody>
<tr>
<td>Giannopapa, Dr C.</td>
<td>Blowing of glass</td>
<td>2.1 CoMe</td>
<td></td>
</tr>
<tr>
<td>Kagan, Dr. P.,</td>
<td>Problems in glass industry</td>
<td>2.1 CoMe</td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbeek, Dr. M.,</td>
<td>Codestar</td>
<td>2.1 CoMe</td>
<td>August 2001 – August 2004</td>
</tr>
<tr>
<td>NL</td>
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</table>

7. Short description of subprogrammes related to research school EM

7.1 Scientific Computing
The main emphasis in this programme is on analysis and numerical simulation of problems arising in technology. Research is often induced by specific applications, yet being seen as part of a larger area where mathematical tools and in particular numerical methods can be applied. Hence both fundamental (numerical) research and applying the results to specific applications are typical for Scientific Computing. The following areas specify the actual research:

7.1.1 Glass Morphology
Analysis and simulation of the glass flow in (partially) confined areas, such as in mould for producing jars and bottles. Flows in a glass tank (oven). Investigating the heat transport by various phenomena, like diffusion and convection.
Co-operation in this research is with TNO-TPD ceramics and glass. The research is embedded in an EU project “MAGICAL”. Furthermore there exists cooperation with the departments of Mechanical Engineering and Chemistry (TU/e).
Related to research themes “Computational Mechanics” and “Mechanics of Materials”.

7.1.2 Ordinary Differential Equations and DAE
Problems that exhibit an evolutionary character will result in ODE after spatial discretisation. Moreover problems in control and mechanics often lead to such equations more directly. Quite often they are coupled with some (algebraic) constraint equations, resulting in DAE. Matters like stability and accuracy of numerical methods still provide for important questions. Co-operation exists with the TU/e-department of Mechanical Engineering.
Related to research theme “Computational Mechanics”.

7.1.3 Large Scale System Solving
In solving partial differential equations numerically, one encounters complex larger (non) linear systems which exhibit a sparsity structure. In order to be able to solve them one need special iterative solvers, like multigrid. In this area one can also often employ parallel architectures fruitfully. Co-operation exists with TNO-TPD and the TU/e-department of Computer Science. Related to research theme “Computational Mechanics”.

7.1.4 Modelling and Finite Element Applications
Although there exists a variety of FEM packages, it is often necessary to tailor methods for specific problems. Further development and improving them is a core activity. A particular aspect is the visualisation, which is increasingly important due to the ever increasing complexity of problems to be solved. Related to research theme “Computational Mechanics”.

7.1.5 Boundary Element Methods and Approximation
The research on BEM is concentrating on the quality of approximations of nonhomogeneous problems. In particular it is investigated how various basic approximation methods like radial basis functions lead to convergence and therefore efficient methods. Related to research theme “Computational Mechanics”.

7.1.6 Wave Analysis for lithography
Analysis of diffraction gratings that are used to determine the position of a wafer in a waferstepper. Numerical methods like RCWA (Rigorous Coupled-Wave Analysis) are investigated to solve these equations in a stable and accurate way. New software tools will be developed for sensors that have the improved RCWA algorithm incorporated. Related to research theme “Computational Mechanics”.

7.2 Applied Analysis
The main emphasis in this programme is on mathematical analysis of technological problems. Research is often fostered by specific application, after which it may trigger more fundamental, and thus more generally applicable research.

7.2.1 Mathematical Methods in Continuum Physics
- Slow viscous flow of polymeric melts: considered is the mathematical simulation of manufacturing processes for polymers such as extrusion and injection moulding. These processes are considered as slow viscous (Stokes-) flows. The polymeric melts are described as nonlinear thermoviscoelastic fluids. Analytical and numerical evaluation of the resulting system of partial differential equations is looked for. Special points of attention are:
  - Research to origins of instabilities/distortions occurring in these processes;
  - Modelling of boundary conditions (slip or stick);
  - Influences of thermal effects and pressure (compressibility);
  - Residual stresses and/or deformations in final products (e.g. compact discs);
  - Morphology of polymer mixtures; break-up of liquid threads.
- Biomechanical foot model: The development of a biomechanical foot model, which can be used in clinical gait analysis, to analyse foot motion during locomotion.
- Modelling of direct imaging processing in photocopiers: Description of the toner particles between drum and dip roller, including collision, friction, and electromagnetic forces. Modelling of the toner as a granular medium or as a conglomerate of many rigid particles. Numerical simulation on basis of discrete element analysis.
- Analysis and numerical simulation of electromagnetic systems for design of antennas and gradient coils in MRI-scanners.

7.2.2 Fundamental Analysis of (Non-Linear) Evolution Problems
Our research in functional analysis is concentrated on evolution equations. An inspiring source of inspiration are non-linear evolution equations arising from free boundary value problems in quasi-stationary fluid dynamics (Stokes flow, Hele-Shaw flow, polymer flow).

7.2.3 Mathematical Methods for Impacting Oscillators
In this subprogramme the dynamics of oscillating systems with impacts is studied. These systems show universal bifurcation behaviour, such as ‘period-adding’ bifurcations. Applications of the theory are found in atomic force microscopy, an experimental method to scan the detailed structure of surfaces from interactions between the surface and an oscillating probe.

7.2.4 Industrial Mathematics
Problems and questions from industry.

All subprogrammes within 7.2 are related to research theme “Mechanics of Materials”.

8. Refereed scientific publications related to research school EM

8.1 Refereed journals


8.2 Books, chapters in books

8.3 Refereed proceedings


9. Dissertations: related to research school EM: name, title, university, date and advisors

Name: D.J. Bekers
Title: Finite antenna arrays: An eigencurrent approach drilling,
Technische Universiteit Eindhoven, 4-11-2004
Advisors: A.G. Tijhuis, C.J. van Duijn, S.J.L. van Eijndhoven
Current position: TNO-defense, Den Haag

Name: A.Y. Gunawan
Title: Stability of immersed liquid threads,
Technische Universiteit Eindhoven, 21-1-2004
Advisors: J. Molenaar, C.J. van Duijn, A.A.F. v.d. Ven
Current position: Institut Teknologi Bandung, Indonesia

Name: B. Tasic
Title: Numerical methods for solving ODE flow,
Advisors: R.M.M. Mattheij, M. Hermann
Current Position: Philips research lab (researcher)

Name: J.C.J. Verhoeven
Title: Modelling laser percussion drilling,
Technische Universiteit Eindhoven, 4-11-2004.
Advisors: R.M.M. Mattheij, M. Rumpf
Current Position: Be-Value (advisor)

10. Membership editorial boards international journals

Prof.Dr. R.M.M. Mattheij:
- Associate editor SIAM News
- Associate editor Surveys on Mathematics for Industry
- Associate editor Electronic Journal of Boundary Elements
- Editor Boundary Element Technology
- Editor International Journal of Nonlinear Modelling in Sciences and Engineering
- Editor Springer series on Mathematics for Industry

Prof.Dr. W.H.A. Schilders:
- Editor of COMPEL, the international journal for computation and mathematics in electrical and electronic engineering
- Editor of special volume Numerical Methods in Electromagnetics in series Handbook of Numerical Analysis (Elsevier)

Dr.Ir. A.A.F. van de Ven:
- Editor International Journal of Applied Electromagnetics and Mechanics
- Editor Journal of Engineering Mathematics

11. Keynote lectures and seminars

Ir. J.M.B. Kroot:
• Seminar Technische Universität Darmstadt: Analysis of eddy currents in a gradient coil, March 3, 2004, Darmstadt, Germany.

Prof. Dr. R.M.M. Mattheij:
• Mathematics of Glass, Summerschool Mathematical Modelling, ICTP, Trieste, March 8, 2004
• Numerical Laboratory for a Robot system, WIAS, Berlin, September 27, 2004
• Industrial Mathematics at Eindhoven, ITWM, Kaiserslautern, September 30, 2004

12. Membership international scientific committees

Prof. Dr. R.M.M. Mattheij:
• Chairman of the organising committee of ECMI2004
• Co-ordinator, chairman of the board of MASCI-net: Mathematics, Simulation and Computing for Industry
• Member Scientific Committee BeTeq 2004

Dr. ir. A.A.F. v.d. Ven:
• CAIM 2004, The 12th Conference on Applied and Industrial Mathematics
• TRECOP 2004, International Symposium on Trends in Continuum Physics

13. Awards and patents

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14. Overview of research input and output

14.1 Input “Computational Science and Engineering” related to EM, 2004

<table>
<thead>
<tr>
<th>Sources of financing¹</th>
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<td>Supporting staff</td>
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<tr>
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<tr>
<td>Postdocs</td>
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<td>Total</td>
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¹ Sources of financing: 1: University
2: STW, SON, NWO, FOM
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI, etc.

² No research input involved for supporting staff.
³ Research input per PhD per year: 0.8 fte
14.2 Output “Computational Science and Engineering” related to EM, 2004

<table>
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<td>Scientific publications: books, chapters in book</td>
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<tr>
<td>Scientific publications: refereed proceedings</td>
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<tr>
<td>PhD theses</td>
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</table>

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

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5. RESEARCH DOCUMENTATION OF THE GROUP ENGINEERING MECHANICS (1)

1. University/Department

Delft University of Technology
Department of Aerospace Engineering

2. Subprogrammes related to research school EM

2.1 Composite Materials
2.2 Advanced Computational Procedures
2.3 Fluid-Structure Interaction
2.4 Active Materials

3. Group director

Prof. Dr. Ir. R. de Borst

4. Senior academic staff: name, position, research input in fte related to research school EM

Borst, Prof. Dr. Ir. R. de full Professor, Director Research School EM 0.5
Brummelen, Dr. Ir. E.H. van UD 0.8
Gutiérrez, Dr. Ir. M.A. UHD 0.4
Hulshoff, Dr. S.J. UD 0.3
Suiker, Dr. Ir. A.S.J. UD 0.5
Tijssens, Dr. Ir. M.G.A. UD 0.4
Turteltaub, Dr. S.R. UHD 0.5

Total fte: 3.4

5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

Akkerman, Ir. I. (PhD 2) Multiscale adaptive methods for LES computations CoMe
Chung, Ir. D.B. (PhD 1) Reliability of fibre-metal laminate structures CoMe
Cid Alfaro, M.V. (PhD 2) Multiscale models for GLARE MeMa
Hagenbeek, Ir. M. (PhD 1) Thermal and off-axis behaviour of GLARE MeMa
Lopez de la Cruz, Ir. J. (PhD 2) Modelling of corrosion CoMe
Michler, Dipl.-Ing. C. (PhD 2) Fluid-structure interaction for low-speed flows CoMe
Munts, Ir. E.A. (PhD 2) Fluid-structure interactions using multiscale LES techniques CoMe
Nawijn, Ir. M. (PhD 2) Meshless methods in design processes CoMe
Remmers, Ir. J.J.C. (PhD 1) Delamination buckling MeMa
Shi, MSc Y. (PhD 1) Solid-state phase transformations MeMa

Annual Report Engineering Mechanics 2004 5.1
6. **Postdocs: name, country, project title, research theme EM and period of stay**

Matsuda, Dr. A.; Japan  
Computational models for shock-absorbing materials, January – July 2004  2.2 MeMa

Chamoret, Dr D.; France  
Computational modelling of phase transformations, January-February 2004  2.2 CoMe

Stan, Dr. F. Romania  
Discontinuous Galerkin Methods for Fracture, April-June, October-December 2004  2.2 CoMe

7. **Short description of subprogrammes related to research school EM**

7.1 **Composite Materials**
Research within the group is primarily directed to developing damage-based models for predicting delamination and matrix-cracking, particularly for fibre-metal laminates such as Glare. These are being applied to the prediction of fatigue durability and thermal behaviour, as well as the analysis of crack stoppers, splices and combined buckling/delamination phenomena. Secondly, the development of robust numerical techniques to optimise composite materials is an area of active research. Advanced methods drawn from optimal control and topology optimisation are investigated to design functionally graded composites.  
Related to the research theme "Mechanics of Materials"

7.2 **Advanced Computational Procedures**
This sub-programme relates to the development of computational models for the simulation of the behaviour of materials and structures. For this purpose accurate and robust models are made for the temporal and spatial discretization and algorithms are constructed for the efficient, accurate and robust solution of the ensuing non-linear algebraic equations. As such it provides basic tools that are utilized in structural engineering research.  
Related to the research theme "Computational Mechanics"

7.3 **Fluid-structure interaction**
The interaction of thin structures and (air) flows is becoming increasingly important. On one hand do composite materials offer the possibility to design wings and rotor blades with specific deformation capacities. On the other hand do contemporary numerical techniques and hardware configurations offer the possibility to analyse the behaviour of such thin composite structures in transient, three-dimensional flows, including full interaction between fluid and structure. It is the aim of this programme to develop such an integrated code, including the development of proper numerical methodologies for the various length and time scales that play a role in this problem. Related to the research theme "Computational Mechanics"

7.4 **Active Materials**
The research of the group in this area is focused on (i) a better understanding of the underlying physics through atomistic modelling and, from this, the development of better continuum theories and (ii) the numerical simulation of phase transformations and the development of efficient numerical techniques to generate the microstructures.  
Related to the research themes "Mechanics of Materials" and "Computational Mechanics".
8. Refereed scientific publications related to research school EM

8.1 Refereed journals

Borst, R. de; Gutiérrez De La Merced, M. A.; Wells, G.N.; Remmers, J.J.C.; Askes, H.: Cohesive-zone models, higher order continuum theories and reliability methods for computational failure analysis. International journal for numerical methods in engineering 60 (1), 2004 pp 289-316 (in co-operation with the group "Computational Mechanics, Structural Mechanics and Dynamics" (TUD)).


8.2 Books, chapters in book


8.3 Refereed proceedings


Borst, R. de; Abellan, M.-A.: Crack models for concrete with a view to durability. In F Stangenberg, OT Bruhns,


Suiker, A S J, and Fleck, N A. Micro-macro behaviour of granular materials. In (Ed.),Symposium on Instabilities across the Scales. 14017 september 2004, Cairns, Australia,


9. Dissertation: related to research school EM: name, title, university, date and advisors

| Name:        | Kononov, A.                          |
| Title:       | Foundations of acoustic methods used in non-destructive inspection of laminated materials, TUD, 13-01-2004 |
| Advisors:    | Prof.dr.ir. R. de Borst               |
| Current position: | Research fellow TUD                  |

10. Membership editorial boards international journals

Prof.Dr.Ir. R. de Borst:
- Editor-in-Chief “International Journal for Numerical and Analytical Methods in Geomechanics”
- Editor-in-Chief "Encyclopedia of Computational Mechanics"
- Associate Editor “International Journal for Numerical Methods in Engineering”
- Member Editorial Board “Archive of Applied Mechanics (Ingenieur-Archiv)”
- Member Editorial Board “European Journal of Mechanics / A: Solids”
- Member Editorial Board “Structural Engineering and Mechanics”
- Member Editorial Board “Engineering Computations: An International Journal”
- Member Editorial Board “International Journal of Multiscale Computational Engineering”
- Member Editorial Board “Computer Modelling in Engineering & Sciences”
• Member Editorial Board "Journal of Computational Methods in Applied Sciences and Engineering"
• Member Editorial Board "Computer Methods in Applied Mechanics and Engineering"
• Member Editorial Board "Communications in Numerical Methods in Engineering"
• Member Editorial Board “Revue Française de Génie Civil”

11. **Keynote lectures and seminars**

Prof. Dr. Ir. R. de Borst:

12. **Membership international scientific committees**

Prof. Dr. Ir. R. de Borst:
- Fifth International Conference on Fracture Mechanics of Concrete and Concrete Structures, Vail, Colorado, 12-16 April, 2004
- Second International Conference on Structural Engineering, Mechanics and Computation, Cape Town, 5-7 July, 2004
- ECCOMAS Congress on Computational Methods in Engineering and Applied Sciences, Jyvaskyla, 24-28 July, 2004
- Sixth World Congress on Computational Mechanics, Beijing, 5-10 September, 2004
- Third International Conference on Advances in Structural Engineering and Mechanics, Seoul, 2-4 September, 2004
- Seventh International Conference on Computational Structures Technology, Lisbon, 7-9 September, 2004

13. **Awards and patents**

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14. Overview of research input and output

14.1 Input “Engineering Mechanics (1)” related to EM, 2004

<table>
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<td>Postdocs</td>
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1 Sources of financing: 1: University 2: STW, SON, NWO, FOM 3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI etc.
2 No research input involved for supporting staff.
3 Research input per PhD per year: 0.8 fte

14.2 Output “Engineering Mechanics (1)” related to EM, 2004

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<tr>
<th>Total</th>
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<tr>
<td>Scientific publications: refereed journals</td>
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<td>Scientific publications: books, chapters in book</td>
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<tr>
<td>Scientific publications: refereed proceedings</td>
</tr>
<tr>
<td>PhD theses</td>
</tr>
</tbody>
</table>

* In co-operation with other EM-groups.

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

Project Title: Multiscale Methods in Computational Mechanics
Participants: Prof.Dr.Ir. R. de Borst (TUD), Prof.Dr.Ir. F. van Keulen (TUD), Dr.Ir. J.M.R.J. Huyghe (TU/e)
6. RESEARCH DOCUMENTATION OF THE GROUP AEROSPACE STRUCTURES (AeS)

1. University/Department

Delft University of Technology
Faculty of Aerospace Engineering

2. Subprogrammes related to research school EM

2.1 Structural Tailoring, and Design and Optimization
2.2 Stability and Vibrations of Imperfect Composite Shells

3. Group director

Prof.Dr. Z. Gürdal

4. Senior academic staff: name, position, research input in fte related to research school EM

Arbocz, Prof.Dr. J. Professor Emeritus 0.3
Gürdal, Prof.Dr. Z. Professor 0.1
Hol, Ir. J.M.A.M. UD 0.1
Jansen, Dr.Ir. E.L. UD 0.6
Vries, Ir. J. de UD 0.3
Total fte: 1.4

5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1 Structural Tailoring, and Design and Optimization
Vervenne, Ir. K. (PhD 1) ADOPT - Sequential Approximate Design Optimization StMe

5.2 Stability and Vibrations of Imperfect Composite Shells
Tiso, M.Sc. P. (PhD 1) Nonlinear dynamic buckling of shells StMe/CoMe
6. **Postdocs: name, country, project title, subprogramme, research theme EM and period of stay**

- **Goldfeld, Dr. Y.; Israel**
  - Buckling of composite shells with variable thickness and fiber density,
  - November 2002 – October 2004
- **Dzyuba, Dr. V.V.; Ukraine**
  - Interaction between the cylindrical shells with the spherical inclusions in a flowing ideal liquid,
  - August 2004 – October 2004
- **Abdalla, Dr. M.M.; Egypt**
  - Applications of the Cellular Automata Paradigm in Structural Analysis and Design,
  - October 2004 – October 2005

7. **Short description of subprogrammes related to research school EM**

7.1 **Structural Tailoring, and Design and Optimization**

New demands of structural integrity, durability, low weight and minimum cost pose an unprecedented challenge to the structural designer. New materials may assist in satisfying some of these demands, but at the same time give rise to significant new problems for the designer. Furthermore the design of the structure can no longer be seen as an isolated activity, but must play its part in a multi-disciplinary approach to the design of the aircraft or spacecraft as a whole. The traditional approach to design is no longer adequate unless it can be supplemented by a numerical, computer-based approach in which the trade-off between conflicting design requirements can be quantified, and many more alternatives evaluated. Optimization plays an important role here, by providing a tool to identify the active design constraints and to steer the design towards some required goal such as minimum weight or cost - a process sometimes termed structural synthesis and sometimes computer-aided design.

The subprogramme includes the following topics:

- Development of design and optimisation procedures for specific structural design problems;
- Theoretical optimisation including multi-level procedures and optimisation of structural shape and layout;
- Tailoring of advanced fibre reinforced composite structures;
- Design and optimisation of actively sensed and actuated structures.

Related to the research theme Structural Mechanics.

7.2 **Stability and Vibrations of Imperfect Composite Shells**

In modern designs, which are often obtained by use of one of the structural optimization codes and which may be of new high strength materials (read advanced composites), it frequently happens that stability behavior dictates the choice of some of the critical dimensions of the structure. This implies the need to investigate the different loading cases quite accurately by carrying out extensive numerical calculation and/or experimental verification.

The central goal of the shell research being carried out is the development of Improved Shell Design Criteria, incorporating all the theoretical knowledge accumulated in the last, say, 25 years through intensive research in the aerospace, the nuclear and the offshore field, and making efficient use of the currently available interactive and (super-) computing facilities.

It has been demonstrated in the past that reliable buckling loads predictions for imperfection sensitive structures depend mainly on the availability of a sufficiently detailed...
statistical sample of the expected initial imperfections and on the appropriate choice of the nonlinear model used for the buckling load calculations. The latter, in turn, requires considerable knowledge by the user of the physical behavior of imperfect shell structures. The analogy between buckling and vibration has stimulated the use of vibration tests to obtain information that is important to assess the buckling behavior, like the so-called vibration correlation technique. Moreover, in certain stability problems inertia plays an essential role. Part of the ongoing shell research is therefore concerned with the vibration behavior and dynamic stability behavior of shells.

The subprogramme includes the following topics:

- Theoretical, numerical, and experimental studies of the collapse behavior and nonlinear vibration behavior of imperfect composite shells under combined loading;
- Development of an International Imperfection Data Bank and DISDECO (Delft Interactive Shell DEsign COde);
- Development of efficient semi-analytical and Finite Element based tools (reduced-basis methods) for the nonlinear static and dynamic analysis of slender and thin-walled structures.

Related to the research themes Computational Mechanics and Structural Mechanics.

8. Refereed scientific publications related to research school EM

8.1 Refereed journals


8.2 **Books, chapters in book**


8.3 **Refereed proceedings**


9. Dissertations related to research school EM: name, title, university, date and advisors

   Name: M.M. Abdalla
   Title: Applications of the Cellular Automata, Paradigm in Structural Analysis and Design; Delft University Press; Delft University of Technology 13-12-2004
   Advisors: Prof.Dr. Z. Gürdal

10. Membership editorial boards international journals

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11. Keynote lectures and seminars

   Gürdal, Z.:

12. Membership international scientific committees

   Gürdal, Z.:
   • IASTED – International Association of Science and Technology for Development, Modelling, Simulation, and Optimization Conference, August 16-18, 2004.

13. Awards and patents

   -----
14. Overview of research input and output

14.1 Input Aerospace Structures and Computational Mechanics related to EM, 2004

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<td>Supporting staff</td>
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<td>Postdocs</td>
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1 Sources of financing: 1: University 2: STW, SON, NWO, Fom 3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI etc.

2 Research input for PhD per year: 0.8 fte

14.2 Output Aerospace Structures and Computational Mechanics related to EM, 2004

<table>
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<tr>
<th>Total</th>
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<td>Scientific publications: refereed journals</td>
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<td>Scientific publications: books, chapters in book</td>
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<tr>
<td>Scientific publications: refereed proceedings</td>
</tr>
<tr>
<td>PhD theses</td>
</tr>
</tbody>
</table>

* In co-operation with other EM-groups

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte.

Project Title: ADOPT: Sequential Approximate Design Optimization including uncertainties, discontinuities and discrete design variables.

Participating Groups: Systems, Dynamics and Control (TU/e) Structural Optimization and Computational Mechanics (TUD) Aerospace Structures (TUD)

Participants: Dr.Ir. L.F.P. Etman (TU/e), Ir. S.P. Gurav (TUD), Ir. J.H. Jacobs (TU/e), Prof.Dr.Ir. F. van Keulen (TUD), Dr. J.J.M. Rijpkema (TU/e), Ir. R.A. van Rooij (TU/e), Dr.Ir. A.J.G. Schoofs (TU/e), Ir. K. Vervenne (TUD).

Research Input in fte: 2.4
7. RESEARCH DOCUMENTATION OF THE STRUCTURAL OPTIMIZATION AND COMPUTATIONAL MECHANICS GROUP

1. University/Department

Delft University of Technology
Faculty of Mechanical, Maritime and Materials Engineering

2. Subprogrammes related to research school EM

2.1 Structural Optimization and Computational Mechanics

3. Group director

Prof. Dr. Ir. F. van Keulen

4. Senior academic staff: name, position, research input in fte related to research school EM

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>UD/FTE</th>
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<tbody>
<tr>
<td>Booij, M.Sc. J.</td>
<td>UD</td>
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<tr>
<td>Goosen, Dr.Ir. J.F.L.</td>
<td>UD</td>
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<tr>
<td>Keulen, Prof. Dr. Ir. F. van</td>
<td>Full Professor</td>
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<tr>
<td>Linden, Dr. Ir. J.C. van der</td>
<td>UD</td>
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</tr>
<tr>
<td>Rijn, Dr. C.J.M. van der</td>
<td>Associate Researcher</td>
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Total fte: 1.0

5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

<table>
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<tr>
<th>Name</th>
<th>Source of Financing</th>
<th>Title</th>
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<tr>
<td>Andreykiv, Ir. A.</td>
<td>StMe</td>
<td>Development of improved endoprostheses for the upper extremities</td>
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<tr>
<td>Broomans, Ir. P.</td>
<td>CoMe</td>
<td>3D Numerical simulation of bone ingrowth for glenoid component design of shoulder prostheses</td>
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</tr>
<tr>
<td>Cerulli, Ir. C.</td>
<td>CoMe</td>
<td>Support of the software development process concerning structure in the context of the Aviator research project</td>
<td></td>
</tr>
<tr>
<td>Gurav, Ir. S.P.</td>
<td>CoMe</td>
<td>Sequential Approximate Design Optimization including Uncertainties, Discontinuities and Discrete Design Variables</td>
<td></td>
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<tr>
<td>Langelaar, Ir. M.</td>
<td>StMe</td>
<td>Development and design of Micro-Electrical Mechanical Systems</td>
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</tr>
<tr>
<td>Lau, Ir. G.</td>
<td>StMe</td>
<td>Electrostatic actuators with embedded sensing</td>
<td></td>
</tr>
</tbody>
</table>
6. Postdocs: name, country, project title, subprogramme, research theme EM and period of stay

Fatemi, Dr. J.; NL Development of improved endoprostheses for the upper extremities, 2000-2004

7. Short description of subprogrammes related to research school EM

7.1 Structural Optimization and Computational Mechanics

Analytical modelling is only possible for a very limited number of structures or parts of structures. With the development of high-performance computer facilities, however, an increasing number of mechanical problems can be modelled and analysed numerically. The finite element method is the method that is often made use of in these cases. Analysis on the basis of numerical techniques is complicated by nonlinearities, caused by material behaviour, geometric effects, contact and/or friction. Moreover, multidisciplinary interaction may be important. This is especially the case for Micro-Electrical-Mechanical Systems (MEMS) and biomedical applications. Because of these aspects, the analysis of practical problems takes a tremendous effort. Therefore, further development of efficient, multidisciplinary numerical modelling techniques is required. These techniques should be tailored for high-performance computer architectures. The aim is to develop such techniques using approaches that strengthen and exploit the fundamentals of engineering mechanics.

Once numerical techniques are incorporated in a design process, for which often many intermediate designs and corresponding design sensitivities must be evaluated, the efficiency requirements are even more demanding. This holds for a design process in which intermediate designs are evaluated “manually”, but becomes more important for (partially) automated optimization processes. Improvement of structural optimization techniques cannot be achieved independently from new developments in Computational Mechanics. Only a close integration of structural optimization techniques and numerical analysis strategies can yield the most efficient design tools.

Within this theme, the fundamentals for modelling, analysis, design sensitivities and optimization of structures will be developed. The focus will be on the multidisciplinary links between these aspects. Furthermore, new developments will be made available for day-to-day practice. For this purpose we are collaborating with more application-oriented groups and companies.

Related to the research themes “Computational Mechanics” and “Structural Mechanics”.

8. Refereed scientific publications related to research school EM

8.1 Refereed journals


Keulen, F. van, K. Vervenne: Gradient-enhanced response surface building. Structural Multidisciplinary Optimization 27, pp 337-351, 2004 (in co-operation with the group "Aerospace Structures" (TUD)).


8.2 Books, chapters in book


8.3 Refereed proceedings


9. Dissertations related to research school EM: name, title, university, date and supervisors

10. Membership editorial boards international journals

Prof.Dr.Ir. A. van Keulen:
- Book review editor for Structural and Multidisciplinary Optimization

11. Keynote lectures and seminars

12. Membership International Scientific Committees

Prof.Dr.Ir. A. van Keulen:
- European Chair, 10th AIAA/ISSMO Multidisciplinary Optimization and Analysis Conference, August 30-September 1, 2004, Albany, New York.

13. Awards and patents
14. Overview of research input and output

14.1 Input “Structural Optimization and Computational Mechanics” related to EM, 2004

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1 Sources of financing: 1: University
2: STW, SON, NWO, FOM
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI etc.

2 Research input per PhD per year: 0.8 fte

14.2 Output “Structural Optimization and Computational Mechanics” related to EM, 2004

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<td>Scientific publications: refereed proceedings 8+1*</td>
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<td>PhD theses -</td>
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* In co-operation with other EM-groups

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

Project Title: ADOPT: Sequential Approximate Design Optimization including uncertainties, discontinuities and discrete design variables.
Participating Groups: Systems, Dynamics and Control (TU/e) Structural Optimization and Computational Mechanics (TUD) Aerospace Structures and Computational Mechanics (TUD)
Participants: Dr.Ir. L.F.P. Etman (TU/e), Ir. S.P. Gurav (TUD), Ir. J.H. Jacobs (TU/e), Prof.Dr.Ir. A. van Keulen (TUD), Dr. J.J.M. Rijpkema (TU/e), Ir. R.A. van Rooij (TU/e), Dr.Ir. A.J.G. Schoofs (TU/e), Ir. K. Vervenne (TUD).
Research Input in fte: 2.4

Project Title: Multiscale Methods in Computational Mechanics
Participants: Prof.Dr.Ir. R. de Borst (TUD), Prof.Dr.Ir. F. van Keulen (TUD), Dr.Ir. J.M.R.J. Huyghe (TU/e)
8. **RESEARCH DOCUMENTATION OF THE GROUP ENGINEERING MECHANICS (2)**

1. **University/Department**

   Delft University of Technology  
   Faculty of Mechanical, Maritime and Materials Engineering  
   Department of Mechanics and Control

2. **Subprogrammes related to research school EM**

   2.1 *Mechanics of Materials*
   2.2 *Dynamic Behaviour of Mechanical Systems*

3. **Group director**

   Prof. Dr. Ir. L. J. Ernst

4. **Senior academic staff: name, position, research input in fte related to research school EM.**

<table>
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<td>Jansen, Dr.Ir. K.M.B.</td>
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<td>Rixen, Prof.Dr.Ir. D.J.</td>
<td>Full Professor</td>
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<tr>
<td>Schwab, Dr.Ir. A.L.</td>
<td>UD</td>
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<td></td>
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<tr>
<td>Woerkom, Dr.Ir. P.Th.L.M. van</td>
<td>UHD</td>
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   Total fte: 2.2

5. **PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM**

5.1 *Mechanics of Materials*

<table>
<thead>
<tr>
<th>Name</th>
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<th>Project Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hof, Ir. C. van 't</td>
<td>MeMa</td>
<td>Process dependent packaging polymer characterization: development of a constitutive model</td>
</tr>
<tr>
<td>Leenders, Ir. W.S.</td>
<td>MeMa/ StMe</td>
<td>Usage of glass fiber reinforced plastics in load carrying structures in conventional ships</td>
</tr>
<tr>
<td>Yang, Ir. D.</td>
<td>MeMa/ StMe</td>
<td>Process dependent packaging polymer characterization: study of (micro-) damage, initiated during the curin process</td>
</tr>
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</table>
5.2 Dynamic Behaviour of Mechanical Systems

Conza, Ir. N. (PhD 2) Doppler Imaging of Vibration System for detection of musculoskeletal disorders StDy

Fransen, Ir. S.H.J.A. (PhD 3) Dynamics Substructuring Techniques for Stress Prediction in Launchers StDy

Mohanty, P. (PhD 1) Experimental Identification of Non-Linear Dynamical Systems StDy

De Kraker, A (PhD 2) Shape optimization under condition of partial hydro elastic lubrication StDy

6. Postdocs: name, country, project title, subprogramme, research theme EM and period of stay

7. Short description of subprogrammes related to research school EM

7.1. Mechanics of Materials

Demands on functionality and reliability of mechanical products, processes and systems and the needs for continuing improvement of product and process quality are of major concern for the worldwide industry. Traditional experience based design approaches, i.e. trial & error methods (designing, production and testing of a multiplicity of prototypes) can no longer be considered as competitive. Therefore, there is an urgent need to develop innovative design methods. As one of the promising alternatives for the traditional design method, virtual (= simulation-based) prototyping is beginning to draw attention from both industries and the academic world.

Adequate virtual prototyping involves a variety of aspects such as mathematical modeling, numerical simulation, functionality and reliability judgement, appropriate optimization tools and adequate experimental verification techniques. Presently, various modeling, simulation and optimization abilities have become available through continuing research and developments in physics, mathematics and engineering. Extension and improvement of these abilities and understanding of the underlying physics have been subject of research and development of many Engineering Mechanics programs. By virtue of the continuing developments in microelectronics and consequently continuing improvement of computational capabilities, an increasing number of mechanical problems can now be modeled and analyzed numerically. Therefore application of virtual prototyping is becoming an increasingly realistic possibility for future design of mechanical products, processes and systems.

One of the important building blocks in the process of virtual prototyping concerns "reliable and efficient (mostly FEM-based) mechanical modeling". Within this building block some bottlenecks (or challenges) are presently remaining, while new ones are emerging, despite the tremendous research effort worldwide. Those bottlenecks are mainly driven by the increasing demands on product complexity (application of new
complex materials, continuing miniaturization, function integration), reliability and short-time-to-market demands. Examples of identified bottlenecks are:

- Characterization and modeling methodologies for process- and geometric dependent material properties for various materials.
- Damage (and damage evolution) modeling (models & criteria) for various materials.
- Reliable experimental techniques for (material-) model parameter identification.
- Reliable experimental methods for FEM-model verification.

The orientation of the recent (and near future) “Mechanics of Materials” research projects is mainly directed to the elimination of the above bottlenecks and thus to improvement of the “virtual prototyping” chain. The necessary research requires combined experimental and numerical mechanics methods. The understanding and subsequent modeling of materials behavior requires the study and description of physical phenomena, ranging from macro- to micro scales.

Two areas of industrial interest and application have been chosen as carriers for the present and future research projects: “Fiber reinforced plastics and flexible fiber systems” and “Micro electronic components and mechanical systems”.

Related to the research themes “Mechanics of Materials” and “Structural Mechanics”.

7.2. Dynamic Behaviour of Mechanical Systems

Tremendous advances have been achieved during the last two decades in the field of mechanical engineering thanks to innovation in materials, production techniques and analysis tools. New designs are better optimized leading to better designs. In that context, predicting and controlling the dynamical behavior of systems has become more important than ever before. Structures have become lighter and therefore more flexible. Thus predicting their dynamic performance with accuracy is crucial (e.g. response of constructions to surrounding perturbations, positioning of flexible manipulators, dynamic load analysis on machines, ...). Also the advent of new materials such as piezoelectric ceramics and the development of novel mechanical structures such as Micro-Electro-Mechanical systems (MEMS) require modern dynamic analysis to take into account the coupling between different physical fields, treated separately in earlier days. Tackling multi-physical problems and analyzing fully coupled systems (thermal, acoustic, electric, fluid and structural for instance) is one of the essential challenges underlying the development of new analysis tools and innovative design approaches in mechanical dynamics.

The objective of the research work in the Engineering Dynamics group is on one hand to develop numerical tools that allow analysis of complex systems, and on the other hand to improve the understanding of dynamical behavior (e.g. vibration analysis and measurement, stability prediction). The research is centered on the development of novel numerical methods and advanced algorithms for efficient computing and testing. Specifically, the section has a strong background in multi-body dynamics, in vibration analysis, substructuring methods, parallel algorithms, and in non-linear stability and bifurcation studies.

Related to the research themes “Computational Mechanics” and “Structural Dynamics and Control”.

8. Refereed scientific publications related to research school EM.

8.1 Refereed journals


Driel, WD van, Liu, C, Zhang, GQ, Janssen, JHJ, Silfhout, RBR van, Gils, MAJ van, and Ernst, LJ. Prediction

Fransen, SHJA. Data recovery methodologies for reduced dynamic substructure models with internal loads. AIAA journal 42 (10), 2130-2142, 2004.


8.2 Books, chapters in book


8.3 Refereed proceedings

Bressers, HJL, Driel, WD van, Jansen, KMB, Ernst, LJ, and Zhang, GQ. From chemical building blocks of polymers to microelectronics reliability. In LJ Ernst, GQ Zhang, P Rodgers and O de Saint Leger (Eds.), EuroSimE 2004: 5th international conference on thermal and mechanical simulation and experiments in microelectronics and microsystems (pp. 621-625), 2004.


Driel, WD van, Jansen, JHJ, Silfhout, RBR van, Gils, MAJ van, Zhang, GQ, and Ernst, LJ. On wire failures in micro-electronic packages. In LJ Ernst, GQ Zhang, P Rodgers and O de Saint Leger (Eds.), EuroSimE 2004: 5th international conference on thermal and mechanical simulation and experiments in microelectronics and microsystems (pp. 53-57), 2004.

Driel, WD van, Zhang, GQ, Vries, JWC de, Jansen, M, and Ernst, LJ. Virtual prototyping and qualification of Board Level Assembly. In KC Toh, YC Mui, J How and JHL Pang (Eds.), EPTC 2004: 6th electronic packaging technology Conference (pp. 772-775), 2004.


Gonda, V, Jansen, KMB, Ernst, LJ, Toonder, J den, and Zhang, GQ. Mechanical characterization of SiLK by Nanoindentation and substrate curvature techniques. In LJ Ernst, GQ Zhang, P Rodgers and O de Saint Leger (Eds.), EuroSimE 2004: 5th international conference on thermal and mechanical simulation and experiments in microelectronics and microsystems (pp. 373-376), 2004.


Silfhout, RBR van, Driel, WD van, Li, Y., Gils, MAJ van, Jansen, JHZ, Zhang, GQ, Tao, G, Bisschop, J, and Ernst, LJ. Effect of metal layout design on passivation crack occurrence using both experimental and simulation techniques. In LJ Ernst, GQ Zhang, P Rodgers and O de Saint Leger (Eds.), EuroSimE 2004: 5th international conference on thermal and mechanical simulation and experiments in microelectronics and microsystems (pp. 69-74), 2004.

Yang, D, Ernst, LJ, Jansen, KMB, Hof, C van t, Zhang, GQ Driel, WD van, and Bressers, HJL. Fully cure-dependent polymer modeling and application to QFN-packages warpage. In KC Toh, YC Mui, J How and JHL Pang (Eds.), EPTC 2004: 6th electronic packaging technology Conference (pp. 87-91), 2004.

Yang, D, Jansen, KMB, Ernst, LJ, Zhang, GQ, Driel, WD van, and Bressers, HJL. Modelling of cure-induced warpage of plastic IC packages. In LJ Ernst, GQ Zhang, P Rodgers and O de Saint Leger (Eds.), EuroSimE 2004: 5th international conference on thermal and mechanical simulation and experiments in microelectronics and microsystems (pp. 33-40), 2004.


9. Dissertations related to research school EM: name, title, university, date and advisors

Name: Chuanjun Liu
Title: On the Prediction of Damage and Fracture Strength of Notched Composites, Delft University of Technology, January 12, 2004
Advisors: Prof.dr.ir. R. Marissen en Prof.dr.ir. L.J. Ernst

10. Membership editorial boards international journals

11. Keynote lectures and seminars

12. Membership international scientific committees

Prof.Dr.Ir. L.J. Ernst:
- Member of the Technical Committee of the 54th Electronic Components & Technology Conference, Conference – Sub-committee on “Modeling & Simulation”.
- Member of the organizing committee and chairman of the technical committee of the 5th International Conference on Thermal and Mechanical Simulation and Experiments in Microelectronics and Microsystems. EurosimE2004, Brussels, May 2004
- Member of the Technical Committee of the 11th Int. Conf. on Mechanics and Technology of Composite Materials.

Dr.Ir. P.Th.L.M. van Woerkom:
- International Astronautical Federation (IAF): co-chairman in the Symposium on Astrodynamics.
- American Institute of Aeronautics and Astronautics (AIAA): International Advisor for Guidance, Control and Dynamics.

13. Awards and patents

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14. Overview of research input and output


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1 Sources of financing:  1: University
                         2: STW, SON, NWO, FOM
                         3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NiMR, DPI etc.

2 No research input involved for supporting staff.

3 Research input per PhD per year: 0.8 fte


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- in co-operation with other EM-groups

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte.

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8.7
9. RESEARCH DOCUMENTATION OF THE GROUP COMPUTATIONAL MECHANICS, STRUCTURAL MECHANICS AND DYNAMICS

1. University/Department

Delft University of Technology
Faculty of Civil Engineering and Geosciences

2. Subprogrammes related to research school EM

2.1 Computational Modelling of Failure
2.2 Advanced Computational Procedures
2.3 Structural Dynamics

3. Group director

Prof. Dr. Ir. L.J. Sluys

4. Senior academic staff: name, position, research input in fte related to research school EM

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<tr>
<th>Name</th>
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<tr>
<td>Al-Khoury, Dr. R.I.N.</td>
<td>Associate Researcher</td>
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<td>Askes, Dr.Ir. H.</td>
<td>UD</td>
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<td>Metrikine, Dr. A.V.</td>
<td>UD</td>
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<tr>
<td>Sluys, Dr.Ir. L.J.</td>
<td>UHD</td>
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<tr>
<td>Stroeven, Dr.Ir. M.</td>
<td>Associate Researcher</td>
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<td>Wells, Dr. G.N.</td>
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5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

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<th>Name</th>
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<tr>
<td>Dung, M.Sc. N.T.</td>
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<td>Computational modeling of laminated structures</td>
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<td>Gitman, B.Sc. I.M.</td>
<td>(PhD 3)</td>
<td>Micro-macro modeling of fracture in partially saturated materials</td>
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<td>Iacono, MSc. C.</td>
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<td>Computational modeling of bore-hole stability</td>
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<td>Lloberas, M.Sc. O.</td>
<td>Moonen, Ir. P.</td>
<td>Multi-scale modeling of discrete fracture</td>
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<td>Coupled analysis of moisture flow and fracture</td>
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<td>Pannachet, MSc. T.</td>
<td>(PhD 1)</td>
<td>Advanced discretization technique for combined continuum-discrete fracture</td>
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<td>Pedersen, R.R.</td>
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<td>Computational study of the dynamic behavior of concrete</td>
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<tr>
<td>Pel, Ir. S.</td>
<td>(PhD 2)</td>
<td>Computational modeling of failure in</td>
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geomechanics
Vegt, Ir. I. (PhD 2)
Experimental study to the dynamic MeMa behaviour of concrete

6. Postdocs: name, country, project title, research theme EM and period of stay

7. Short description of subprogrammes related to research school EM

7.1 Computational Modelling of Failure:
Simulation of failure and the associated phenomenon of strain localisation for a range of materials. Activities focus on improved computational procedures and on the integration of experimental methods and sophisticated computational procedures.
Related to the research theme "Mechanics of Materials".

7.2 Advanced Computational Procedures:
This research topic is concerned with the development of computational models for the simulation of the behavior of materials and structures. For this purpose accurate and robust models are made for the temporal and spatial discretization and algorithms are constructed for the efficient, accurate and robust solution of the ensuing non-linear algebraic equations.
Related to the research theme "Computational Mechanics".

7.3 Structural Dynamics:
The development of analytical procedures for moving loads in railway transport and offshore engineering applications.
Related to the research theme "Structural Dynamics and Control".

8. Refereed scientific publications related to research school EM

8.1 Refereed journals


Holmen, J,Hughes, TJR, Oberai, AA. and Wells, GN. Sensitivity of the scale partition for variational multiscale large-eddy simulation of channel flow. Physics of Fluids 16 (3), 824-827.

Hughes, TJR, Wells, GN and Wray, AA. Energy transfers and spectral eddy viscosity in large-edy simulations of homogeneous isotropic turbulence: comparison of dynamic smagorinsky and multiscale models over a range of discretizations. Physics of Fluids 16 (11), 4044-4052.


8.2 Books, chapters in book

8.3 Refereed proceedings


Alfaiate, J. and Sluys, LJ. On the use of embedded discontinuities in the framework of a discrete crack approach. In ZH Yao, MW Yuan and WX Zhong (Eds.), Computational Mechanics (pp. 1-10). Beijing: Tsinghua University Press.


Guo, Z and Sluys, LJ. Comparison of Computational Models for Damage-Induced Stress Softening. In A Tadeu and SN Atluri (Eds.), Advances in Computational and Experimental Engineering and Sciences (pp.1827-1832). Madeira: ICCES '04.


Iacono, C, Sluys, LJ and Mier, JGM van. Inverse procedure for parameters identification of continuum damage models. In VC Li, CKY Leung, KJ Willam and SL Billington (Eds.), Fracture Mechanics of Concrete Structures (pp. 447-454). s.l.: La-Framcos.


Proft, K de, Wilde, WP de, Wells, GN. and Sluys, LJ. A combined experimental-numerical study of tensile behaviour of limestone. In D van Hemelrijck, A Anastasopoulos and NE Melanitis (Eds.), Emerging technologies in non destructive testing; proceedings of the 3rd international conference; may 2003, Greece (pp. 295-300). Lisse: Swets and Zeitlinger.


9. Dissertations: related to research school EM: name, title, university, date and advisors

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10. Membership editorial boards international journals

Dr.Ir. L.J. Sluys:
   • Editor-in-Chief “Heron”
   • Member Editorial Board “Computers and Concrete”.

11. Keynote lectures and seminars

Dr.Ir. L.J. Sluys:
   • “Determination of length scale effects in nonlocal media” Sixth World Congress on Computational Mechanics (WCCM VI), Beijing, China, 5-10 September, 2004.

Dr. G.N. Wells:
• "Material instabilities and numerical modeling", seminar University of Bologna, May 2004.

12. Membership international scientific committees

Dr. G.N. Wells
• Member of the international scientific committee of “Centre of Study and Research on the Identification of Materials and Structures (CIMEST), University of Bologna.

13. Awards and patents

Dr.ir. L.J. Sluys
• Special STW-grant recipient on Computational Modelling of High-performance Materials, 2004

Dr. G.N. Wells:
• VENI-grant 2004

14. Overview of research input and output.

14.1 Input “Computational Mechanics, Structural Mechanics and Dynamics” related to EM, 2004

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<th>Sources of financing1</th>
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1 Sources of financing: 1: University 2: STW, SON, NWO, Fom 3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, DPI etc.

2 No research input involved for supporting staff
3 Research input per PhD per year: 0.8 fte
14.2 Output “Computational Mechanics, Structural Mechanics and Dynamics” related to EM, 2004

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<td>Scientific publications: refereed proceedings</td>
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* In co-operation with other EM-groups.

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte.

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10. RESEARCH DOCUMENTATION OF GROUP APPLIED MECHANICS

1. University/Faculty

University of Twente
Faculty of Engineering Technology

2. Subprogrammes related to research school EM

2.1 Structural Dynamics
2.2 Mechanics of Forming Processes

3. Group directors

Prof.dr.Ir. A. de Boer
Prof.dr.Ir. J. Huétink

4. Senior academic staff: name, position, research input in fte related to research school EM

De Boer, Prof.Dr.Ir. A. Full Professor 0.4
Boogaard, Dr.Ir. A.H. van den UHD 0.2
Geijselaers, Dr.Ir. H.J.M. UD 0.2
Hoogt, Dr.Ir. P.J.M. van der UD 0.3
Huétink, Prof.Dr.Ir. J. Full Professor 0.2
Meinders, Dr.Ir. V.T. UD 0.2
Spiering, Ir. R.M.E.J. UD 0.3
Wijnant, Dr.Ir. Y.H. UD 0.4

Total fte: 2.2

5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1 Structural Dynamics

Beijers, Ir. C.A.J. (PhD 3) Fluid-structure interaction and acoustics StDy
Hannink, Ir. M.H.C. (PhD 3) Fluid-structure interaction and acoustics StDy
Huls, Ir. R. (PhD 3) Fluid-structure interaction and acoustics StDy
Nijhof, Ir. M.J.J. (PhD 3) Fluid-structure interaction and acoustics StDy
Oosterhuis, Ir. E.J. (PhD 2) Inverse Dynamics StDy
Sloetjes, Ir. P.J. (PhD 2) Structural Dynamics StDy

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1 Per 2003 the former group “Applied Mechanics and Polymer Engineering” has been split up in two separate groups; “Applied Mechanics” and “Production Technology”
5.2. Mechanics of Forming Processes

Avetisyan, Ir. M. PhD 3 Sheet metal forming/springback CoMe
Bonte, Ir. M.H.A. PhD 1 Optimization of Forming processes CoMe
Burchitz, Ir. I. PhD 3 Sheet metal forming CoMe
Haaren, Ir. L. van PhD 3 Warm forming of Aluminium CoMe
Koopman Ir. A.J.J. PhD 3 Aluminium Extrusion CoMe
Lingbeek, Ir. R. PhD 3 Springback Compansation CoMe
Perdahcioglu E.S. PhD 2 Processing Meta Stable Steels CoMe
Snippe Ir. Q.H.C. PhD 2 Thin Structures for Vertex detectors CoMe
Yu, Ir. Y. PhD 3 Semi continuous processes CoMe

6. Postdocs: name, country, project title, research theme EM and period of stay

Datta, Dr. K. Metastable Steels (May2001-May2004) CoMe
Oude Nijhuis, Dr.Ir. M.H.H. Tyre noise (Jan. – Dec 2004) StDy
Wisselink, Dr.Ir. H.H. Stretch/Plate forming, BoltJoints (indefinite) CoMe

7. Short description of subprogrammes related to research school EM

7.1 Structural Dynamics and Acoustics (Prof. Dr. Ir. A. de Boer)

The research in this discipline is directed towards structural dynamics and fluid-structure interaction, with emphasis on acousto-elastic coupling of plate-type structures and the accompanying noise production. The aim of these studies is to develop and validate numerical and measuring methods to analyze and reduce (passively as well as actively) responses of vibrating and noise radiating structures. For the latter attention is focused on models for the interaction of vibrating structures with the surrounding air.

Topics of special interest are:

Structural Dynamics
(1) Robust Inversion of Nonlinear Dynamic Systems
   For fatigue analyses one needs to know the load spectra that are applied to the structure or a part of it. In the case the load is not known it has to be derived from other information such as responses in the structure. Once these responses are known the load can be determined with inverse dynamics. For nonlinear systems this inversion is complex. This project, which is carried together with the Systems and Control group of prof. Verhaegen at the TUDelft, focus on the development of inverse methods for nonlinear structural dynamic structures. In principle this project is related with the source localisation method mentioned below however in this case structural sources (loads) have to be localised instead of acoustic sources (see point 4 of the section Fluid Structure Interaction and acoustics). The part of the research at the Structural Dynamics and Acoustics group will be the subject of the PhD-thesis of Ekke Oosterhuis.

(2) Rotor Dynamics
   Rotating parts in machinery are sources of vibrations and can therefore affect the life time of the rotating part itself and the whole machine drastically. The tendency to optimize the functional performance of structures results in modern designs which often exhibit a minimal weight and very tight safety factors. The latter may jeopardize the overall system integrity and eventually lead to severe damage and possible failure. Furthermore the vibrating parts of the machine (e.g. the housing) can radiate...
unwanted noise which must be limited to meet the legal regulations on noise emission and the growing consumer demands for quiet design.
The life of the machinery (parts) can be extended and the radiated noise minimized by applying vibration reduction measures. The life time can be extended too, when a structural part with potential fatal damage is repaired or replaced in time. At present, this requires off-line inspections which is time consuming and expensive since the machinery is inactive at those times. This can be avoided through on-line monitoring of the condition of the (rotating) machinery. Weight can be reduced by using composite materials instead of metals. An additional advantage of composites is that the production process makes it possible to integrate monitoring and vibration reduction systems in the material. This research will be the subject of the PhD-thesis of Peter Sloetjes.

Fluid-structure interaction and acoustics
(1) Viscothermal wave propagation
New, analytical models, which include the effects of inertia, viscosity and thermal conductivity, led to the development of a new finite element for viscothermal wave propagation in narrow gaps. Coupling of this acoustic element with finite elements for the structure enables fully coupled acousto-elastic calculations for a complex geometry to be made. The models were validated with specially designed experiments. The enormous effect that the presence of air can have on the vibrational behaviour of a structure was shown and it appeared possible to generate a considerable amount of damping.
Further studies are performed towards practical applications more specifically for computers. In 2003 source localisation measurements were carried on complete computer housings and CD drives separately. Based on the obtained data and the developed theory treatments for noise reduction have been proposed and are now worked out in detail. This research will be the subject of the PhD-thesis of Martin Nijhof.

(2) Sound-absorbing materials.
A closely related part of the research program, involves the development and validation of a model to predict and optimise the impedance of sound-absorbing materials. Emphasis is put on the development of highly efficient sound-absorbing configuration of bores, arranged in an optimal way. Further studies are under way to design optimised acoustic panels for aircraft cabins, which is carried out within the European project FACE (Friendly Aircraft Cabin Environment). In 2003 an optimisation program has been developed with which bore configurations in a panel can be determined such that sound absorption in a predefined frequency band is maximally. This research will be the subject of the PhD-thesis of Marieke Hannink.

(3) Active and passive vibration damping
A third method to reduce the noise emitted from vibrating structures is to damp the structural vibrations, which cause the noise. This can be carried out by damping the vibrations of the structure directly or by isolating the source that excites the structure (e.g. engine in a car). Vibration damping and isolation can be performed with passive means like viscous layers or rubber springs and active means like a linear motor or an electromagnet. A combination of passive and active means is possible too. This is called hybrid damping.
At the moment research is carried out on the application of hybrid damping for engine mounts with the objective to reduce noise caused by structural vibrations excited by the engine. In 2003 research is carried out on both the passive and active part of the hybrid mount. For the passive part a design tool has been developed with which the dynamic transmissibility of a rubber mount can be predicted. For the active part strategies for the positioning of sensors near the source (in stead of near the radiating
structure) have been developed and evaluated. This research will be the subject of the PhD-thesis of Clemens Beijers which will be defended on the 2nd of June 2005.

(4) Efficient analysis and measuring methods for source localisation
Acoustic source localisation concerns a combination of measuring and numerical analysis methods with the goal to detect the parts of a structure that are responsible for the generation of noise. The idea is to measure the sound pressure or particle velocity on a grid around the radiating object and to determine the radiating source with inverse analysis methods. One of the methods under investigation is the so-called multilevel method developed by the Tribology group of the University of Twente. The project consists of three parts: (1) the development of the multigrid/multilevel method for acoustic radiation problems, (2) a study on the applicability of microflows (sensors that measure the particle velocity) for this purpose and (3) the validation and integration to a complete measuring chain for practical applications. The Structural Dynamics and Acoustics group at the UT covers the last topic. In 2003 the Inverse Boundary Element Method (IBEM) that is used to localize the source is extended such that measured particle velocities can be used to reconstruct the source. The method has been tested successfully for several applications. This research was the subject of the PhD-thesis by René Visser, defended on the 9th of September 2004.
Together with prof. Slump of the UT Department of Electrical Engineering, Signals and Systems group and prof. N.B. Roozen of the TUE Department of Mechanical Engineering, Section Dynamics and Control a follow on proposal has been written. This STW proposal, called ‘Inverse Acoustics’ has been accepted.

(5) Thermo-acoustic structural interaction
During combustion in a gasturbine noise is generated which can interact with the gasturbine wall. Due to this interaction undesirable acoustic pressure fields can be generated that disturb the flame. The latter can affect the efficiency of the combustion process. The objective of this study is to investigate the interaction between the gasturbine structure and the thermo-acoustic pressure generated in the combustion chamber. This study is carried out in close collaboration with the Thermal Mechanics group of the University of Twente. In 2003 the combustion chamber for the experimental set-up has been designed and analysed. Further has been started with the development of a numerical model of the flame that should be integrated in a finite element model such that a coupled analysis can be carried out. This research will be the subject of the PhD-thesis of Rob Huls.

(6) Tyre/road noise
Traffic road noise is a serious environmental problem and effective countermeasures are needed to reduce noise. The main components of the radiated noise are engine noise and tyre/road noise, where engine noise dominates at low speeds. Road noise is generated through the interaction between a rolling tyre of a vehicle and the road surface. Many different mechanisms contribute to the generation of tyre/road noise. Because most generation mechanisms originate from the contact region, modelling of the interaction between tyre tread and road surface is crucial for an accurate prediction of tyre/road noise. With such a complete model, one can study the effect of modifications to the tyre or road, and ultimately design quieter tyre/road combinations. The objective is to develop numerical tyre/road models with emphasis on what is happening in the contact region and the material models for rubber. This research is the subject of the post-doc Marco Oude Nijhuis.
There is deliberation with prof. N.B. Roozen from the TUE on this research subject.

All activities within 7.1 are related to the research theme “Structural Dynamics and Control”.

7.2 Mechanics of forming processes (Prof.Dr.Ir. J. Huétink)
The research in this discipline is directed towards the development and validation of numerical methods to simulate forming and production processes. Industrial application of numerical simulations of forming processes is gradually finding its way in industry. For specific forming processes commercially available software packages can provide predictive answers. There is a strong need for more accurate macroscopically based descriptions of material behaviour during specific parts of the forming process, more accurate descriptions of the process conditions such as friction and heat transfer between tools and workpiece and above all, experimental verification of the capability of the models to describe the phenomena with sufficient accuracy.

The fundamental problems associated with new algorithms, the inclusion of relevant boundary conditions like contact and friction between tool and product, and the deformation of flexible tools are addressed. These fundamental problems obviously occur in very important technologies that have attracted (renewed) attention in recent years, e.g. rubber pad forming, hydro-mechanical forming, and incremental sheet forming. Therefore these processes will serve for benchmarking of software tools. Processes as rolling, extrusion and also laser hardening can be approximately modelled as continuous (steady state) processes. Hence special attention is paid to (fast) solution algorithm for finding directly a steady state solution.

Increased demands for accuracy of these simulations and computationally efficient simulations require that a number of topics have to be addressed:

- **Improved macroscopic models for describing the material**

  Accurate constitutive equations are required including (evolution of) sheet metal anisotropy in order to predict the final shape after forming and subsequent “spring back”. In particular the effect of the initial sheet anisotropy, the changes in loading path as present in multi-stage forming processes and through process modelling, the strain rate dependency, the consequences of temperature changes in warm forming processes, the effects of annealing periods between successive forming steps and strain rate effects have to be properly accounted for. The test facility allows for biaxial loading under simultaneous bi-directional shear and tension/ compression of sheet metal, including strain path changes and strain rate changes.

  Project “Simulation of thermo-mechanical forming of aluminium sheet” addresses both the material hardening aspects during warm forming and the effect of annealing periods. With the TU/e and TUDelft a joint FOM-NIMR project “Tailoring of processable metastable steels” is started. The project will result into constitutive equations for FEM simulations, including the phase transitions during forming. At the TU/e micro level FEM models are developed. These numerical micro scale models cannot directly be applied on macro-scale. A Multi Level Finite Element Method (MLFEM) procedure is being developed to bridge the gap between micro and macro scale models. Via homogenization steps using Representative Volume Elements (RVE), constitutive relations are generated on integration point level of the macro model. For small two-dimensional academic problems this approach shows promising results. However the computation time of this kind of methods is still too high for application in full-scale three dimensional forming process simulations.

  As long as these MLFEM procedures are too much computer time consuming, approximations have to be used in which micro-structural phenomena are translated into averaged continuum constitutive relations.
Springback after forming
The problems related to spring back are becoming more pronounced due to the increasing use of materials such as aluminium alloys and high strength steels. A disadvantage is that they are highly sensitive to spring back phenomena due to the high yield stress/Young’s modulus ratio. Therefore it is hard to obtain the nominal shape of components formed with these materials. Nevertheless aluminium alloys and high strength steels are desirable in many industrial products because of their high strength/weight ratio, especially in transport industry.

In the first phase of the springback project a detailed study of the numerical predictability is being carried out on 4 sheet metal parts of various complexity, known to be sensitive to spring back. The study includes a full sensitivity analysis of both numerical and physical factors on the springback behaviour, using several finite element codes (Abaqus/Standard, DiekA, MSC.MARC and Pamstamp/Optris). The following items are varied: Normal contact definition, Friction, Numerical damping, Material models and Material properties, Sheet discretisation, Deformable tools, Tool discretisation, Method of unloading, Plane strain elements versus shell elements, Thickness integration, Tool velocity (explicit codes) and, Plastic anisotropy.

A rather paradoxical conclusion is that for an accurate prediction of elastic springback after forming an accurate plasticity model is more important that for the simulation of the preceding plastic forming.

Optimisation
Attention is paid to Springback compensation in die design for sheet metal forming
In cooperation with the new NIMR partner INPRO (Berlin) a project is started with the aim to compensate the tool design, based on predicted springback after forming. The project should result into a software that can optimise the tool-set automatically, using the results of a FE simulation. The tool can also be used earlier in the process, integrating structural and geometrical design right from the start. The application of ‘design for manufacturing’ opens up new possibilities for creating parts with high performance materials and complex shapes.

Optimisation of Forming processes
A project is being carried out on optimisation of the structural component to be formed and optimisation of the process conditions. The project should result into guidelines for industry, more optimal process conditions, shorter lead-through times and less material waste.

Improvement of solution algorithms for specific parts of the numerical simulation.
Extensions to the meshing algorithms for ALE applications, evaluation of remeshing and field mapping techniques are evaluated for the analysis of cutting processes; implementation of local stress fields resulting from cutting and hemming processes in subsequent forming analysis will be explored. In addition continued research will be performed on dynamic- implicit algorithms in combination with iterative solvers.

All activities within the sub programme “Mechanics of Forming Processes” are related to the research theme “Computational Mechanics”. 
8. Refereed scientific publications related to research school EM

8.1 Refereed journals


8.2 Books, chapters in books

77

8.3 Refereed proceedings


Hannink, M.H.C., Wijnant, Y.H., Boer, A. de, Optimised Sound Absorbing Trim Panels for the Reduction of


9. Dissertations: related to research school EM: name, title, university, date and advisors

Name: Visser, R.
Advisor: Prof. Dr.Ir. H. Tijdeman
Current position: Employee Daimler Benz

Name: Zandbergen P.
Title: A composite beam as a multifunctional suspension component, 25 november 2004, ISBN 90-365-2104-1
Advisor: Prof. Dr.Ir. H. Tijdeman, Prof. Dr. Ir. R. Akkerman
Current position: Employee Ford

Name: Post, J.
Advisor: Prof. Dr.Ir. J. Huétink, Dr.Ir. H.J.M. Geijseelaers.
Current position: Employee Corus

10. Membership editorial boards international journals.

Prof.Dr.Ir. J. Huétink:

- Reviewer and member of scientific advisory committee of International Journal of Forming Processes
11. **Keynote lectures**

Prof. Dr. Ir. J. Huétink:
- Invited Plenary Keynote lecture NUMIFORM'04 "Implementation of Microstructural Material Phenomena in Macro Scale Simulations". In S. Ghosh, J.M. Castro and J.K. Lee (Eds.), *CP712, Materials Processing and Design: Modelling, Simulation and Applications* (pp. 52-56) Columbus, Ohio, USA: American Institute of Physics, 2004.

12. **Membership International Scientific Committees.**

Prof. Dr. Ir. J. Huétink:
- Member of the NUMIFORM Steering Committee
- Member Board of directors ESAFORM, European scientific association for material forming
- Member of the Numisheet scientific committee

Prof. Dr. Ir. A. de Boer:
- Netherlands representative in the Programme Committee of ICAS (International Counsel of Aerospace Sciences).
- Member of the accreditation committee for the departments of Electrical-Mechanical Engineering at the Flemish universities of Brussel, Gent and Leuven.

13. **Awards and patents.**

-----

14. **Overview of research input and output**

14.1 *Input “Applied Mechanics” related to EM, 2004*

<table>
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<th>Sources of financing</th>
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<td>Senior academic staff</td>
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<td>Supporting staff</td>
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¹ Sources of financing:
1: University
2: STW, SON, NOW, FOM
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, etc.

² No research input involved for supporting staff.

³ Research input per PhD per year: 0.8 fte
14.2 Output “Applied Mechanics” related to EM, 2004

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<td>PhD theses</td>
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*In co-operation with other EM-groups*

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

- **Project Title:** STW project TW 6618, Inverse Acoustics  
  **Participating Groups:** Applied Mechanics (UT), Dynamics and Control (TUe)  
  **Participants:** Prof. Dr. Ir. A. de Boer (UT), Dr. Ir. Y.H. Wijnant (UT), Vacancy (UT), Prof. Dr. Ir. N.B. Roozen (TUe), Dr. I. Lopez (TUe), Ir. R. Scholte (TUe)  
  **Research Input in fte:** 2.0

- **Project Title:** Hybrid Isolation of Construction noise (HIC)  
  **Participating Groups:** Applied Mechanics (UT), Mechanical Automation (UT)  
  **Participants:** Prof. Dr. Ir. A. de Boer (UT), Prof. Dr. Ir. B. Jonker (UT), Ir. C.A.J. Beijers (UT), Ir. H. Super (UT), Dr.Ir. J. van Dijk (UT)  
  **Research Input in fte:** 1.9

- **Project Title:** Rotor Dynamics  
  **Participating Groups:** Applied Mechanics (UT), Mechanical Automation (UT)  
  **Participants:** Prof. Dr. Ir. A. de Boer (UT), Prof. Dr. Ir. B. Jonker (UT), Ir. P. Sloetjes (UT), Ir. P.J.M. van der Hoogt (UT)  
  **Research Input in fte:** 1.0

- **Project Title:** Friction and roughness transfer in rolling and metal forming processes  
  **Participating Groups:** Applied Mechanics (UT), Surface Technology and Tribology (UT)  
  **Participants:** Prof. Dr.Ir. J. Huetink (UT), Ir. E.C. Dillingh (TNO), Prof. Dr.Ir. D.J. Schipper (UT)  
  **Research Input in fte:** 1.0

- **Project Title:** NIRM-project MC1.03158, Strain path dependent materials models for forming and crash  
  **Participating Groups:** Applied Mechanics (UT) Materials Technology (TU/e)  
  **Participants:** Prof.Dr.Ir. J. Huëtink, Dr.Ir. A.H. van den Boogaard (UT), Prof.Dr.Ir. M.G.D. Geers, Dr.Ir. W.A.M. Brekelmans (TU/e)
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<tr>
<th>Project Title</th>
<th>FOM-project 02EMM30, Tailoring of metastable steels</th>
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<td>Materials Technology (TU/e)</td>
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<tr>
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<table>
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<th>Project Title</th>
<th>High Precision Rubber Forming</th>
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<td>Participating Groups:</td>
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<td>Participants:</td>
<td>Prof. dr. ir. R. Akkerman (UT), Prof. Dr. Ir. J Huétink (UT), Dr. ir. T. Meinders (UT), Ir. E.A.D. Lamers (UT), Ir. S. Wijskamp (UT)</td>
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11. RESEARCH DOCUMENTATION OF GROUP SURFACE TECHNOLOGY and TRIBOLOGY

1. University/Faculty

University of Twente
Faculty of Engineering Technology

2. Subprogrammes related to research school EM

2.1 Tribology
2.2 Surface Technology and Roughness
2.3 Materials and Coatings
2.4 Experimental Validation

3. Group director

Prof.dr.ir. D.J. Schipper

4. Senior academic staff: name, position, research input in fte related to research school EM

Rooij, Dr.Ir. M.B. de UD 0.3
Schipper, Prof.Dr.Ir. D.J. Full Professor 0.3
Total fte: 0.6

5 PhD- projects related to research school EM 2004: name, source of financing, project title and research theme EM

5.1 Tribology

Deladi, Msc. E.L. (PhD 3) Static friction StDy
Drogen, Ir. M. van (PhD 3) Load carrying capacity CVT StDy
Sloetjes, Ir. J.W. (PhD 3) Micro-EHL StDy

5.2 Surface Technology and Roughness

Dillingh, E.C (PhD 3) Friction and roughness transfer MeMa
Faraon, Msc. I.C. (PhD 3) Friction in continuous variable transmission StDy
Jamari, Ir. J. (PhD 3) Running-in of surfaces StDy
Tasan, Msc. Y.C. (PhD 2) Contactless detection and monitoring of micro- and macro wear using imaging methods MeMa
5.3 **Materials and coatings**

Pasaribu, Ir. H.R. (PhD 2) Nano-scale wear resistant ceramic materials with low friction MeMa
Moodij, Ir. E. (PhD 3) Hydrostatische Magnesium Extrusie StDy

5.4 **Experimental Validation**

Linde, Ir. G. v.d. (PhD 3) Gallina Performance Indicator MeMa

6. **Postdocs: name, country, project title, research theme EM and period of stay**

Heide, Dr.Ir. E. van der The Netherlands Friction and Wear; 8 months 5.3 MeMa

7. **Short description of subprogrammes related to research school EM**

The subject of research in surface technology and tribology is the interaction of material surfaces and engineering practices related thereto. The nature of the interaction between the opposing surfaces depends on the operational conditions. Therefore: different lubrication regimes are distinguished: A) full film lubrication, mixed lubrication and boundary lubrication and B) unlubricated or dry contact. The physics describing the interaction is quite different. Since in most mechanical engineering applications all regimes are encountered, research is conducted in all these areas, with special attention for the transitions between the regimes with respect to friction and wear. The modelling is aimed at design tools for reliable and accurate prediction of tribological behaviour in practical applications. The main subjects are I) Lubricated systems: (elasto-) hydrodynamic lubrication, mixed- and boundary lubrication, II) Special materials and Coatings: ceramics, MMC’s, PMC’s, lasertreated surfaces and PVD and III) Surface Textures: human-product interaction.

7.1 **Tribology**

The research conducted in this subprogramme deals with the frictional behaviour in lubricated concentrated contacts. Special attention is paid to the rheology of the lubricant, shear thinning effects and starvation. Besides this the local interaction between the opposing surfaces is studied by developing elastic-plastic contact models. On the basis of this work one is able to predict for line- and point contacts the Stribeck curve for I) heavily loaded contacts, II) shear thinning of the lubricant and III) starved lubricated contacts. Due to the fact that one is able to predict friction in these contacts one is able in combination with the critical contact temperature hypothesis to predict the load carrying capacity of lubricated systems, like continuous variable transmissions. For systems set in motion or set still friction is determining the position of a system in time and space. Therefore, in this subprogramme attention is paid to this phenomenon (static friction). Special attention is paid to rubber-metal contact.

Related to research theme “Structural Dynamics and Control”.

7.2. *Surface technology and Surface Roughness*

Surface roughness has a significant influence on the tribological behaviour (friction and wear) of a system. Therefore, the prediction of the change in roughness, running-in, as a function of the operational conditions is one of the topics which is under investigation by the surface technology and tribology group. Modeling takes place by combining a contact model and a wear model. On the basis of this combined model one can determine what the initial roughness should be to generate a certain roughness level during operation. It is, for instance, possible to generate micro-EHL instead of boundary lubricated micro-contacts. In certain applications, like a continuous variable transmission, the surface roughness should not change too much in order to maintain a certain friction level. The change in surface roughness cannot be detected in the traditional way (profile measurements). By matching and stitching several images before and after a tribological experiment the change in surface roughness can be determined in a quantitative way (deterministic and statistically). This change in roughness is the result of local deformation and the wear mechanism involved. For certain applications, as for instance in sheet metal forming, transfer of sheet material to the tool changes the micro-geometry of the tool significantly and as a result friction changes during operation. The research also includes the phenomenon “galling” occurring during deep drawing and extrusion investigated in section 7.3 and 7.4.

Related to research themes “Mechanics of Materials” and “Structural Dynamics and Control”.

7.3 *Materials*

Oxide ceramics (alumina, zirconia and their composites) are studied because of their specific properties. The research focuses on the development of nano-scale oxide ceramic couples with low friction. The reason for this is that in previous research it was shown that nano-scale oxide ceramics are highly wear resistant. However, the application of these materials is hampered by the fact that the coefficient of friction is too high, 0.5 and higher likewise for other ceramics. Therefore, metal oxides are added during the material processing of oxide ceramics. The basis for this idea is that the additive forms a thin interfacial layer between the opposing surfaces during rubbing. Initial experiments showed that the coefficient of friction could be reduced to a value of 0.2 for a sliding distance of 4 km. The mechanism of the interfacial layer formation will be studied as well as the friction will be modeled in order to optimize the ceramic material. The friction model is based upon ploughing and adhesion.

In sheet metal forming processes coatings are becoming more and more important. This because lubricants are more and more omitted for environmental reasons. Large tools in sheet metal forming are made of cast iron. By locally re-melting, by using a laser, and subsequently applying a layer, by means of PVD, a duplex coating for these applications is studied. The modeling with respect to friction and wear focuses on local ploughing, cutting and wedge formation. The abrasive wear is experimentally studied with a surface force apparatus and will be compared with the model.

The galling phenomenon is studied for the hydrostatic magnesium extrusion process. The influence of the fluid is studied extensively.

Related to research theme “Mechanics of Materials” and “Structural Dynamics and Control”.

7.4 *Experimental Validation.*

Different friction and wear models are developed which are validated by experiments. For certain processes, as for instance cold rolling, models are available which are not validated by experiments yet. In this research measurement techniques will be developed to measure friction and wear under specific operational conditions. Attention is paid to measure 1) on line micro-wear by using an interference microscope and 2) friction during...
cold rolling in the roll-bite by means of a special designed friction sensor. Next, measurement techniques are developed to measure the material transfer of the sheet to the tool by using interference microscopy and a surface force apparatus. Related to research theme “Structural Dynamics and Control” and “Mechanics of Materials”.

8. **Refereed scientific publications related to research school EM**

8.1 **Refereed journals**


8.2 **Books, chapters in book**


8.3 **Refereed proceedings**


Drogen, M. van and Laan, M. van der. Determination of variator robustness under macro slip conditions for a push belt CVT. In (Ed.), SAE 2004 World Congres, Detroit, USA, 2004.


material aspects in forming stainless steel with easy-to-clean lubricants. In (Ed.), Innovations in Metal Forming, Brescia, Italy.


9. Dissertations: related to research school EM: name, title, university, date and advisors

Name: Masen, M.A.
Title: Abrasive tool wear in metal forming processes
University of Twente, September 2004 (ISBN 90-365-2061-4).
Advisors: Prof.dr.ir. D.J. Schipper
Co-Advisor: Dr.ir. M.B. de Rooij

10. Membership editorial boards international journals

Prof. dr.ir. D.J. Schipper
• Member editorial board Industrial Lubrication and Tribology
• Member editorial board Tribotest
• Member editorial board Lubrication Science

11. Keynote lectures

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12. Membership International Scientific Committees

Prof.dr.ir. D.J. Schipper:
• Secretary of the International Research group on Wear of Materials, IRG-OECD.
• Member University Grants Committee of the University of Hong Kong.
13. Awards and patents

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14. Overview of research input and output

14.1 Input “Tribology” related to EM, 2004

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<td>2</td>
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1 Sources of financing:
1: University
2: STW, SON, NOW, FOM
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, etc.

2 No research input involved for supporting staff.
3 Research input per PhD per year: 0.8 fte

14.2 Output “Tribology” related to EM, 2004

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<td>Scientific publications: refereed proceedings</td>
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<tr>
<td>PhD theses</td>
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</table>

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

Project Title: Friction and roughness transfer in rolling and metal forming processes.

Participating Groups: Applied Mechanics (UT) Surface Technology and Tribology (UT)
Participants: Prof. Dr.Ir. J. Huetink (UT), Ir. E.C. Dillingh (TNO), Prof.dr.ir. D.J. Schipper (UT)
Research Input in fte: 1.0
12. RESEARCH DOCUMENTATION OF GROUP MECHANICAL AUTOMATION

1. University/Faculty

University of Twente
Faculty of Engineering Technology (CTW)

2. Subprogrammes related to research school EM

2.1 Robotics and Machine Dynamics
2.2 Hybrid isolation of structure borne noise
2.3 Laser machining of materials

3. Group director

Prof.Dr.Ir. J.B. Jonker

4. Senior academic staff: name, position, research input in fte related to research school EM

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<tr>
<th>Name</th>
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<td>Aarts, Dr.Ir. R.G.K.M.</td>
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5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1 Robotics and Machine Dynamics

<table>
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<th>Name</th>
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<tr>
<td>Graaf, Ir. M.W. de</td>
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<td>Seam-tracking for robotized laser</td>
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<td>Hakvoort, Ir. W.B.J.</td>
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<td>Iterative Learning Control for Robotized</td>
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<td>Laser Welding</td>
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<td>Hardeman, Ir. T.</td>
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<td>Model Based Beam Manipulation Control</td>
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<td>Waiboer, Ir. R.R.</td>
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<td>Off-Line Programming software for laser</td>
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5.2 Hybrid isolation of structure borne noise

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<td>control algorithms</td>
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<td>Super, Ir. H.</td>
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<td>Hybrid isolation of structure borne noise</td>
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</table>
5.3 Laser machining of materials

Aalderink, Ir. B.J. (PhD 3) Multivariable weld pool control for double spot laser welding

6. Postdocs: name, country, project title, research theme EM and period of stay

Lange, Dr. Ir. D.F. de Unsteady meltpool and keyhole modelling for laser welding; Feb 2002- Feb 2007

7. Short description of subprogrammes related to research school EM

The research topics of the group Mechanical Automation related to the speciality of Engineering Mechanics can be summarised as:

7.1 Robotics and Machine Dynamics

The dynamic behaviour of industrial robots is investigated in order to get a better understanding of the achievable performance and to enlarge the industrial applicability especially for robotised laser welding. The research deals with the modelling of the robotic manipulator, the identification of the dynamic parameters, simulations of the closed-loop system of manipulator and its controller, enhancements of the (industrial) controller and the integration of sophisticated sensors. The robot models take into account all aspects of the inertia properties, friction, flexibility and the control system. For efficient simulations the computer program “SPACAR” has been developed. It is based on a non-linear finite element method to analyse and simulate the kinematics and dynamics of mechanisms and manipulators or, more generally, multibody systems with non-linear behaviour due to large displacements and/or rotations. In this approach mechanisms may be composed of both rigid and flexible components. Furthermore, the linearization and subsequent use of modal techniques resulted in a computationally efficient simulation algorithm.

The NIMR-project “Off-Line Programming software for laser welding” is carried out in collaboration with the Joining group of the Technical University of Delft and Corus. Realistic dynamic simulations of the robot's motion path are combined with off-line programming software for laser welding. The aim is to predict the ability to weld a complex weld seam with a specific robot. This requires a combination of accurate dynamic simulations and a database with extensive knowledge of the required process settings and allowable tolerances.

For the simulations accurate dynamic models of the robot and the controller are necessary. A linear parameter estimation technique has been developed to obtain the inertia parameters of a complete six degree-of-freedom rigid robot model. Joint friction plays an important role. A new friction model has been developed with a minimal and physically sound parameter set. All friction parameters are initially identified in dedicated experiments. Some parameters depend strongly on the operating temperature of the robot and need to be identified again in every subsequent identification experiment. For realistic closed-loop simulations a controller model has been created based on manufacturer data and experimental validation with common system identification techniques. At the moment it is possible to simulate the joint motion of the robot sufficiently accurately for a specific welding task. This result can be used to examine the ability to weld a complex three-dimensional product.

Next to joint motion also the actual tip motion should be considered. This has been investigated using a 6-DOF camera based measurement system. These experiments revealed that also elasticity of the robot plays a role at the desired level of accuracy.
Modelling and parameter estimation of a robot with elasticity is being considered in a more recently started UT/NIMR-project on “Improved laser beam manipulation control for robotized laser welding”. The goal of this project is to avoid tracking errors during robotized laser welding. Two independent solutions are being investigated. In “Model Based Beam Manipulation Control for Robotized Laser Welding” the laser beam will be manipulated with an additional lightweight manipulator mounted at the robot tip. To assure a sufficiently fast correction, the actual robot motion will be analysed in real-time and future errors are estimated. As the real tip motion has to be simulated, the rigid robot models will have to be extended with elastic components. The research so far concentrated on the development of the models, possibilities to increase the speed of the simulations and identification techniques for the parameters in the models with elasticity. A new model structure for the parameter identification has been derived. It has been tested with simulations, but experimental results are not yet available. In “Iterative Learning Control for Robotized Laser Welding” it is attempted to improve the tracking accuracy by adding an Iterative Learning Controller to the standard industrial (feedback) robot controller. Tracking errors measured in the past are used to compute a feedforward during subsequent trials of a repetitive motion. This feedforward is computed using the existing closed-loop model of controller and (rigid) robot model. So far it proved to be possible to improve the tracking performance of the joint motion considerably within only a few trials. Next ILC algorithms will be developed using data from a tip mounted seam sensor that measures the actual tip tracking performance.

The application of such a seam sensor is also investigated in a European project on “Seam-tracking for robotized laser welding” as in many practical situations robotized laser welding cannot be successful without using a seam-tracking sensor. Such a sensor measures the relative position and orientation of the robot tip with the laser head with respect to the seam. From such data the actual seam position with respect to the robot coordinate system has to be calculated. Typical applications are a priori teaching of an unknown seam or real-time measurement of differences between the actual seam position and a nominal seam, e.g. due to thermal loading. The scope of this project covers the development and testing of advanced seam tracking algorithms. It involves the whole seam tracking system starting with the sensor, the interfacing with the robot controller, the actual processing of the measured data and the resulting robot tip motion. An important part of this work deals with non-ideal system components like errors in the kinematic model of the robot and in the calibration of the sensor and laser tool centre point (TCP). To study the significance of these errors a model of the whole seam tracking system has been developed. With this model it was possible to analyse the effects of each imperfection separately or in combinations. By combining simulations and experimental results valuable insight was obtained. “Standard” seam tracking algorithms that have been in use for conventional welding for many years appeared to be inadequate for laser welding.

Based on these results improved seam tracking procedures are being developed and tested. Furthermore, the procedures for sensor and laser TCP calibration are considered and where possible the accuracy and reliability will be improved. A protocol for accurate synchronisation between sensor and robot controller is being implemented in order to be able to use sensor data that is measured while the robot is moving.

Related to the research theme "Structural Dynamics and Control".

7.2 Hybrid Isolation of Structure Borne Noise
Isolation of vibrations in mechanical structures is important for a large number of applications. Passive vibration isolation techniques, such as the use of springs and dampers, are well known and widely used. However, the achievable performance can be insufficient in some cases, especially at lower frequencies. In co-operation with TNO-TPD and other research groups at our university we are studying the applicability of hybrid
vibration isolation control. In addition to passive vibration isolation an active vibration isolation control system is used with sensors and actuators to compensate for vibrations in the lower frequency range. The strength of this method is the possibility to have a relatively stiff connection between two objects while still being able to provide active vibration isolation control for specific vibrations. An example application of such a hybrid isolation system is the use of hybrid mounts to isolate engine vibrations from the support structure. The method is also promising for applications in the field of precision and manufacturing technology where vibrations often reduce the achievable accuracy and performance.

For research and development of hybrid vibration isolation techniques different experimental set-ups have been realized. In the first set-up only a single degree of freedom (DOF) is considered. In the second set-up a vibrating body (source) is mounted on a metal plate (receiver) by stiff mounts containing six piezo-electric actuators and accelerometers.

The set-ups are used for the development of control systems for active vibration isolation control. The controllers need to minimize the vibrations of the receiver structure by controlling the mounts. Developing fast and numerically reliable feedforward and feedback controllers is an important aspect. In our approach we focus both on the suppression of (deterministic and stochastic) narrow-band disturbance signals and on the suppression of stochastic broadband signals. A key contribution is the incorporation of subspace model identification techniques for obtaining models of the plant under control. Subspace identification is being used to identify straightforwardly accurate and numerically reliable state space models of our complex multiple input output systems, which can easily be incorporated in the control scheme. Up to the current date, several promising control schemes have been implemented and validated successfully on the two set-ups. Some of the results have been reported in the literature.

Related to the research theme "Structural Dynamics and Control".

7.3 Laser machining of materials

During laser welding with high laser intensity the laser penetrates deep into the material creating a so-called keyhole. The keyhole is a narrow and deep crater formed by the pressure of the evaporating metal. In keyhole laser welding of metals, in particular aluminium, the occurrence of porosity and holes in the weld and spatter are serious problems. These phenomena are closely related to the stability of the keyhole and the surrounding liquid metal in the melt pool during the welding process. In two NIMR projects the laser welding process is being investigated both by simulations and experimentally.

Simulations of the unsteady three-dimensional behaviour of keyhole and melt pool are the goal in the project "Unsteady meltpool and keyhole modelling for laser welding". The research aims at the development of a simulation tool that includes the heat balance, radiation (e.g. from the laser), fluid dynamics (in the liquid and vapour domain and at the interface) and material properties. Current focus is on two-dimensional and three-dimensional models with simplified physics to describe the unsteady keyhole. Numerical results of the temperature distribution at the surface are in qualitative agreement with thermal images recorded experimentally by measuring the infrared radiation emitted during laser welding experiments. The numerical models are also being applied for laser drilling and laser cladding.

The experimental work on laser welding is concentrated in the project on "Multivariable weld pool control for double spot laser welding". The goal of this project is to obtain reliable process conditions for laser welding of aluminium sheets. Process stability as mentioned previously is one concern. Furthermore, the weld quality depends strongly on the gap width of the seam to be welded. During welding experiments it was found that for perfect seams the process could be stabilised by using sufficiently high laser power or by using a double spot beam delivery system. With such a system the laser power is focussed in two spots. It can also be used in combination with filler wire to obtain good weld quality for a larger range of gap widths. A sensor system is needed to monitor the
welding process in real-time. Based on a CMOS camera such a sensor is being developed. The optical emissions during the aluminium welding process have been recorded and are being used to design and test sensor concepts. The ultimate goal is the development of a sensor system for application in a closed-loop control system for improved quality of the laser welds.

Related to the research theme "Structural Dynamics and Control".

8. **Refereed scientific publications related to research school EM**

8.1 **Refereed journals**


8.2 **Books, chapters in book**

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8.3 **Refereed proceedings**


9. **Dissertations: related to research school EM: name, title, university, date and advisors**

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10. Membership editorial boards international journals


11. Keynote lectures


12. Membership international scientific committees


13. Awards and patents


14. Overview of research input and output

14.1 Input “Mechanical Automation” related to EM, 2004

<table>
<thead>
<tr>
<th>Sources of financing</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Number</th>
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^1 Sources of financing: 1: University  
2: STW, SON, NWO, FOM  
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, NIMR, etc.

^2 No research input involved for supporting staff.

^3 Research input per PhD per year: 0.8 fte

14.2 Output “Mechanical Automation” related to EM, 2004

<table>
<thead>
<tr>
<th>Total</th>
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<tbody>
<tr>
<td>Scientific publications: refereed journals</td>
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<tr>
<td>Scientific publications: books, chapters in book</td>
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<tr>
<td>Scientific publications: refereed proceedings</td>
</tr>
<tr>
<td>PhD theses</td>
</tr>
</tbody>
</table>
15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte

Project Title: HIC: Hybrid isolation of structure borne noise.
Participating Groups: Applied Mechanics and Polymer Engineering (UT), Mechanical Automation (UT).
Participants: Prof. Dr. Ir. A. de Boer (UT), Ir. C.A.J. Beijers (UT), Prof. Dr. Ir. J.B. Jonker (UT), Dr. Ir. J. van Dijk (UT), Ir. H. Super (UT), Ir. G. Nijsse (UT).
Research Input in fte: 1.9

Project Title: Rotor Dynamics
Participating Groups: Applied Mechanics (UT), Mechanical Automation (UT)
Participants: Prof. Dr. Ir. A. de Boer (UT), Prof. Dr. Ir. B. Jonker (UT), Ir. P. Sloetjes (UT), Ir. P.J.M. van der Hooft (UT)
Research Input in fte: 1.0
13. RESEARCH DOCUMENTATION OF GROUP PRODUCTION TECHNOLOGY

1. University/Faculty

University of Twente
Faculty of Engineering Technology

2. Subprogrammes related to research school EM

2.1 Composites

3. Group director

Prof.dr.ir. R. Akkerman

4. Senior academic staff: name, position, research input in fte related to research school EM

Akkerman, Prof.Dr.Ir. R. Full Professor 0.4
Warnet, Dr.Ir. L. UD 0.3
Bor, Dr.Ir. T.C. UD 0.1
Total fte: 0.8

5. PhD-projects related to research school EM per December 2004: name, source of financing, project title and research theme EM

5.1. Composites

Kruijer, Ir. M. (PhD 3) Reinforced Thermoplastic Pipes MeMa
Loendersloot, Ir. R. (PhD 3) Resin Transfer Moulding CoMe
Thijje, Ir. R.H.W. ten (PhD 3) Resin Transfer Moulding CoMe
Villa-Rodriguez, Ir. B.H. (PhD 3) Resin Transfer Moulding CoMe
Wijskamp, Ir. S. (PhD 3) High Precision Rubber Pressing CoMe

6. Postdocs: name, country, project title, research theme EM and period of stay

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7. Short description of subprogrammes related to research school EM

7.1 Composites
The Composites Group conducts research into the mechanisms and modelling of deformation and failure of continuous fibre composites under different rates of loading. This modelling is combined with an experimental programme (for identifying the mechanisms operating) to establish material property data for the modelling and to test the modelling accuracy. In 2003, the Composites Group was transferred from the Applied Mechanics and Polymer Engineering group to the "van der Leeuw" chair in Production Technology. This was publicly announced by means of the inaugural lecture of prof. Akkerman in February 2004. Dr.ir. T.C. Bor joined the group in September. He will expand the research area of the group to metallic materials.

Composite Damage Development
These studies are aimed at gaining insight into damage development in continuous fibre reinforced plastics in order to optimise materials and structures with respect to impact performance. Most efforts were devoted to the “Large Diameter Reinforced Thermoplastic Pipe” programme. This Eureka funded programme is a co-operation with Pipelife Pipelife (NL), Seaflex AS (N), Sulzer Innotec (CH). Most efforts were directed towards steel cord reinforced polyethylene pipes for larger diameters than the currently commercially available 4” aramide reinforced pipe. The long term strength can be predicted by taking into account the time dependent response of the composite system, and the resulting reorientation of the reinforcement structure. The pipe fittings appeared to be a critical element for the pipes with steel reinforcement. Pull-out was identified to be a problem for this particular composite system. Experimentally based investigations were performed to identify and quantify the characteristics of this transverse shear mechanism.

High Precision Composites Moulding
Further progress was made in the NIVR funded programme on High Precision Rubber Press Forming of Thermoplastic Laminates. The full process cycle of pressing, cooling and trimming was successfully simulated and validated against actual demonstrator products (stiffener ribs for the wing leading edge of the new Airbus A380 aircraft). This part of the work was reported in the PhD thesis of E.A.D. Lamers (May 2004). The work on residual stresses and process distortions was continued by S. Wijskamp, resulting in the identification of previously unknown mechanisms. This work will be concluded in 2005.

Resin Transfer Moulding
The major part of the research work on Resin Transfer Moulding is performed in collaboration with the National Aerospace Laboratory (NLR). The simulation method of the braiding process was improved and extended, e.g. to include zones with different surface characteristics (slip). The micro-geometry of braided specimens was investigated for subsequent micromechanical predictions of the thermo-elastic properties of braid reinforced composite materials. These will be employed to predict the overall stiffness of composite components.

The investigations on permeability focused on the analysis of statistical effects. The micro-geometry of carbon Non Crimp Fabrics was analysed to find the distribution of flow channel dimensions. These were subsequently used to predict the effects of these distributed properties on the overall macroscopic permeability, by means of dedicated microscopic Stokes flow solvers, combined with a macroscopic network analysis. The distribution in properties leads to a significant decrease of the permeability, compared with the results for a network with a uniform averaged geometry only. Further work was devoted to other textile structures, i.e. biaxial woven fabrics and triaxial braids.

A new NIVR funded project started on a national round robin exercise on permeability
measurements, in collaboration with the Centre of Lightweight Structures and the NLR. Permeability is a material property which is recognized as very difficult to measure in a reproducible manner, not only within a single laboratory but even more between different labs. The UT is the prime responsible partner for the out-of-plane permeability measurements.

Further work on NCF’s was performed within the Framework 5 programme FALCOM (Failure, Performance and Processing Prediction for Enhanced Design with NCF Composites). Stability issues in the finite element formulation for drapeability analysis required significant effort. These were eventually solved by replacing the mixed formulation with stress and displacement degrees of freedom by using only displacement degrees of freedom.

All activities within the programme are related to the research themes “Mechanics of Materials” and “Computational Mechanics”.

8. **Referred scientific publications related to research school EM**

8.1 **Referred journals**

8.2 **Books, chapters in books**

8.3 **Referred proceedings**


9. **Dissertations: related to research school EM: name, title, university, date and advisors**

Name: Lamers, E.A.D.
Title: Shape distortions in fabric reinforced composite products due to processing induced fibre reorientation, 23rd April 2004, ISBN 90-365-2043-6
Advisor: Prof. Dr.Ir. R. Akkerman, Prof.Dr.Ir. J. Huétink
Current position:

10. **Membership editorial boards international journals**
11. **Keynote lectures**

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12. **Membership International Scientific Committees.**

Prof. Dr. Ir. R. Akkerman
- Member of the organising committee of the Composites minisymposium within the Esaform conference

Dr. Ir. L. Warnet
- Member of the organising committee of the ESIS TC4 conference on Fracture of Polymers, Composites and Adhesives.

13. **Awards and patents**

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14. **Overview of research input and output 2004**

14.1 *Input “Production Technology” related to EM, 2004*

<table>
<thead>
<tr>
<th>Sources of financing</th>
<th>Total number</th>
<th>fte</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
<td>Senior academic staff</td>
<td>3</td>
<td>-</td>
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<td>Supporting staff</td>
<td>1</td>
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<tr>
<td>PhD</td>
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<tr>
<td>Postdocs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td><strong>6</strong></td>
</tr>
</tbody>
</table>

1 Sources of financing:
1: University
2: STW, SON, NOW, FOM
3: Industry, TNO, Brite-Euram, Nuffic, Min. Econ. Affairs, etc.

2 No research input involved for supporting staff.

3 Research input per PhD per year: 0.8 fte
14.2 Output “Production Technology” related to EM, 2004

<table>
<thead>
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<th></th>
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<tr>
<td>Scientific publications: refereed journals</td>
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<tr>
<td>Scientific publications: refereed proceedings</td>
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<td>Scientific reports</td>
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<tr>
<td>PhD theses</td>
<td>1</td>
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</tbody>
</table>

* In co-operation with other EM-groups

15. Co-operation with other EM-groups: project title, participating groups, participants and research input in fte.

Project Title: High Precision Rubber Forming
Participating Groups: Production Technology (UT), Applied Mechanics (UT)
Participants: Prof.dr.ir. R. Akkerman (UT), Prof. Dr. Ir. J Huétink (UT), Dr.ir. T. Meinders (UT), Ir. E.A.D. Lamers (UT), Ir. S. Wijskamp (UT)
Research Input in fte: 2.2
### A Summaries of EM-dissertations completed in 2004

In 2004 sixteen dissertations were completed within the context of the Research School Engineering Mechanics. This appendix contains summaries and further information on each of them. Included are:

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdalla, M.M.</td>
<td>Applications of the Cellular Automata, Paradigm in Structural Analysis and Design</td>
<td>A.3</td>
</tr>
<tr>
<td>Bekers, D.J.</td>
<td>Finite antenna arrays: An eigencurrent approach drilling</td>
<td>A.5</td>
</tr>
<tr>
<td>Gunawan, A.Y.</td>
<td>Stability of immersed liquid threads</td>
<td>A.6</td>
</tr>
<tr>
<td>Hesseling, R.J.</td>
<td>Active Restraint Systems - Feedback Control of Occupant Motion</td>
<td>A.8</td>
</tr>
<tr>
<td>Jacobs, J.H.</td>
<td>Performance quantification and simulation optimization of manufacturing flow lines</td>
<td>A.10</td>
</tr>
<tr>
<td>Kononov, A.</td>
<td>Foundations of acoustic methods used in non-destructive inspection of laminated materials</td>
<td>A.12</td>
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<td>Lamers, E.A.D.</td>
<td>Shape distortions in fabric reinforced composite products due to processing induced fibre reorientation</td>
<td>A.13</td>
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<tr>
<td>Liu, Chuanjun</td>
<td>On the Prediction of Damage and Fracture Strength of Notched Composites</td>
<td>A.14</td>
</tr>
<tr>
<td>Masen, M.A.</td>
<td>Abrasive tool wear in metal forming processes</td>
<td>A.17</td>
</tr>
<tr>
<td>Post, J.</td>
<td>On the constitutive behaviour of Sandvik Nanoflex: modelling, experiments and multi-stage forming</td>
<td>A.18</td>
</tr>
<tr>
<td>Stijnen, J.M.A.</td>
<td>Interaction between the mitral and aortic heart valve- an experimental and computational study</td>
<td>A.20</td>
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<tr>
<td>Tasic, B.</td>
<td>Numerical methods for solving ODE flow</td>
<td>A.22</td>
</tr>
<tr>
<td>Verhoeven, J.C.J.</td>
<td>Modelling laser percussion drilling</td>
<td>A.24</td>
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<tr>
<td>Visser, R.</td>
<td>A boundary element approach to acoustic radiation and source identification</td>
<td>A.28</td>
</tr>
<tr>
<td>Zandbergen P.</td>
<td>A composite beam as a multifunctional suspension component</td>
<td>A.30</td>
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</tbody>
</table>
Applications of the Cellular Automata, Paradigm in Structural Analysis and Design

Abdalla, M.M.

Advisor: Prof. Dr. Z. Gürdal
Prof. Dr. ir. F. van Keulen

Delft University of Technology, 2004

EM research theme: Structural Mechanics

A recently emerging approach based on the use of the cellular automata (CA) paradigm is aimed at addressing the automated combined analysis and design of one-, two-, and three-dimensional elastic systems within a massively parallel computational environment. Implementation of the methods of cellular automata to the design of structural systems is, in some sense, an attempt for a simultaneous solution of the state and design variables that appear in the highly nonlinear governing differential equations and associated optimality conditions. The main advantages of CA for structural optimizations are 1) its potential for massively parallel implementation on advanced hardware, 2) both the analysis and design are treated locally, and 3) it lends itself readily to optimality based approaches where the solution of the field problem and the design problem are arrived at simultaneously.

An algorithm for designing structures for eigenvalue requirements was presented. Conceptually, this was an important area of investigation because the local nature of CA algorithms would, at least apparently, be challenged by the global nature of the eigenvalue response. The proposed algorithm was designed to be fully local in nature, and thus suitable for CA type implementation. The algorithm was applied to the design of Euler-Bernoulli columns against buckling. The analysis rule used to predict displacements was, for the first time, derived using energy principles. The CA combined analysis and design algorithm proved effective in accurately predicting optimal column shapes and the corresponding buckling mode shapes.

CA topology design algorithm was presented where the design rules for minimum compliance design of two-dimensional linearly elastic continuum topology were derived using variational calculus. The CA design rule was obtained based on the continuous optimality criteria interpreted as local Kuhn-Tucker conditions. As such, the design rule at each cell involved the solution of a simple one-dimensional optimization problem. The CA analysis rule was derived, similarly to the eigenvalue design work, based on energy minimization. Numerical experiments with the proposed algorithm indicated that the CA design rule is quite robust and does not suffer from checkerboard patterns, mesh-dependent topologies, or numerical instabilities. Given the simplicity of the CA algorithm, it became clear that CA is a good candidate as a topology design tool.

Topology optimization to minimize the compliance of a structure required a detailed CA lattice to capture topological features. In this respect, it was found that the CA analysis rule converged rather slowly. The deterioration of CA convergence rate with lattice refinement was to be expected given that CA relied completely on local exchange of information. In a hypothetical ideal CA computing machine, where all cells are updated in parallel at a high rate, convergence rate deterioration would pose no particular problems. The efficiency of CA would still be considerable due to the simplicity of the processing elements. On the other hand, such deterioration in convergence rate would be a significant limiting factor when CA is used on existing serial processors.
Encouraged by the success of optimality-based CA design rules in topology optimization, CA design rules for nonlinear problems showing limit point behavior were next derived using rigorous optimality conditions. The design rule was successfully formulated as a local cell-level optimization problem. The CA design rule was coupled to nonlinear finite element analysis to solve the problem of shape design of a MEMS microbeam. The convergence of the CA design rule was quite fast requiring only twenty to thirty nonlinear finite element analyses. The results confirmed that local design rules based on optimality perform satisfactorily and could be indeed considered a general method for deriving CA design rules.

The structural response of MEMS microbeam is nonlinear due to the nonlinear dependence of electrostatic load on the microbeam deflection, and exhibits limit point (pull-in) behavior. We considered optimizing the shape of a capacitive micro-beam for maximum pull-in voltage. Extensive results for different beam boundary conditions were generated. The optimization results indicated that substantial increase in pull-in voltage can be achieved by varying the width and/or thickness distribution.

The implementation of CA as combined analysis and design tool where both CA analysis rules and CA design rules are applied to obtain a final converged design together with the corresponding displacements can be considered to be established at the algorithmic level. A combination of energy minimization for the derivation of the analysis rule and optimality for the design rule is generally applicable for a wide range of structural problems. The main challenges lie mainly in devising suitable hardware and software implementations where the CA computational advantage stemming from massive parallelism would be clearly demonstrated.
Finite Antenna Arrays: An Eigencurrent Approach

D.J. Bekers

Advisor: Prof. Dr. A.G. Tijhuis  
Prof. Dr. Ir. C.J. van Duijn  
Co-advisor: Dr. Ir. S.J.L. van Eijndhoven

Eindhoven University of Technology, 2004  
ISBN 90-386-1012-2  

EM research theme: Mechanics of Materials

No summary in English available.
Stability of Immersed Liquid Threads

Gunawan, A.Y.

Advisors: Prof. Dr. J. Molenaar
           Prof. Dr. Ir. C.J. van Duijn
Co-advisor: Dr. Ir. A.A.F. van de Ven

Eindhoven University of Technology, 2004
ISBN 90-386-0752-0

EM research theme: Mechanics of Materials

In a polymer blending process, relatively big drops of one material are immersed into a shear flow of a second material. Due to the shear stresses, long threads are formed. At some moment a thread may become so thin that the interfacial stress (surface tension) becomes important. The effect of the interfacial stress is a tendency to attain the drop-shape. Initiated by random perturbations, surface waves may develop along the thread. Driven by surface tension, these waves may grow or attenuate in amplitude, depending on the stability of the system. In an unstable state, the thread will eventually break up into an array of small spherical droplets.

The main interest of this thesis is to consider two unexpected phenomena observed in experiments: first, in-phase and out-of-phase break-up as reported by Knops (1997) and Elemans et al. (1997) for parallel polymeric liquid threads, and second, a stable string (thread) in droplet-string formation as reported by Migler (2001) in a concentrated polymer blend. The experiments reported by Knops (1997) and Elemans et al. (1997) reveal that the interactions between the threads are of essential relevance for the way they break up. The experiments on shear between plates reported by Migler (2001) reveal that if the size of the string becomes comparable to the gap width, the wall effect (confinement) suppresses the instability of the string.

In this thesis, the origin of the phenomena described above and the dependence on the geometrical and rheological parameters is studied by analytical means. The dynamical behaviour of liquid threads immersed in a fluid is considered in relation to surface tension, viscous forces, presence of a wall and external flow. In most of this work the fluids are assumed to be incompressible, Newtonian, and so viscous that the creeping flow approximation is applicable. So, the system is governed by the equation of continuity and the Stokes equations. The thread surface is perturbed by a small random perturbation and it is studied how this evolves in time. The governing equations are solved by means of separation of variables. In this, the dependence on the azimuthal directions is written in the form of (complex) Fourier expansions. Substitution of the general solution into the boundary conditions yields an infinite set of linear equations for the unknown coefficients of the expansion. This set is solved using the method of moments. From this the so-called growth rate is calculated, which is a measure for the growth (or decay) of the perturbations. A positive growth rate indicates that the system is unstable, a negative one that it is stable.

First, the stability of a single Newtonian thread immersed in an unconfined region is considered. The stability is studied for two types of driving forces: pure surface tension, and surface tension together with shear flow. Under influence of surface tension only, the thread turns out to be unstable. Under influence of both surface tension and shear flow, the instability is suppressed provided that the applied shear is large enough.

Next, as an extension of the single-thread case, the (in)stability of a set of immersed threads under influence of surface tension is considered: first, the two-threads system, and, second, the
many-threads system. Here, the equations are formulated in two, or more, systems of cylindrical coordinates, each one connected to one of the threads. For the two-threads system, the stability is examined based on is zero-order and a first-order Fourier expansion; the improvement due to a higher-order expansion turned out to be rather small. It is found that the thread can break up either in-phase or out-of-phase. The break-up behaviour depends on the ratio of the viscosities and the distance between the centers of the threads. These findings are in full agreement with the experimental results reported by Knops (1997) and Elemans et al. (1997).

For the many-threads system, the stability is investigated for two types of configuration: a system of \( L \) threads on a row, and a system of threads at triangular vertices. For a system with \( L \) threads on a row, the growth rate of the perturbations can be calculated by optimizing over only \( L \) so-called basic phase patterns. For the triangular configurations the break-up pattern depends on the type of triangle, i.e. an equilateral triangle or a non-equilateral one.

For fluids with equal viscosities, the growth rate of a set of parallel threads on a row is calculated using Hankel transformations. An expression for the upper bound of the growth rate is derived. This upper bound turns out to be sharp estimate for the maximum growth rate of the perturbations.

Finally, the study is extended to non-Newtonian fluids. The stability of a viscoelastic thread immersed in a tube filled with a Newtonian fluid is considered. As constitutive relation for the thread Jeffreys model is applied. The thread is moving in the tube due to a prescribed constant pressure gradient (Poiseuille flow). The effects of the ratio of viscosities, fluid elasticity, confinement and prescribed flow, on the stability of the immersed thread are studied. The more viscous a thread is, the more time it takes to break up. However, a viscoelastic thread breaks up faster and in larger droplets than a Newtonian one with the same viscosity. The elasticity has not much influence on the magnitude of the eventual droplets, and the thread breaks up slower when the degree of confinement is higher. A critical gap width beyond which the presence of the wall of the tube has no longer an effect on the stability of the thread is found. In case of a Newtonian thread, the Poiseuille flow causes the thread to be oscillatory unstable with the growth rate equal to the one within a fluid at rest, whereas, in case of a viscoelastic thread, the Poiseuille flow contributes to both the real and the imaginary part of the growth rate of the perturbation. It is found that a viscoelastic thread immersed in a Poiseuille flow will break up faster than one within a fluid at rest. So, in short, Poiseuille flow destabilizes the thread but shear flow stabilizes it.

From the point of view of blending the present results may provide important insights for the control of the production process. For example, they yield insights into characteristic drop formation times, spatial distributions of the droplets and droplets or strings (liquid threads) formation. The present results show how the blending process can be controlled by adjusting the properties of the fluids, the geometrical properties of the system and the type of an imposed flow.
Active Restraint Systems
Feedback Control of Occupant Motion

Hesseling, R.J.

Advisor: Prof. Dr. Ir. M. Steinbuch
Prof. Dr. Ir. P.J.J. van den Bosch
Co-advisor: Dr. Ir. F.E. Veldpaus

Eindhoven University of Technology, 2004
ISBN 90-386-2616-9

EM research theme: Structural Dynamics

Major drawbacks of transportation by motor vehicles are crashes and the consequences thereof like injuries and fatalities. The safety belt and the airbag, often referred to as the restraint system, have been introduced to reduce the number and severity of injuries. The restraint system should behave differently for different crashes and/or different occupants. State-of-the-art belt and airbag systems are "adaptive", meaning that they have a limited set of modes of operation to adapt to different occupants and crashes. Examples of these modes of operation are different deformation characteristics of the load limiter in the belt system and different points of triggering the inflators of the airbag.

Design of such modes of operation focus on achieving a satisfactorily low risk of injury for classes of occupants and crashes. Examples of measures for the risk of injury are the maximum chest acceleration, the maximum chest deflection and the maximum head acceleration. Appropriate modes of operation are typically obtained by minimization of the risk of injuries, using complex nonlinear models to simulate a vehicle and occupant, subjected to a crash test. Such an approach is time-consuming and the obtained modes are a compromis.

In this thesis, an innovative view on (the design of) restraint systems is elaborated. The idea is to add sensors and actuators in order to allow feedback control of the restraint system. The airbag and/or the belt are manipulated during the crash to force one or more occupant variables, representing the risk of injuries, to follow an a priori defined reference signal. This reference signal represents the lowest possible risk of injuries. This view on restraint systems can be seen as a starting point for the development of future restraint systems, and as a basis for an effective design expedient for modes of operation of real world restraint system components.

The concept of active restraint systems has been elaborated using the numerical model of a mid-size male dummy as the "driver" of a mid-size passenger car, subjected to the US-NCAP frontal crash test. To manipulate the airbag, the size of the vent in the airbag and the mass flow into the airbag have been chosen. To manipulate the belt, the force in the belt section near the load limiter, has been chosen. The chosen occupant variables are the chest acceleration, the head acceleration and the chest deflection. Reference signals are pragmatically determined.

Controllers to manipulate the airbag or the belt, cannot be designed using the available numerical model, since that is nonlinear and far too complex. Therefore, linear time-invariant (LTI) control design models are derived to approximate the relevant dynamic behavior of the restraint system, the dummy and their interactions. These control design models are obtained with the approximate realization method, using the responses of the occupant variables to stepwise perturbations in the manipulated variables of the restraint system. Low order feedback controllers are designed using "looshaping" techniques, aiming at a stable closed loop system with satisfactory performance. Finally, the controllers are implemented and evaluated in the closed loop system with the complex nonlinear model.
In comparison with the original restraint system, control of the chest acceleration by manipulation of the belt force can reduce the risk of chest injuries by 60%. Control of the head acceleration by manipulation of the vent size reduces the risk of head injuries by 50%. Appropriate simultaneous control of the chest and the head acceleration reduces the risk of injury to the chest and head by 50% or more.

The modelling and the control design strategy have also been applied successfully to arrive at a controller for the chest deflection by manipulation of the belt force. In addition, the strategies have been applied successfully to arrive at controllers for the chest and the head acceleration for the case of a small female dummy as the "driver".

It has become clear that the dynamic behavior of the belt and/or the airbag, interacting with the dummy can be considered linear, at least for control design purposes. Besides that, low order feedback controllers are effective to enforce the desired behavior of the complex nonlinear model. Furthermore, it turned out that the control design problem for simultaneous control of the head acceleration and the chest acceleration by manipulation of the vent size and the belt force can be treated as a decoupled control design problem. The modelling and control design strategy have shown to be effective and efficient. Insight into appropriate modes of operation for adaptive restraint systems can be obtained from results of closed loop simulations.
Performance Quantification and Simulation Optimization of manufacturing Flow Lines

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This PhD project was part of the ADOPT-project funded by the Dutch Technology Foundation STW. ADOPT is a joint effort of research activities at the Eindhoven University of Technology and the Delft University of Technology. The ADOPT-project aims to develop numerical optimization techniques for engineering design problems with a computationally expensive analysis model in the loop. The acronym ADOPT stands for Approximate Design OPTimization referring to the optimization approach followed in the project. A sequence of approximate optimization subproblems is generated and solved. This Sequential Approximate Optimization (SAO) approach avoids a direct coupling between the computationally expensive analysis model and the evaluation intensive optimizer. Through the approximations specific problem properties observed in certain application domains can be taken into account. In this regard, the ADOPT-project considers the treatment of stochastic and noisy responses, discontinuities in responses, uncertain design variables, and integer design variables, as well as the application to a range of mechanical engineering design problems.

The contribution of the thesis is threefold. First, a software framework for sequential approximate optimization has been developed in the scope of the ADOPT-project. The framework provides an open environment for the specification and implementation of SAO strategies. This enables one to re-define the SAO strategy and to tailor the approximations such that they match well with the problem properties at hand. Secondly, approximation methods are developed specifically for simulation-based optimization of manufacturing flow lines. The analysis model involved in this type of problems is a discrete-event simulation model. Optimization properties that arise relate to the stochastic responses from the simulation model and the integer design variables, such as the numbers of machines and batch sizes. Thirdly, the thesis contributes on the development of the so-called Effective Process Time (EPT) approach. EPT is a means to characterize flow time performance from a queueing physics point of view. The new metric gives the opportunity to arrive at simple but accurate simulation models since it avoids the detailed modeling of all kinds of processing disturbances present at the shop floor.

The framework for sequential approximate optimization has been developed using an object-oriented class structure and contains a toolbox of methods, (external) numerical routines, and interfaces to other software. The framework enables to specify (i) the optimization problem, including the simulation model for the evaluation of the objective function and constraints, (ii) the SAO sequence defining the order of computational steps, and (iii) the numerical routines used in each step. A typical SAO sequence consists of a number of computational steps, regarding to, e.g., the design of experiments, the approximation building, and the approximate optimization solving. The numerical routines used in the SAO steps are represented as 'black-box' functions, e.g. from external software libraries. The framework enables the user to (re-)specify or extend the SAO sequence and computational steps, which is generally not possible in most available SAO implementations. A ten-bar truss design problem with fixed loads and uncertain loads demonstrates the flexibility of the framework. Within the ADOPT-project, the SAO framework has
been applied to a broader range of optimization problems, including optimization of Microelectromechanical Systems (MEMS) and manufacturing systems, and optimization for robustness and reliability.

The Effective Process Time (EPT) approach is a means to characterize capacity and variability in workstations of manufacturing systems. The concept of EPT has already been formulated in work of others, but no method has been proposed to actually measure EPT in operating factories or simulation models. EPT is an overall measure that includes process time of a product and process disturbances, such as machine failure, setup times, and operator availability. The aim is to develop algorithms which compute the EPT capacity and variability measures based on data from the manufacturing system. The computed EPT values can be used as performance measure that relate to the queueing physics of workstations and indicate the flow time performance of a manufacturing system. Algorithms have been developed for workstations that manufacture single products and workstations that manufacture products in batches. Both types of workstations are commonly used in semiconductor manufacturing. The EPT algorithms have been tested using small examples of simulation models and have been applied on operational data of a Philips Semiconductor wafer fab. This application resulted in simulation meta models of each workstation, which may be combined into a meta model of the complete factory.

Sequential approximate optimization of manufacturing systems requires good quality approximation models. In this thesis manufacturing systems are optimized for flow time performance. Queueing theory shows that flow time behaves highly non-linear for capacity-related design variables. The newly proposed approximation functions developed for the SAO method are able to characterize these nonlinearities. In earlier work the use of linear regression models was suggested. In this thesis, the method is extended and generalized using the concept of EPT. With the proposed EPT parameters available, the flow time performance of a workstation can be characterized. The idea is to use the EPT parameters in the flow time approximation model and include queueing physics in the response surfaces. The parameters of the response surface model are estimated based on simulation responses of the discrete-event model. This new type of approximation has been implemented in the SAO framework. The proposed optimization approach has been successfully tested on two simulation-based design problems: a four-station flow line and a twelve-station re-entrant flow line. Both pure integer and mixed-integer cases were considered and the optimization problems included up to twelve design variables.
Ultrasonic inspection has become one of the most popular nondestructive testing techniques because of its versatility and easy operation. It can detect internal cracks and inclusion type defects in homogeneous or layered materials, often without much difficulty. Layered materials, which are also called laminated materials, have become widely used in the aerospace industry, naval engineering and many other industries, and thus have attracted considerable interest of researchers in the last two decades.

The present work can logically be subdivided into two parts: conventional ultrasonic methods and laser driven techniques. First, the conventional ultrasonic methods applied to a planar laminated structure immersed in a fluid are considered from a general point of view. Next, the study is extended to laser ultrasonic methods. An extended physical description of phenomenon of elastic wave excitation due to laser irradiation is given. Then, the focus is shifted to the directivity of laser generated ultrasound and various methods of control. As a means to achieve a narrow directivity of radiation, the moving laser source is introduced. Special properties of the radiation due to moving sources such as directivity and spectrum are described and analyzed thoroughly. Considerable part of the work is devoted to the theoretical study of ultrasound generation in laminates by moving laser sources. The following cases have been investigated: a) rectilinear motion of the laser beam; b) oscillatory motion of the beam; c) saw-tooth motion; d) uniform circular motion of the beam. Finally, in the last chapter we introduce more realistic laminates with anisotropic elastic properties. Such laminates consist of one or many fiber-reinforced lamina that are bonded together in order to achieve better structural properties and performance over conventional materials.
Shape distortions in fabric reinforced composite products due to processing induced fibre reorientation

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EM research theme: Computational Mechanics

Woven fabric reinforced composite materials are typically applied in plate or shell structures, such as ribs, stiffeners and skins. Products of these types can be produced with several production processes. A few examples are diaphragm forming, matched metal die forming and rubber press forming. Shape distortions can occur during manufacturing of composite products. During the development stage of the products these distortions often exceed the high dimensional accuracy required in, for example; the aeronautical and car industry. Costly trial and error methods are generally applied to meet the dimensional accuracy. Modelling the shape distortions on beforehand can aid to reduce the development costs of these products.

To predict shape distortions, the mechanical properties (stiffness) and thermal expansion behaviour (shrinkage and warpage), referred to as thermo elastic properties, of the product need to lie included in the model. The distortions can be introduced by, for example, thermal loading or stresses induced by forming. Obviously, the materials used and the lay up of the composite affect the resulting behaviour. However, due to processing induced fibre reorientation, the thermo elastic properties of the composite change locally as a function of the fibre reorientation. The fibre arrangement and resulting local composite properties need to be taken into account in order to model the product distortions.

Here, the objective is to model the shape distortions using a Finite Element method with computationally effective plate elements. First, the fibre reorientation during processing is predicted, including the processing induced fibre stresses. The processing induced fibre reorientation, or draping, is considered for single and multi layered bi axial fabric composites. The material model accounts for the intro and inter-ply shear behaviour of these composites. The drape model predicts a clear dependency between the drape-ability and lay-up of multi layered composites. Experiments on rubber press formed fabric reinforced thermoplastic laminates confirm this dependency.

Secondly, the product distortions are predicted, accounting for the locally changed composite properties due to the fibre reorientation during forming. A weave model, to predict the thermo-elastic properties of the deformed weave while accounting for the local structure of the weave, is combined with the results from the drape model. The results are validated on the shape distortions of a woven fabric reinforced thermoplastic composite with a double dome geometry. Additionally, the shape distortions of a hemispherical product and it wing leading edge stiffener are demonstrated.
On the Prediction of Damage and Fracture Strength of Notched Composites

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EM research theme: Mechanics of Materials

Fibre reinforced plastics (FRPs) are increasingly used as lightweight structural materials. However, the anisotropy and heterogeneous features of composites result in a variety of possibilities of failure. Due to this reason, the failure behaviour of these anisotropic inhomogeneous materials is insufficiently understood. Consequently, product strength cannot be predicted with sufficient accuracy and hence the strength advantage of the materials cannot be utilised to the fullest. This is one of the main problems against more extensive applications of the materials. In traditional strength theories, the consequence of the matrix-dominated failure in composites is not adequately handled, or even completely neglected. Furthermore, strong interaction/intersection exists between different types or failure. The interaction and its effect on the evolution of the matrix-dominated failure as well as its effect on the final failure of a notched composite laminate has not been sufficiently addressed so far. Additionally, due to the locally intensified stresses, a notch may induce extra forms of matrix cracks beside those observed in plain specimens. Specifically, the study focuses on symmetric cross-ply laminates, which are composed of unidirectional layers laid in such a way that the fibre directions in two neighbouring 0° and 90° layers are perpendicular to each other. The typical forms of matrix-dominated failure in such a notched cross-ply laminate include notch-induced splits (NIS), notch-induced delamination (NID) in addition to transverse cracks (TC) and conventional longitudinal cracks (CLC).

The present thesis presents a new progressive failure model and its applications for studying the matrix-dominated failure in notched composites. The occurrence of the various damage systems and their interaction is taken into account in double-edge-notched laminates with semi-circular notches — the specimens have the shape of a dumb-hell. The consequence of the damage on the stress in the critical longitudinal fibres at the notch not is then established. It is critical because the fibres there are most severely loaded and the first fibre/fibre-bundle fracture event occurs in these areas. This explains, in rather detail, the fact that composites arc less sensitive to notches than it would be concluded based on linear elastic theory.

The so-called local-global method is used to establish the progressive failure model. Constitutively, it is assumed that the laminate is made up of homogeneous orthotropic layers before and after matrix-dominated failure occurs. Consequently, the average reduced layer stiffness as a function of the applied strain is separated from the reduced stiffness of the laminate, and it is used as the input of the FEM model. Firstly, a stiffness reduction model, which is represented by a local stiffness reduction and local stress redistribution, is introduced to formulate the matrix-dominated failures in FRP laminates. A one-step stiffness reduction is assumed to transfer global stiffness degeneration into local stiffness reduction. Then, a laminate is physically described as a sequence of stacked homogeneous orthotropic layers with thin interfacial layers in between every two neighbouring layers. Accordingly, two basic material components are then introduced: the single lamina and the interfacial layer. The constitutive behaviour of is single lamina is assumed to be linear elastic, except for the nonlinear behaviour caused by matrix failure. Specific forms of failure can only occur in these two types of essential
entities. Furthermore, a few failure criteria are separately applied to the relevant entities to induce the multi-modes of local matrix failure.

A few principal issues, which might be objected to the present progressive failure model and its applications, are investigated. First of all, due to the local singular stresses at a crack-tip, the calculated local stresses will depend on the numerical discretization. To eventually remove this kind of mesh dependence, an identical mesh can be used in the evaluation of the local critical stresses and in stress estimation. However, the calculated local stresses, as a function of the local residual stiffness, show that a relatively high local residual stiffness, i.e. 5% to 10% of the originals, will be effective in reducing the mesh dependence. Secondly, the growth direction of the matrix-dominated failure, from a macro mechanics point of view, will be dominated by the fibre orientation in each layer. The model is then calibrated to experiments where specific matrix-dominated failure modes can be obtained in an isolated manner without a disturbing contribution of other failure modes. Moreover, the FEM parameter study indicates that the model predictions will be reproduced if the FEM model parameters are reasonably chosen. Finally, the presented numerical results demonstrate that the predictions of the present model agree satisfactorily with analytical solutions in stress estimations, and with experimental observations for simple cracking circumstances.

The notches accelerate the initiation and the growth of the matrix-dominated damage in forms of transverse cracks, NIS and NID. These matrix-dominated damages, particularly NIS and NID, dominate the failure process of a notched cross-ply laminate. The matrix-dominated damages in front of the notch significantly reduce the stress concentrations, and hence the fibre fracture in these critically damaged areas is delayed. The notch size and the lamina thickness are two her parameters determining the formation and propagation of the matrix-dominated damage and the ultimate failure mode of the laminates, and therefore the ultimate strength of the notched laminates. Ultimate failure may occur in a fibre-dominated form or in a form of interlaminar delamination in case of an unfavourable combination of a larger notch-width aspect ratio \(2R/W\), see its definition in section 4.2, chapter 4) and a larger lamina thickness.

The constructed numerical model is used to study the progressive formation of transverse cracks, NIS and NID in notched cross-ply laminates. First, the formation of transverse cracks from the notch is simulated. The notch size effect and the lamina thickness effect on the formation of transverse cracks are numerically investigated. The local stresses in the longitudinal layers increase with the development of the transverse cracks. Then, the formation of NIS with the influence of other forms of matrix failure e.g. transverse cracking and interlaminar delamination, is examined. The NIS growth is linearly proportional to the far-field applied strain. The numerical results indicate that the propagation of the NIS and NID is rather sensitive to the critical values applied in the failure criteria. Particularly, the simulation here gives a sense of the interaction effect between MS and the transverse cracks and between NIS and NID. For a correct prediction of the evolution of the local damage, the interaction effect has to be taken into account indeed. The simulations finally lead to the estimation of the most important aspects of the critical damage zone, the width of the damage zone and the growth rate of NIS. The final effect is a large critical damage zone with a uniform distribution of relieved stress in the critical longitudinal layer next to each of the notches. Moreover, the present modelling approach leads to a good understanding of other effects, including the notch-size effect, thickness effect, and further the stacking sequence effect. All these parameters affect the formation of the critical damage zones, and the local stresses in the critical damage zones. The results are compared with the experimental observations.

One of the most striking results is that a new approach is established to predict the ultimate strength of notched laminates. The new approach is applied to predict the ultimate strength of the notched cross-ply laminates. It is based on the estimation of the local stress in the critical part of the damage zones around the notches. The 0\(^\circ\) layers are (as in most composites) the critical element of the composite. So the stress in the 0\(^\circ\) layers near the notch is evaluated under the influence of the system. A method was applied to decompose the total local stress concentration
into several parts, e.g. the geometrical contribution, the stacking-ratio contribution, and the damage contribution. Combined with a single numerical simulation for a notched sample, the damage dependent stress concentration for this type of notched laminates can be established for different notches and applied to predict the ultimate strength for this type of laminates with different notches. The applications of this method show that the model prediction agrees with the experimental observations very satisfactorily.
Tool-life is an important parameter in industrial metal forming processes and is determined by demands and requirements of the product; when the final product shows deviations in shape or the surface quality is insufficient, the tool needs to be refurbished or replaced. Recent developments, among other things the processing of non-conventional materials and the reduced use of lubricants, result in a more severe load on the tool and therefore in a decrease of the tool-life. An example is abrasive wear of the tool during the forming operation hard particles of the deforming product plough and scratch through the tool surface.

In this work a model is presented that quantifies this abrasive tool wear. The foundation of the model is on the level of surface roughness. The surface micro-geometry of both the abrasive surface and the wearing tool are measured using an interferometer. Based on this data, the surface geometry in each of the micro-contacts is represented using a so-called asperity. Such an asperity has either a conical or a paraboloidal shape and is fitted through the surface geometry. The behaviour of an asperity, or summit, in contact with a deforming counter surface is described in an elastic-elastoplastic-plastic contact model. Using experiments, the abrasive wear of model-summits is studied. These results are embedded in an empirical model. The summation over all the summits in contact finally results in the abrasive wear behaviour in the contact of rough surfaces.

The developed model distinguishes itself from conventional abrasive wear models by new elements, such as the elastic-elastoplastic-plastic model for sliding contacts and the deterministic modelling of micro-contacts, which enables describing the growth and merger of asperities with increasing load. Furthermore, the deterministic approach is required for a correct description of the abrasive wear process.

The model is applied to the wear of cast iron tools in the processing of tailor welded blanks. The results of the model agree with experimental results. Also it is shown that the application of a hard surface layer does not necessarily result in an increased resistance to abrasive wear, as the applied tool material in deep drawing operations is inhomogeneous and therefore quite difficult to apply a coating to. The application of intermediate layers can increase the wear resistance. The developed model can as well be applied to other processes where abrasive wear plays a significant role, for example in extrusion of aluminium and magnesium alloys.
Metastable stainless steels can be characterised by a good combination of corrosion resistance, strength, formability and a large crack resistance. These properties make these materials highly suitable for various applications. As these materials transform, their behaviour is much more complex than that of conventional steel types. Sandvik Nanoflex™ is one of these metastable austenitic steels, but it also includes two extra properties:

- Depending on the austenitising conditions and chemical composition, the material can become unstable to such an extent that stress-assisted transformation occurs as well as strain-induced transformation;

- The martensite phase of this material shows a substantial aging response (more than 1000 $N/mm^2$).

The behaviour of Nanoflex is characterised by two transformations. The first transforms the material during plastic deformation. This is strain-induced transformation. The second transforms the material without plastic deformation. This is stress-assisted transformation. These transformations may occur simultaneously or consecutively. The degree of stress-assisted transformation depends particularly on the stability of the material. Due to these transformations, the description of the work hardening and the accompanying strains is much more complex than in the case of noel transformable steels. Both transformations depend on temperature and the stress state, which means that heat transport and friction during deformation cannot be neglected.

First, the behaviour of this material was mapped under various conditions. Transformation measurements were largely done by means of inductive sensors. Special attention was paid to the calibration of these sensors. In addition a model was constructed with which the deformation behaviour and the transformation behaviour can be simulated. This model is partly physically based, but macroscopic. The model was implemented in a dedicated FEM solver called CRYSTAL. This solver is an internal Philips code. Implementation involves a flexible approach, in which a material definition file is combined with lookup tables and neural networks, in order to create a proper formal separation between the solver and the constitutive model that allows easy adaptation of the model and material behaviour. The purpose of this setup is that:

- Developments in material behaviour and the solver can be implemented in parallel;
- In various models one executable can be used, which facilitates version management and protection;
- Complex material models can be used by non-specialists.

The implemented model was validated by means of a number of FEM calculations that were compared with martensite and hardness profiles in combination with product contours.
software program was developed for these validations. With this implemented model various calculations of different metal-forming process were made, including a multi-stage metal forming process consisting of three steps.

Finally the developed model and solver were used to carry out a process window study of a multi-stage metal forming processes, using standard Design and Analysis of Computer Experiments (DACE) tools. The model includes not only the deformation steps but also the intervals between the steps, as stress-assisted martensite transformation may occur during these intervals and because the temperature changes during the intervals. The product is then austenitised, after which it transforms again due to stress-assisted transformation. The results were processed and analysed with a program called 'Compact'.
Interaction between the mitral and aortic heart valve; an experimental and computational study

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In cardiac surgery, a failing native heart valve can be replaced by a mechanical pros-thesis, the design and orientation of implantation of which can be chosen deliberately by the surgeon. Due to the geometrical differences, the flow downstream a prosthetic valve could differ significantly from that downstream the native valve. Besides geometrical influences, also the orientation in which a non axi-symmetrical valve is implanted in mitral position largely influences the ventricular flow patterns down-stream. It is hypothesized that the left ventricular flow field can influence the timing of opening and closing of the aortic valve. In this way, the efficiency of the heart as a pump would depend partly on the geometry and orientation of implantation of a prosthetic mitral valve. Understanding this relation from basic physical principles would contribute to optimization of the choice of valve geometry and alignment in a specific patient.

A computational model that describes the relation between mitral valve orientation and the efficiency of the heart as a pump can be of major importance to predict a preferred valve orientation pre-operatively and patient specifically. The results of such a computational model must be assessed in a quantitative manner, by comparison to experimental measurements in equal circumstances. An experimental setup featuring a deforming rubber model ventricle was designed in which velocity fields were obtained using digital particle image velocimetry (DPIV). The geometry of the rubber ventricle model is based on MRI images of the heart of a healthy volunteer. In the setup, both the mitral and aortic orifices were equipped with Carbomedics bi-leaflet valves, and flow fields were obtained for two mutually perpendicular orientations of the mitral valve. A computational model is developed of the experimental setup, where simplifications were made to the geometry of the ventricular cavity and the mitral valve, and the timing of opening and closing of the valves was prescribed. The valve leaflets are represented by regions of increased viscosity. For both valve orientations, the flow fields predicted by the computational method are comparable to the experimental data. It is shown by both methods that the orientation of the mitral valve largely influences the global interaction of the valve with the ventricular flow patterns. However, a quantitative comparison between computations and experimental results shows that the measured velocities differ significantly from the computationally predicted velocities. These differences are attributed to simplified description of the geometry of the valves and the ventricular cavity in the computational model.

In light of the complex nature of the three dimensional flow in the ventricular cavity, a two dimensional setting was chosen to study the exact interaction between valve motion and local fluid flow. Valve motion and fluid flow was studied in a model of a stiff valve. The fluid velocity fields and the valve motion predicted by the computational method match with DPIV measurements in an in-vitro setup. It is concluded that the fictitious domain method used to model the fluid-structure interaction is a suitable method for describing the dynamic response of stiff heart valves. Further-more, it is concluded that the regurgitant volume that is necessary to close the valve, is depending on the stroke volume and the frequency of the flow pulses applied.
Since in the left ventricle the aortic and mitral valve are located side by side, an interdependence of the dynamic behavior of the valves is expected. To study this interdependence, the model previously used to study the fluid-structure interaction of a single valve leaflet is extended to accommodate a second valve. Thus, the fictitious domain method was applied to a two dimensional finite element model of a ventricle with a mitral and an aortic valve. Results show that the sum of the regurgitant volumes changes for variations in the flow conditions, realized by changing stroke volume or heart rate. Cycle-to-cycle variations in valve motion and regurgitant volumes were found to exist, depending on the characteristics of the flow applied, in terms of the Reynolds and Strouhal number. This finding is of major importance to studies involving bi-valve systems and to medical applications like heart valve replacements; investigation of only one cycle is no longer adequate. Using the same computational model, a change in rotation direction of the mitral valve was shown to cause significantly different ventricular flow patterns under the same flow conditions. The pump efficiency of the ventricle and the cycle-to-cycle variation of valve motion and regurgitant volumes were found to depend on valve orientation.

Based on simulations using the two dimensional ventricle model with two valves the hypothesis that the efficiency of the ventricle as a pump is depending on the orientation of the mitral valve is considered valid. Application of the method used to a three dimensional model ventricle with moving heart valves can lead to realistic predictions of actual loss of stroke volume due to valve regurgitation, for several orientations of both mitral and aortic valve prostheses as well as give directions for improvement of prosthetic valve design.

In conclusion, the three dimensional ventricular flow patterns were found to be largely dependent on the orientation of the mitral valve. The fictitious domain method was found a suitable method for predicting the dynamic response of stiff valves. An interdependence between aortic and mitral valve motion was found to exist and depend both on the applied flow and mitral valve orientation. This interdependence is reflected in the pump efficiency of the model ventricle.
Ordinary differential equations (ODEs) are present in almost every technical discipline. Electrical circuits, mechanical systems, control problems, physical and chemical processes, etc. are typically modelled by systems of ODEs. Many of these are autonomous. For example, in glass industry the common ODE problem is a deforming material blob, where one needs to obtain the boundary evolution of the molten glass. To solve such a problem, one needs to obtain the time evolution of a continuum of solutions, which is called a flow. Another example is coming from electrical networks where one is interested in the circuit behaviour under the influence of various initial values or variations of components parameters. The solution is again a flow, which needs to be obtained on a certain time interval.

Although the theory is extensive, solving a flow problem cannot be seen as a trivial task in general. Since not all ODEs can be solved analytically, the solution has to be obtained numerically. To do so one needs to perform a proper time discretisation. This discretisation is done by a numerical method for solving ODEs. Numerical methods are numerous and their application area depends on the nature of the problem. How to choose an appropriate numerical method for a particular problem depends on dimensionality, requested accuracy, stiffness, preservation of volume, energy, etc. Often one needs to use an implicit method, like for solving so-called stiff problems or problems where the preservation of the volume is an essential issue. Implicit methods introduce an additional problem in solving (non)linear system of equations at every time-level. To solve such a system, one needs to use Newton's iterative method. This is not a straightforward matter as the iteration function is not known explicitly.

In this thesis a new method is constructed based on existing implicit methods. To preserve favourable properties of these methods and avoid iteration, we apply in-verse interpolation. Inverse interpolation turns out to be a powerful tool for solving nonlinear systems coming from discretised ODEs. Moreover, the interpolation theory is rich and a variety of interpolation methods can be used in these settings. The natural choice is for a method which is not computationally expensive, like piece-wise linear interpolation. This method is easy to implement and does not require regular grids.

The method discussed in this thesis is referred to as the flow method. It can be based on any existing implicit integration method. The most interesting ones are linear multistep methods and Runge-Kutta methods that are used for solving stiff problems; in particular, BDF and methods based on Gaussian quadrature, such as Gauss, Radau and Lobatto, which are A(x)-stable. The flow method inherits this property and gives similar results. The method can also be constructed based on so-called symplectic methods, which are used for solving Hamiltonian problems. Some of these methods, like the midpoint rule, are implicit and introduce similar implementation difficulties. In problems, where the volume needs to be preserved during the computational time, the implementation of the flow method shows that this can be done with high accuracy even for large time scales.
The accuracy of the flow method depends on two sources of errors. The first one arises from discretisation and the second one from interpolation. The overall error should be controlled so that both errors are the same order. This can be achieved by choosing a proper time discretisation and a proper interpolation method.

A number of numerical examples illustrates the potential of the method. It is also shown that the flow method can be applied successfully for problems where the explicit time dependency is present via a forcing term only.
Since the first demonstrations of the ruby laser in 1960, lasers quickly found their way into different application areas. These applications range from the laser used in a CD-player via lasers used in surgery, to lasers that operate as a material processing tool. In this last area, the laser owes its success a great deal on its concentrated and contactless energy supply. It is for these reasons that the laser can be used for drilling when conventional techniques fail, as is the case for drilling holes in parts of gas turbine engines. Drilling these cooling holes is necessary because the gas from the combustion chamber flows along these parts thus exposing them to extremely high temperatures. Overheating these blades leads to damage. The desired cooling comes from relatively cold air flowing through the drilled holes. For drilling these cooling holes, conventional drilling techniques fail for two reasons: the diameter of the holes is very small (+1 mm) and the hard superalloy material the parts are made of. A promising alternative is therefore laser percussion drilling.

In laser percussion drilling multiple laser pulses are fired at the material. The drilling is achieved via two material removal mechanisms. Material is evaporated due to the laser energy and molten material is pushed out by the vaporization pressure, the so-called recoil pressure. First, the material is heated up by the laser energy. At some point the surface reaches the melting temperature. To achieve the phase change of the material, an extra amount of energy, the so-called latent heat of fusion, has to be supplied. The surface of the growing melt pool is constantly heated up further and eventually reaches vaporization temperature. From this moment on, the greater part of the incoming energy is used for the phase change to vapour. Because of this vaporization, the recoil pressure increases and, eventually, the molten material is pushed out. This effect is commonly referred to as the splashing mechanism. During this splashing the molten material flows along the relatively cold walls, partly resolidifying on its way. The vapour may have a second (negative) effect. Depending on the laser settings, a part of the incoming beam can be absorbed to such an extent that a plasma forms. This plasma, in turn, can shield the material completely. At this moment several drilling experiments are performed to improve the drilling technique. Rather than performing drilling experiments on the expensive superalloy the parts are made of one can use numerical simulations as a cheap and useful alternative.

In this thesis the physical phenomena playing a role in the drilling process are studied. Concluding from the time scales of the various processes, a subpulse behaviour can be expected. Multiple cycles of heating/splashing will occur during a pulse. The melting is studied extensively both analytically and numerically. Two mathematical formulations of phase change problems, also called Stefan problems, are discussed. The first formulation makes use of a boundary condition (the Stefan condition) to describe the evolution of the solid-liquid interface. The second is based on enthalpy formulation of the problem. These two methods are assessed numerically. A next essential part of this thesis treats the incoupling of energy into the material. This incoupling is described in terms of reflection. This reflection strongly depends upon both the laser, via its wavelength, and the irradiated material, via its index of refraction. In this thesis the
reflection is dealt with using the Algebraic Ray Trace Method (ARTM). The importance of this phenomenon is illustrated by some examples. With the aid of both the melting model and the reflection model the influence of the settings of the laser beam is investigated. Both the spatial and the temporal pulse shape are assessed. Furthermore, a complete numerical simulation is presented.

The splashing and solidification is described mathematically and leading-order analytical systems are derived through asymptotic analysis. The numerics for the solidification model are studied extensively. Our study explains why local clumps of material may arise in the drilled hole during the laser percussion drilling process. Finally, NumLab, a computational platform on which all computations are carried out, is briefly described. The advantage of NumLab is lying in the fact that it uses existing and often well documented libraries. One merely needs to write an interface for each library translating the NumLab datatype to the library datatype and vice versa. This usage is illustrated by an example.
Numerical Tools for Comfort Analyses of Automotive Seating

Verver, M.M.

Advisor: Prof.Dr.Ir. J.S.H.M. Wismans
Prof.Dr.Ir. F.P.T. Baaijens
Co-advisor: Dr.Ir. C.W.J. Oomens

Eindhoven University of Technology, 2004
ISBN 90-386-2855-2

EM research theme: Structural Mechanics

Anno 2004, the majority of the people in the western society can afford to buy a car. Many factors play a role in the purchase of a new car, e.g. styling, safety, environment and driving preferences. Seating comfort is also an important issue. Manufacturers use comfort to distinguish their products from their competitors. The introduction of a new car seat or interior is both time consuming and costly: the process requires many prototypes, because the assessment of seating comfort is still mainly based on subjective measurements. In addition, more cars than ever are used professionally. The prolonged sitting in automotive conditions of professional drivers introduced new physical complaints, resulting in high social costs. However, the cause of these complaints is not well understood. The use of virtual testing tools can provide a partial solution for the above described problems. Computer models of human and seat will enable comfort analyses of prototypes in early stages of the design process. Thereby, the development time and costs can be reduced. Moreover, the models can provide insight in the mechanics in the human body due to the human-seat interaction in both static and dynamic conditions and allow investigations of parameters that are hard to measure or even not measurable in relation with (dis)comfort and physical complaints.

This research aims at the development of numerical tools that can be used for comfort analyses of automotive seats. In literature, relationships have been defined between comfort and objective parameters. Vertical vibrations and seat pressure distributions appear to be mechanical objective parameters that have been related to comfort. Currently, no numerical tools exist that enable analyses of these parameters. Therefore, this study has concentrated on the development of numerical tools suitable for analyses of human behaviour in vertical vibrations and analyses of the seat pressure distributions at the contact interface between human and seat.

Analyses of human behaviour in vertical vibrations require models of a human and a seat. The multi-body 50th percentile occupant model developed in MADYMO has been used because of its realistic geometric description of the outer surface and detailed spinal representation. A protocol has been defined for the development of seat models using numerically efficient simulation techniques, which are preferred for the prolonged simulation times of vibration analyses. Experiments for determination of seat properties, required for the development and validation of the seat model, have been performed. For validation of the human model in vertical vibrations, volunteer experiments have been performed with a rigid seat and a standard car seat. Transmissibility of accelerations from floor to seat and human have been investigated in the frequency domain from 0-15 Hz. Comparison of data on the rigid seat and the standard car seat showed the large influence seat properties have on the human response to vertical vibrations. The human model showed realistic responses in both the rigid seat and standard car seat condition. Investigation of spinal loading at each vertebra level showed a large influence of the interaction between human back and seat back on the spinal shear and compressive forces.
For analyses of the seat pressure distribution at the contact interface between human and seat, a finite element (FE) model of the human buttocks has been developed. The model comprises a detailed geometric description of the skin, soft tissues and bony structures. The soft tissues have been lumped together; only the skin has been modelled separately. The bones have been assumed rigid. The hip-joints have been implemented to allow investigations on the influence of the hip angle on the contact interaction. The FE buttocks model allows analyses of parameters that are important in the human-seat contact interaction but are hard to measure, like the shear stresses at the contact interface and the stress distribution inside the human soft tissues under the bony structures. The FE buttocks model has been validated for static conditions based on volunteer experiments with a rigid and soft cushion. The FE buttocks model showed realistic responses in both the rigid and the soft cushion condition.

Both the human model and the FE buttocks model have been used in a sensitivity study. It has been evaluated whether the output of the models is sensitive to variations in seat parameters relevant for seat developers in the design process of new seats. The sensitivity study on vertical vibrations showed that the human model responses in vertical vibrations are sensitive to variations in cushion and suspension stiffness. The sensitivity study on seat pressure distributions showed that the cushion stiffness and thickness have a large influence on the human-seat contact interaction. Summarising, it can be concluded that both the human model and the FE buttocks model are rather promising tools for comfort analyses of automotive seating.
A Boundary Element Approach to Acoustic Radiation and Source Identification

Visser, R.

Advisor: Prof. Dr. Ir. H. Tijdeman

University of Twente, 2004
ISBN 90-365-2051-7

EM research theme: Structural Dynamics

Over the past few decades noise pollution has emerged as an important issue in modern society and provides much of the impetus for the development of noise prediction and reduction techniques. The ability to locate different sound radiating sources and to determine their contributions to the overall sound distribution is a first step towards solving the noise problem.

This research deals with the development of methods to compute acoustic radiation from a stationary vibrating object and, vice versa, methods to identify the sources of sound on the surface of the object, provided a measurement of the sound field is available.

The first type of problem is referred to as a forward problem because the cause is known (surface vibrations) and the effect (sound field) has to be determined. In contrast herewith, the source identification technique is denoted as an inverse problem since it deals with the opposite direction. A typical example of an inverse problem is an engine that generates, for unclear reasons, too much noise. In such cases source identification methods can provide a solution by approximating the regions of acoustic energy on the engine's boundary surface based on the observed sound field. The forward and inverse problems are closely related in the sense that in order to solve the inverse problem, the forward problem has to be coped with first.

This study adopts the Helmholtz integral equation as a basis for modeling the interior (cavity) and exterior (free/half-space) acoustic radiation process. In the latter case an additional set of equations is accounted for to ensure a unique solution at all wave numbers. Discretization of the integral equation is realized by means of the direct boundary element method (BEM) in combination with a collocation based solution approach. In order to obtain a formulation suitable for efficient numerical implementation, the singular and oscillatory behavior of the kernel functions is treated separately. The singular parts are evaluated with a specially developed adaptive quadrature, whereas the oscillatory parts are amenable to standard Gauss quadrature. The next step involves the assembly of the so-called acoustic transfer matrices, which explicitly relate the structural vibrations at the boundary surface of the radiating object to the acoustic variables in the surrounding or enclosed fluid domain. Once these matrices are known, the forward problem of computing the sound field reduces to a simple multiplication of the transfer matrix with the specified boundary condition vector(s).

Unfortunately, solving the inverse problem requires special treatment since the transfer matrices turn out to be ill-conditioned. As a consequence, a stable inversion of the system can only be achieved with regularization techniques. Without these techniques the reconstructed solution will be dominated by effects resulting from modeling discrepancies and measurement noise. Several regularization approaches are suggested and explained in detail within the scope of this work. In all cases, the L-curve criterion proved to be a reliable tool in determining the optimum amount of regularization.
Unlike many other studies, the present investigation is not limited to identification methods based on acoustic pressure data only, but additionally the use of acoustic particle velocity measurements is considered. This, in combination with application of the recently developed Microflown sensor, resulted in a new particle velocity based source identification technique that, under certain circumstances, proved to be more robust and accurate than the conventional type of identification techniques that depend solely on pressure data.

After the developed BEM solver and the associated source identification techniques were successfully validated with test examples of which the analytical solutions are known, an experimental setup was built to demonstrate the applicability in a more practical situation. The experiments were conducted on a specially designed structure-borne sound source of which the vibro-acoustic behavior is well understood. The comparison of numerical and experimental results showed a good agreement in both the forward and the inverse problems. Finally, the source identification techniques were successfully applied to a series of real-life products including a printed circuit board, a CPU cooling fan and a hairdryer.

In conclusion, this thesis covers the full chain of development starting from a mathematical theory, its numerical implementation, followed by a theoretical and experimental validation process and eventually the successful employment of the acquired tools on actual engineering applications.
With the upcoming, increasingly stringent requirements for CO₂ reduction, the trend of increasing weight for passenger cars must be reversed. Therefore, development engineers need to seek areas in which weight can be reduced. The suspension system is an example of an area with a high potential for reducing the vehicle weight. Substitution of steel suspension components by similar components of a lighter material is an easy way to save weight. However, the resulting cost increase is unacceptable.

In this thesis, a cost-effective way to reduce the weight of the suspension system is introduced. The concept is based on integrating multiple functions into a composite beam. By reducing the number of components, the weight and cost are reduced.

The main challenges of this project were to establish a generic development process for suspension systems and to apply it to a new front suspension, which was required to weigh considerably less than a reference suspension. At the same time, it was required to satisfy the same vehicle dynamics performance criteria as the reference vehicle. Moreover, the cost should either remain the same or increase minimally, and of course, durability and safety requirements have to be met.

At the start of the development process, the targets relating to the new suspension system were defined. The emphasis was on the targets relating to the suspension kinematics and compliance (K&C) characteristics. A number of suspension concepts were designed. The kinematics and compliance behaviour of each concept was predicted using multi-body analysis. Two concepts were selected for further development based on an assessment of a number of criteria. Both concepts include a composite beam, which integrates the functions of vertical control, roll control and part of the wheel support.

The next part of the development process concerned the detailed design of the suspension. The design of the beam was a complex task due to the high level of function integration and the application of composite material. A structured approach to achieve an optimal design was proposed, successively based on simple linear bending theory for beams and the more advanced finite element analysis.

The present thesis demonstrates the suspension design process for the two selected concepts. The emphasis was on the design of the composite beam. Other suspension parts developed for the new concepts are a set of flexible clamping devices to support the beam (bushings), a set of control arms, and a crossmember. These parts together form an important suspension sub-system, known as the centre module.

A number of processes applicable for the manufacture of the composite beam was known from a literature search. The selection of a suitable process depends on the shape, the required production rate, the strength, and finally, the cost. One of the suspension concepts was developed to fit in an existing vehicle. The manufacture of a beam for this concept turned out to be extremely difficult due to its complex shape, which was the result of the limited package space.
The resulting high costs were the main reason for cancelling further work on this beam. The other concept was developed as an efficient solution for a future, lightweight vehicle application. This beam has a simple shape and can be successfully produced in series at a reasonable cost.

An essential part of the new development process was the validation of the suspension by means of an extensive test program. The experiments included measurements of the stiffnesses and strains of the components and the kinematics and compliance characteristics of the suspension system. In general the predicted results showed a good correlation with the measured results. Moreover, the new suspension fulfils the same kinematics and compliance behaviour as the reference vehicle.

A test procedure was developed to investigate the effects of cyclic loading on the composite beam and the clamping devices. The tests defined in this procedure were successfully applied to the composite beam on its own and to the complete centre module. On the basis of these results it could be concluded that the new suspension concept with a multifunctional beam is durable.

An important aspect of this study was the balance between cost and weight. It was shown that the new suspension technology could be characterized as a lightweight, cost-effective solution.

Finally, the new suspension technology can be recommended for different vehicle applications. It was proven that the development process established during this project is representative. Therefore the suspension with the multifunctional beam can be rapidly implemented in the vehicle program.
Summary of information per research theme
B SUMMARY OF INFORMATION PER RESEARCH THEME

An important goal of the Graduate School Engineering Mechanics is the co-ordination and combination of research activities of participating groups. In accordance to this it was decided to group the research activities into four research themes:

- Computational Mechanics,
- Mechanics of Materials,
- Structural Dynamics and Control,
- Structural Mechanics.

Starting point in all research themes is modeling based on the foundations of Engineering Mechanics. Based upon this modeling modern numerical and experimental tools are developed enabling to solve problems in mechanics related to engineering science.

This appendix summarizes information per research theme. It contains lists of participating groups, actual PhD-projects per December 2004 and dissertations completed in 2004.
**B.1 Computational Mechanics**

The research theme “Computational Mechanics” is related to the potential of modern computing hardware for solving problems in mechanics. Much attention is paid to optimal numerical procedures and to large-scale computing. Important applications are in the field of crash simulation of vehicle systems, simulation of production processes, in particular forming processes, as well as complex structures in civil engineering and aerospace engineering.

**B.1.1 Groups participating within “Computational Mechanics”**

<table>
<thead>
<tr>
<th>University</th>
<th>Department</th>
<th>Group, Group director(s)</th>
<th>Group-code</th>
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<tr>
<td>TU/e</td>
<td>Mechanical Engineering</td>
<td>Materials Technology Prof.Dr.Ir. F.P.T. Baaijens, Prof.Dr.Ir. M.G.D. Geers</td>
<td>TU/e-MaTe</td>
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<tr>
<td></td>
<td>Mathematics and Computing Science</td>
<td>Analysis Scientific Computing and Applications Prof.Dr.Ir. J. de Graaf, Prof. Dr. R.M.M. Mattheij</td>
<td>TU/e-CASA</td>
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<tr>
<td></td>
<td>Aerospace Engineering</td>
<td>Engineering Mechanics (1) Prof.Dr.Ir. R. de Borst</td>
<td>TUD-EnMe1</td>
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<tr>
<td>TUD</td>
<td>Design, Engineering and Production</td>
<td>Aerospace Structures Prof.Dr. Z. Gürdal</td>
<td>TUD-Aero</td>
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<td>Structural Optimization and Computational Mechanics, Prof.Dr.Ir. F. van Keulen</td>
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<tr>
<td>Civil Engineering</td>
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<td>Engineering Mechanics (2) Prof.Dr.Ir. L.J. Ernst</td>
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<tr>
<td>UT</td>
<td>Engineering Technology</td>
<td>Applied Mechanics Prof.Dr.Ir. A de Boer, Prof.Dr.Ir. J. Huëtink, Prof.Dr.Ir. H. Tijdeman</td>
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<td>Production Technology Dr.Ir. R. Akkerman</td>
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**B.1.2 PhD-projects per December 2004 within “Computational Mechanics”**

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<td>Aa, Ir. N.P. van der</td>
<td>(PhD 3)</td>
<td>Field based parameter estimation for lithography</td>
<td>TU/e-CASA</td>
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<td>Akkerman, Ir. I.</td>
<td>(PhD 2)</td>
<td>Multiscale adaptive methods for LES computations</td>
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<td>Allaart-Bruin, Drs. S.M.A.</td>
<td>(PhD 3)</td>
<td>Blowing of Glass</td>
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<td>Avetisyan, Ir. M.</td>
<td>PhD 3</td>
<td>Sheet metal forming/springback</td>
<td>UT-ApMe</td>
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<tr>
<td>Aydemir, Ir. A.</td>
<td>(PhD 3)</td>
<td>Multi-scale mechanics of thin structures*</td>
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<td>Bonte, Ir. M.H.A.</td>
<td>PhD 1</td>
<td>Optimization of Forming processes</td>
<td>UT-ApMe</td>
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<tr>
<td>Bosch, Ir. M.J. v. d.</td>
<td>(PhD 3)</td>
<td>Deformation limits of polymer coated metal sheets**</td>
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<td>Broomans, Ir. P.</td>
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<td>3D Numerical simulation of bone ingrowth for glenoid component design</td>
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<td>Burchitz, Ir. P.</td>
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<td>Cerulli, Ir. C.</td>
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<td>Support of the software development process concerning structure in the context of the Awiator research project</td>
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<td>Chung, Ir. D.B.</td>
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<td>Reliability of fibre-metal laminate structures</td>
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<td>Dijkstra, Ir. W.</td>
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<td>Boundary Element methods</td>
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<td>Driessen, Ir. N.J.B.</td>
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<td>Heart valve tissue differentiation</td>
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<td>Dung, M.Sc. N.T.</td>
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<td>Computational modeling of laminated structures</td>
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<td>Engelken, Ir. R.A.B.</td>
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<td>Gurav, Ir. S.P.</td>
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<td>Sequential Approximate Design Optimization including Uncertainties, Discontinuities and Discrete Design Variables</td>
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<td>Haaren, Ir. L. van</td>
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<td>Heres, Ir. P.</td>
<td>(PhD 2)</td>
<td>Codestar</td>
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<td>Fatigue damage in metals**</td>
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<td>Koopman Ir. A.J.J.</td>
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<td>Aluminium Extrusion</td>
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<td>Kraaij, Ir M.G.M.M. v.</td>
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<td>Rigorous Coupled-Wave Analysis</td>
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<td>Lingbeek, Ir. R.</td>
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<td>Springback Compansation</td>
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<td>Loendersloot, Ir. R.</td>
<td>(PhD 3)</td>
<td>Resin Transfer Moulding</td>
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<td>Lopez de la Cruz, Ir. J.</td>
<td>(PhD 2)</td>
<td>Modelling of corrosion</td>
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<td>Mediavilla, Ir. J.</td>
<td>(PhD 3)</td>
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<td>Michler, Dipl.-Ing. C.</td>
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<td>Fluid-structure interaction for low-speed flows</td>
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<td>Munts, Ir. E.A.</td>
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<td>Fluid-structure interactions using multiscale LES techniques</td>
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<td>Nawijn, Ir. M.</td>
<td>(PhD 2)</td>
<td>Meshless methods in design processes</td>
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<td>Pannachet, MSc. T.</td>
<td>(PhD 1)</td>
<td>Advanced discretization technique for combined continuum-discrete fracture</td>
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<td>Patricio Dias, M.J.M., M. Sc.</td>
<td>(PhD2)</td>
<td>Structural integrity</td>
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<td>Perdahcioglu E.S.</td>
<td>PhD 2</td>
<td>Processing Meta Stable Steels</td>
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<td>Ruiter, Ir. M.J. de</td>
<td>(PhD 1)</td>
<td>Topology optimization on the basis of continuous design variables</td>
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<td>Shcherbakov,E., MSc</td>
<td>(Phd 1/2)</td>
<td>Model Reduction Techniques</td>
<td>TU/e-CASA</td>
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<td>Snippe Ir. O.H.C.</td>
<td>PhD 2</td>
<td>Thin Structures for Vertex detectors</td>
<td>UT-ApMe</td>
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<td>Thije, Ir. R.H.W. ten</td>
<td>(PhD 3)</td>
<td>Resin Transfer Moulding</td>
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<td>Tiso, M.Sc. P.</td>
<td>(PhD 1)</td>
<td>Nonlinear dynamic buckling of shells*</td>
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<td>Ubachs, Ir. R.L.J.M.</td>
<td>(PhD 2)</td>
<td>Thermomechanical integrity of solder joints**</td>
<td>TU/e-MaTe</td>
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<td>Verhoeven, Ir. A.</td>
<td>(PhD 3)</td>
<td>Circuit Simulation</td>
<td>TU/e-CASA</td>
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<td>Viatkina, Ir. E.M.</td>
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<td>Strain path effects and forming limits</td>
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<td>Villa-Rodriguez, Ir. B.H.</td>
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<td>Wijakamp, Ir. S.</td>
<td>(PhD 3)</td>
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<td>Wit, Ir. A.J. de</td>
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<td>Yu, Ir. Y.</td>
<td>PhD 3</td>
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<td>Zee, Ir. K.G. van der</td>
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* Also mentioned under “Structural Mechanics”

** Also mentioned under “Mechanics of Materials”

More detailed information can be found in the description of the research programme of individual groups, presented in the main part of this annual report.

**B.1.3 Dissertations completed in 2004 within “Computational Mechanics”**

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<td>Lamers, E.A.D.</td>
<td>Shape distortions in fabric reinforced composite products due to processing induced fibre reorientation</td>
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<tr>
<td>Tasic, B.</td>
<td>Numerical methods for solving ODE flow</td>
<td>TU/e-CASA</td>
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B.2 Mechanics of Materials

The research theme “Mechanics of Materials” is related to the prediction of the material behaviour in engineering structures from the internal structure of the material. This includes the prediction of collapse. The interchange between numerical and experimental techniques is of major importance. Important applications are in the field of biomedical technology, concrete structures, ceramic materials and polymer technology.

B.2.1 Groups participating within “Mechanics of Materials”

<table>
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<th>Department</th>
<th>Group, Group director(s)</th>
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<td>TU/e</td>
<td>Mechanical Engineering</td>
<td>Materials Technology Prof. Dr. Ir. F.P.T. Baaajens, Prof. Dr. Ir. M.G.D. Geers</td>
<td>TU/e-MaTe</td>
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<tr>
<td></td>
<td>Mathematics and Computing Science</td>
<td>Analysis Scientific Computing and Applications Prof. Dr. Ir. J. de Graaf, Prof. Dr. R.M.M. Mattheij</td>
<td>TU/e-CASA</td>
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<td>TUD</td>
<td>Aerospace Engineering Design, Engineering and Production</td>
<td>Engineering Mechanics (1) Prof. Dr. Ir. R. de Borst Engineering Mechanics (2) Prof. Dr. Ir. L.J. Ernst</td>
<td>TUD-EnMe1 TUD-EnMe2</td>
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<td></td>
<td>Civil Engineering</td>
<td>Computational Mechanics, Structural Mechanics and Dynamics, Dr. Ir. L.J. Sluys</td>
<td>TUD-CoSt</td>
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<td>UT</td>
<td>Engineering Technology</td>
<td>Surface Technology and Tribology Prof. Dr. Ir. D.J. Schipper Production Technology Dr. Ir. R. Akkerman</td>
<td>UT-Trib UT-ProTe</td>
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B.2.2 PhD-projects per December 2004 within “Mechanics of Materials”

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
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<th>Group-code</th>
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<tr>
<td>Bosch, Ir. M.J. v. d.</td>
<td>(PhD 3)</td>
<td>Deformation limits of polymer coated metal sheets**</td>
<td>TU/e-MaTe</td>
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<tr>
<td>Cid Alfaro, M.V.</td>
<td>(PhD 2)</td>
<td>Multiscale models for GLARE</td>
<td>TUD-EnMe1</td>
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<tr>
<td>Dillingh, E.C</td>
<td>(PhD 3)</td>
<td>Solder joint fatigue</td>
<td>UT-Trib</td>
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<tr>
<td>Eriniç, M.Sc. M.</td>
<td>(PhD 2)</td>
<td>Micro-macro modeling of fracture in partially saturated materials</td>
<td>TUD-CoSt</td>
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<tr>
<td>Gitman, B.Sc. I.M.</td>
<td>(PhD 3)</td>
<td>Front instabilities in injection moulding of polymer melts</td>
<td>TU/e-CASA</td>
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<tr>
<td>Gramberg, Ir. H.J.J.</td>
<td>(PhD 1)</td>
<td>Thermal and off-axis behaviour of GLARE</td>
<td>TUD-EnMe1</td>
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<tr>
<td>Hagman, Ir. F.</td>
<td>(PhD 1)</td>
<td>Biomechanical foot model for the kinetic analysis of locomotion</td>
<td>TU/e-CASA</td>
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<tr>
<td>Hendriks, Ir. F.M.</td>
<td>(PhD 3)</td>
<td>Mechanics of skin</td>
<td>TU/e-MaTe</td>
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<tr>
<td>Heru Utomo, Ir. B.H.</td>
<td>(PhD 3)</td>
<td>High-speed Impact Modelling and Testing of Composites*</td>
<td>TUD-EnMe2</td>
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<tr>
<td>Hof, Ir. C. van 't</td>
<td>(PhD 1/3)</td>
<td>Process dependent packaging polymer characterization: development of a constitutive model</td>
<td>TUD-EnMe2</td>
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<tr>
<td>Hrapko, Ir. M.</td>
<td>(PhD 1)</td>
<td>Determination of the mech. behaviour of brain tissue for impact conditions</td>
<td>TU/e-MaTe</td>
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<tr>
<td>Iacono, MSc. C.</td>
<td>(PhD 2)</td>
<td>Computational modeling of bore-hole stability</td>
<td>TUD-CoSt</td>
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<tr>
<td>Janssen, Ir. P.J.M.</td>
<td>(PhD 3)</td>
<td>Miniaturisation and forming micro-parts</td>
<td>TU/e-MaTe</td>
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<tr>
<td>Kasyanyuk, Ir. Y.</td>
<td>(PhD 3)</td>
<td>Fatigue damage in metals**</td>
<td>TU/e-MaTe</td>
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<tr>
<td>Kruijer, Ir. M.</td>
<td>(PhD 3)</td>
<td>Reinforced Thermoplastic Pipes</td>
<td>UT-ProTe</td>
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<tr>
<td>Leenders, Ir. W.S.</td>
<td>(PhD 1)</td>
<td>Usage of glass fiber reinforced plastics in load carrying structures in conventional ships*</td>
<td>TUD-EnMe2</td>
</tr>
<tr>
<td>Linde, Ir. G. v.d.</td>
<td>(PhD 3)</td>
<td>Gallina Performance Indicator</td>
<td>UT-Trib</td>
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<tr>
<td>Lloberas, M.Sc. O.</td>
<td>(PhD 2)</td>
<td>Multi-scale modeling of discrete fracture</td>
<td>TUD-CoSt</td>
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</table>
More detailed information can be found in the description of the research programme of individual groups, presented in the main part of this annual report.

**B.2.3 Dissertations completed in 2004 within “Mechanics of Materials”**

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Group-code</th>
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<tbody>
<tr>
<td>Bekers, D.J.</td>
<td>Finite antenna arrays: An eigencurrent approach drilling</td>
<td>TU/e-CASA</td>
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<tr>
<td>Gunawan, A.Y.</td>
<td>Stability of immersed liquid threads</td>
<td>TU/e-CASA</td>
</tr>
<tr>
<td>Liu, Chuanjun</td>
<td>On the Prediction of Damage and Fracture Strength of Notched Composites</td>
<td>TU/e-EnMe2</td>
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<tr>
<td>Masen, M.A.</td>
<td>Abrasive tool wear in metal forming processes</td>
<td>UT-Trib</td>
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<tr>
<td>Verhoeven, J.C.J.</td>
<td>Modelling laser percussion drilling</td>
<td>TU/e-CASA</td>
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</tbody>
</table>
B.3 Structural Dynamics and Control

The research theme “Structural Dynamics and Control” is related to the dynamic behaviour of engineering structures. Particular attention is paid to nonlinear dynamics and fluid-structure-interaction. Also of importance is the interaction with control. Important applications are in the field of rotating machinery, noise reduction and drive systems.

B.3.1 Groups participating within “Structural Dynamics and Control”

<table>
<thead>
<tr>
<th>University</th>
<th>Department</th>
<th>Group, Group director(s)</th>
<th>Group-code</th>
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<tbody>
<tr>
<td>TU/e</td>
<td>Mechanical Engineering</td>
<td>Systems, Dynamics and Control, Prof. Dr. H. Nijmeijer, Prof. Dr. Ir. M. Steinbuch, Prof. Dr. Ir. J.E. Rooda</td>
<td>TU/e-DyCo</td>
</tr>
<tr>
<td>TUD</td>
<td>Design, Engineering and Production</td>
<td>Engineering Mechanics (2) Prof. Dr. Ir. L.J. Ernst</td>
<td>TUD-EnMe2</td>
</tr>
<tr>
<td>UT</td>
<td>Civil Engineering</td>
<td>Computational Mechanics, Structural Mechanics and Dynamics, Dr. Ir. L.J. Sluys</td>
<td>TUD-CoSt</td>
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<tr>
<td></td>
<td>Engineering Technology</td>
<td>Applied Mechanics Prof. Dr. Ir. A de Boer, Prof. Dr. Ir. J. Huétink, Prof. Dr. Ir. H. Tijdeman</td>
<td>UT-ApMe</td>
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<td></td>
<td>Surface Technology and Tribology Prof. Dr. Ir. D.J. Schipper</td>
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<td>Mechanical Automation Prof. Dr. Ir. J.B. Jonker</td>
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B.3.2 PhD-projects per December 2004 within “Structural Dynamics and Control”

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<tr>
<td>Aalderink, Ir. B.J.</td>
<td>(PhD 3)</td>
<td>Multivariable weld pool control for double spot laser welding</td>
<td>UT-MeAu</td>
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<tr>
<td>Berg van de, Ir. R.</td>
<td>(PhD 1)</td>
<td>Performance based design of hybrid systems</td>
<td>TU/e-DyCo</td>
</tr>
<tr>
<td>Bonsen, Ir. B.</td>
<td>(PhD 3)</td>
<td>Modelling and control of slip in a push-belt</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Conza, Ir. N.</td>
<td>(PhD 2)</td>
<td>Doppler Imaging of Vibration System for detection of musculoskeletal disorders</td>
<td>TUD-EnMe2</td>
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<tr>
<td>Debiesme, M.Sc. F.X.</td>
<td>(PhD 3)</td>
<td>Design tools for low noise products with uncertain parameters</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Deladi, Msc. E.L.</td>
<td>(PhD 3)</td>
<td>Static friction</td>
<td>UT-Trib</td>
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<tr>
<td>Dijkhof, Ir. W.J.</td>
<td>(PhD 3)</td>
<td>Analysis methods for low noise products with uncertain parameters</td>
<td>UT-e-DyCo</td>
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<tr>
<td>Drogen, Ir. M. van</td>
<td>(PhD 3)</td>
<td>Load carrying capacity CVT</td>
<td>UT-Trib</td>
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<td>Eekelen v., Ir. J.A.W.M.</td>
<td>(PhD 1)</td>
<td>Modeling of Manufacturing Systems for Control</td>
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<tr>
<td>Faassen, Ir. R.P.H.</td>
<td>(PhD 3)</td>
<td>Chatter in high-speed Milling</td>
<td>TU/e-DyCo</td>
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<td>Faraon, Msc. I.C.</td>
<td>(PhD 3)</td>
<td>Friction in continuous variable transmission</td>
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<tr>
<td>Graaf, Ir. M.W. de</td>
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<td>Seam-tracking for robotized laser welding</td>
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<tr>
<td>Hakvoort, Ir. W.B.J.</td>
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<td>Iterative Learning Control for Robotized Laser Welding</td>
<td>UT-MeAu</td>
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<tr>
<td>Hamelinck, Ir. R.F.M.M.</td>
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<td>Adaptive Optics</td>
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<td>Hardeman, Ir. T.</td>
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<td>Henselmans, Ir. R.</td>
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<td>Fee-form optics measurement instrument</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Hofman, Ir. T.</td>
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<td>Hybrid Vehicle Topology</td>
<td>TU/e-DyCo</td>
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<td>Jamari, Ir. J.</td>
<td>(PhD 3)</td>
<td>Running-in of surfaces</td>
<td>UT-Trib</td>
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<tr>
<td>Kock, Ir. A.A.A.</td>
<td>(PhD 2)</td>
<td>Effective Process Time</td>
<td>TU/e-DyCo</td>
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<tr>
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<tr>
<td>De Kraker, A</td>
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<td>Shape optimization under condition of partial hydroelastic lubrication</td>
<td>TUD-EnMe2</td>
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<tr>
<td>Mallon, Ir. N.J.</td>
<td>(PhD 2)</td>
<td>Dynamic stability of thin walled structures</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Meerakker vd, Ir. KG.O.</td>
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<td>Alternative variator actuation</td>
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<tr>
<td>Mihajlovic, M.Sc. N.</td>
<td>(PhD 1)</td>
<td>Limit cycling in mechanical systems</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Mohanty, P.</td>
<td>(PhD 1)</td>
<td>Experimental Identification of Non-Linear Dynamical Systems</td>
<td>TUD-EnMe2</td>
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<tr>
<td>Moodij, Ir. E.</td>
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<td>Hydrostatische Magnesium Extrusie</td>
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<tr>
<td>Nijsse, Ir. G.</td>
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<td>State-space based active vibration isolation control algorithms</td>
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<tr>
<td>Oosterhuis, Ir. E.J.</td>
<td>(PhD 2)</td>
<td>Inverse Dynamics</td>
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<td>Scholte, Ir. R.</td>
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<td>Acoustic holography</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Sloetjes, Ir. P.J.</td>
<td>(PhD 2)</td>
<td>Structural Dynamics</td>
<td>UT-ApMe</td>
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<tr>
<td>Super, Ir. H.</td>
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<td>Hybrid isolation of structure borne noise</td>
<td>UT-MeAu</td>
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<tr>
<td>Veggel, Ir. A.A. van</td>
<td>(PhD 3)</td>
<td>Design of a metrology system for GAIA</td>
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<tr>
<td>Werner, Ir. C.</td>
<td>(PhD 3)</td>
<td>Large stroke AFM</td>
<td>TU/e-DyCo</td>
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* Also mentioned under “Computational Mechanics”

More detailed information can be found in the description of the research programme of individual groups, presented in the main part of this annual report.

**B.3.3 Dissertations completed in 2004 within “Structural Dynamics and Control”**

<table>
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<tr>
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<tr>
<td>Hesseling, R.J.</td>
<td>Active Restraint Systems - Feedback Control of Occupant Motion</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Jacobs, J.H.</td>
<td>Performance quantification and simulation optimization of manufacturing flow lines</td>
<td>TU/e-DyCo</td>
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<tr>
<td>Kononov, A.</td>
<td>Foundations of acoustic methods used in non-destructive inspection of laminated materials</td>
<td>TUD-EnMe1</td>
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<tr>
<td>Visser, R.</td>
<td>A boundary element approach to acoustic radiation and source identification</td>
<td>UT-ApMe</td>
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</table>
B.4 Structural Mechanics

The research theme “Structural Mechanics” is related to the development of design procedures based on reliability, as well as to structural optimization with respect to mechanical behaviour. Important applications are in the fields of biomedical technology (e.g. heart valves) and in the field of thin-walled structures.

B.4.1 Groups participating within “Structural Mechanics”

<table>
<thead>
<tr>
<th>University</th>
<th>Department</th>
<th>Group, Group director(s)</th>
<th>Group-code</th>
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<tr>
<td>TU/e</td>
<td>Mechanical Engineering</td>
<td>Systems, Dynamics and Control, Prof.Dr. H. Nijmeijer, Prof.Dr.Ir. M. Steinbuch, Prof.Dr.Ir. J.E. Rooda, Materials Technology Prof.Dr.Ir. F.P.T. Baaijens, Prof.Dr.Ir. M.G.D. Geers</td>
<td>TU/e-DyCo</td>
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<td>TU/e-MaTe</td>
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<tr>
<td>TUD</td>
<td>Aerospace Engineering</td>
<td>Aerospace Structures, Prof.Dr. Z. Gürdal</td>
<td>TUD-Aero</td>
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<tr>
<td></td>
<td>Design, Engineering and Production</td>
<td>Structural Optimization and Computational Mechanics, Prof.Dr.Ir. F. van Keulen</td>
<td>TUD-SOCM</td>
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<td>Engineering Mechanics (2), Prof.Dr.Ir. L.J. Ernst</td>
<td>TUD-EnMe2</td>
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B.4.2 PhD-projects per December 2004 within “Structural Mechanics”

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<tbody>
<tr>
<td>Andreykiv, Ir. A.</td>
<td>(PhD 1)</td>
<td>Development of improved endoprostheses for the upper extremities</td>
<td>TUD-SOCM</td>
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<tr>
<td>Aydemir, Ir. A.</td>
<td>(PhD 3)</td>
<td>Multi-scale mechanics of thin structures*</td>
<td>TU/e-MaTe</td>
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<tr>
<td>Boers, Ir. S.H.A.</td>
<td>(PhD 1)</td>
<td>Discrete multi-path forming</td>
<td>TU/e-MaTe</td>
</tr>
<tr>
<td>Heru Utomo, Ir. B.H.</td>
<td>(PhD 3)</td>
<td>High-speed Impact Modelling and Testing of Composites**</td>
<td>TUD-EnMe2</td>
</tr>
<tr>
<td>Langelaar, Ir. M.</td>
<td>(PhD 1)</td>
<td>Development and design of Micro-Electrical Mechanical Systems</td>
<td>TUD-SOCM</td>
</tr>
<tr>
<td>Lau, Ir. G.</td>
<td>(PhD 1)</td>
<td>Electrostatic actuators with embedded sensing</td>
<td>TUD-SOCM</td>
</tr>
<tr>
<td>Leenders, Ir. W.S.</td>
<td>(PhD 1)</td>
<td>Usage of glass fiber reinforced plastics in load carrying structures in conventional ships**</td>
<td>TUD-EnMe2</td>
</tr>
<tr>
<td>Milosheva, Ir. B.</td>
<td>(PhD 1/3)</td>
<td>Characterisation of fast curing systems**</td>
<td>TUD-EnMe2</td>
</tr>
<tr>
<td>Poort, Ir. G.</td>
<td>(PhD 1)</td>
<td>Development of improved endoprostheses for the upper extremities</td>
<td>TUD-SOCM</td>
</tr>
<tr>
<td>Tiso, M.Sc. P.</td>
<td>(PhD 1)</td>
<td>Nonlinear dynamic buckling of shells*</td>
<td>TUD-Aero</td>
</tr>
<tr>
<td>Tosserams, Ir. S.</td>
<td>(PhD 1)</td>
<td>Analytical Target Cascading</td>
<td>TUD-DyCo</td>
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<tr>
<td>Vervenne, Ir. K.</td>
<td>(PhD 1)</td>
<td>ADOPT - Sequential Approximate Design Optimization</td>
<td>TUD-Aero</td>
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<tr>
<td>Wang Ir. L.</td>
<td>(PhD 1/3)</td>
<td>Flexible Substrate**</td>
<td>TUD-EnMe2</td>
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<tr>
<td>Weustink, Ir. A.P.D.</td>
<td>(PhD 3)</td>
<td>Impregnation and winding using thermoplastic materials</td>
<td>TUD-SOCM</td>
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<tr>
<td>Yang, Ir. D.</td>
<td>(PhD 1/3)</td>
<td>Process dependent packaging polymer characterization: study of (micro-) damage, initiated during the curing process**</td>
<td>TUD-EnMe2</td>
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</tbody>
</table>

* Also mentioned under “Computational Mechanics”
** Also mentioned under “Mechanics of Materials”

More detailed information can be found in the description of the research programme of individual groups, presented in the main part of this annual report.
### B.4.3 Dissertations completed in 2004 within “Structural Mechanics”

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Abdalla, M.M.</td>
<td>Applications of the Cellular Automata, Paradigm in Structural Analysis and Design</td>
<td>TUD-Aero</td>
</tr>
<tr>
<td>Stijnen, J.M.A.</td>
<td>Interaction between the mitral and aortic heart valve- an experimental and computational study</td>
<td>TU/e-MaTe</td>
</tr>
<tr>
<td>Zandbergen P.</td>
<td>A composite beam as a multifunctional suspension component</td>
<td>UT-ApMe</td>
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</table>