# Basic Contents, Facts & Figures

CASA

Annual Report 2015

Centre for Advanced Structural Analysis

sfi Centre for Research-based Innovation

SINTEF

NTNU

sapa:

HYDRO

AkerSolutions

DNV·GL

HONDA

GASSCO

NSM

Forsvarsbygg

BENTELER Automotive

TOYOTA

SSAB

BMW

Audi

NORWEGIAN MINISTRY OF LOCAL GOVERNMENT AND MODERNISATION

Statoil

Statens vegvesen

# Contents



**CONTACT – RESPONSE**

**Professor Magnus Langseth**
**Dr. ing., Centre Directer**
Phone: +47 73 59 47 82,
Mobile: +47 930 37 002
Email: magnus.langseth@ntnu.no

**Peter Karlsaune, Coordinator**
Phone: +47 73 59 46 72,
Mobile: + 47 450 02 177
Email: peter.karlsaune@ntnu.no

**Albert H. Collett,**
**Communication Officer**
Phone: +47 73 59 07 93,
Mobile: +47 917 66 127
Email: albert.collett@ntnu.no

**Website:** https://www.ntnu.edu/casa
**Newsletter:** http://sfi-casa.no

**Postal address:**
SFI CASA,
Department of Structural Engineering,
NTNU, NO-7491 Trondheim, Norway

**Office location:**
NTNU, Richard Birkelands vei 1a,
Trondheim, Norway

**Cover:**
All partners were well represented at the SFI CASA kickoff in Trondheim, September 2015.

**Photos:**
All photos this section except pp. 20-25: Ole Morten Melgård

**Layout:**
NTNU Grafisk Senter

# Summary

CASA (Centre for Advanced Structural Analysis) officially opened on 1 July 2015. The aim is to become a world-leading centre for multi-scale testing, modelling and simulation of materials and structures for industrial applications.

**History**

The research group SIMLab (Structural Impact Laboratory) at NTNU (Norwegian University of Science and Technology) provided the foundation for CASA. The research group's activity culminated in the SFI by the same name, SFI SIMLab (2007-2014), which became a world leader in the design of crashworthy and protective structures.

**Organization**

CASA is also an SFI – a Centre for Research-based Innovation*. It is hosted by the Department of Structural Engineering in close cooperation with the Department of Materials Science and Engineering and the Department of Physics at NTNU. SINTEF Materials and Chemistry is a research partner.

The industrial partners are Aker Solutions, Audi AG, Benteler Aluminium Systems Norway AS, BMW Group, DNV-GL AS, Gassco AS, Honda R&D Americas Inc., Hydro Aluminium AS, Ministry of Local Government and Modernisation, Norwegian Defence Estates Agency, Norwegian National Security Authority, Norwegian Public Roads Administration, Sapa AB, SSAB, Statoil Petroleum AS and Toyota Motor Europe.

SFI CASA's board comprises representatives from all the partners. A director heads the daily operation, assisted by a core team and programme heads. A Scientific Advisory Board of international experts has been appointed to provide scientific and strategic advice. In addition, CASA has established an Industrial Reference Group to oversee and facilitate industrial implementation.

**Generic research**

The Centre will develop validated computational tools for innovation with and for the partners working in the oil and gas industry, in transportation and with physical security. Although the partners represent different fields they have similar needs in advanced structural analysis. The basic research in the Centre is pre-competitive and generic. This facilitates cooperation and transfer of knowledge across business sectors. A multi- and interdisciplinary research approach based on multi-scale testing, modelling and analysis in an industrial context is applied.

Another characteristic is the top-down/bottom-up approach. The main goal is always the final structure of the product.

**Point of departure**

Based on discussions with the partners, the Centre has formulated three research questions as its point of departure:

1. How can we establish accurate, efficient and robust constitutive models based on the chemical composition, microstructure and thermo-mechanical processing of a material?
2. How can we apply knowledge of material, geometry and joining technology to obtain optimal behaviour of hybrid structures for given load situations?
3. How can we describe the interaction between the load and the deformable structure under extreme loading scenarios?

**Five programmes**

Motivated by these questions, the Centre has defined five basic research programmes to increase the prediction accuracy of numerical simulations: Lower Scale, Metallic Materials, Polymeric Materials, Structural Joints, and Protective Structures.

Each programme has annual work plans with contributions from PhD candidates, post docs and scientists from the partners.

The Methods and Tools and the Industrial Implementation activities serve as links between the basic research and the industrial need for the technology developed and are gathered in the SIMLab Tool Box for implementation at the industrial partners.

**Kick-off**

SFI CASA held its kick-off meeting on 16 September 2015 with all partners well represented and its first board meeting on the following day.

In 2015, research work in the Centre resulted in 16 papers published in peer-reviewed journals. The research group has given 17 seminar and conference contributions, including 2 keynote and 2 invited lectures.

**SFI SIMLab**

Some of the PhD projects in SFI SIMLab were not finished at its closure on 31 December 2014. They continue in SFI CASA as parallel projects as the topics are closely related. Three PhD candidates at SFI SIMLab defended their theses in 2015:

Mikhail Khadyko: *Experimental and numerical study of yielding, work-hardening and anisotropy in textured AA6xxx alloys using crystal plasticity models.*

Vincent Vilamosa: *Behaviour and modelling of AA6xxx aluminium alloys under a wide range of temperatures and strain rates.*

Octavian Knoll: *A probabilistic approach in failure modelling of aluminium High Pressure Die Castings.*

**International cooperation**

International cooperation and leading-edge research are fundamental to an SFI. The key researchers in CASA all have an extensive international network. Three of the professors are editors of leading international journals.

SFI CASA has cooperated with the following universities and research laboratories in 2015:

Ecole Normale Supérieure de Cachan/Laboratorie de Mécanique et Technologie (ENS/LMT), France; Federal University of Rio de Janeiro, Brazil; University of São Paulo, Brazil; Department of Materials Science and Engineering, University of Toyama, Japan; Department of Metallurgy and Ceramics Science, Tokyo Institute of Technology, Japan; Karlsruhe Institute of Technology, Germany; IMPETUS Afea AB, Sweden; Joint Research Centre, Institute for the Protection and Security of the Citizen, Italy.

**Visibility**

CASA's media strategy aims at popular science presentations of its research activities. It is also an aim to make female researchers particularly visible in order to recruit female researchers and contribute to a more even gender balance in this research field.

The popularized part of this report exemplifies how the strategies are carried out. It contains articles from the monthly newsletter that was established in September 2015.

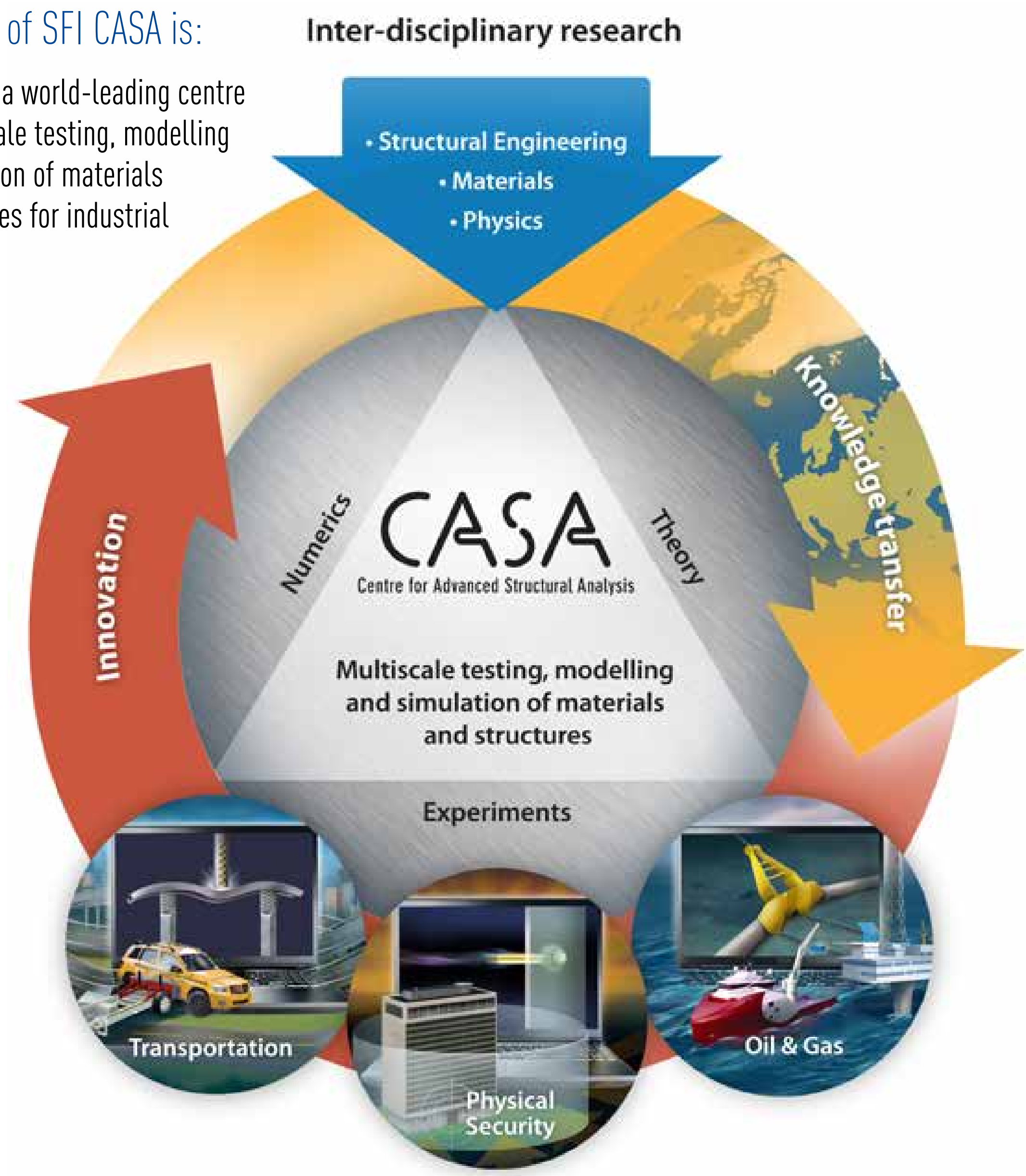
Last, but not least, scientific accomplishments increase visibility. In 2014, the Research Council of Norway invited three international panels to carry out an evaluation of 64 technological research groups in Norway. The results were published in 2015. Two of the 64 qualified as world leaders in their field. SIMLab was one of them.

* For further explanation of the SFI scheme, see page two in the other side of this report.

# Vision and objective

## The vision of SFI CASA is:

To establish a world-leading centre for multi-scale testing, modelling and simulation of materials and structures for industrial applications




## Objective

The Centre will develop validated computational tools for innovation together with and for partners in the oil and gas industry, the transportation industry (automotive and infrastructure along Norwegian roads) and in industry and public enterprises working with physical security (protection of critical infrastructure that could be subjected to terrorist acts and sabotage). Even though these partners represent different business sectors, they have similar needs in advanced structural analysis because the underlying theories and formulations behind the different computer tools are the same. Accordingly, the basic research in the Centre is pre-competitive and generic in nature to facilitate cooperation between the user partners and hence transfer of knowledge across business sectors. This supports the success criteria defined by the Research Council of Norway for an SFI centre where research at a high international level aims to create a platform for innovation and value creation.

In order to facilitate the use of validated numerical simulations by the user partners and to meet their technology roadmaps and business plans for process and product development, a multi- and interdisciplinary research approach based on multi-scale testing, modelling and analysis in an industrial context is required. This represents a major research initiative that is only achievable for a centre with long-term objectives and funding.

Thus the main objective with CASA is:

To provide a research and technology platform for the creation and development of smart, cost effective, safe and environmentally friendly structures and products through multi-scale testing, modelling and simulation.

# Goals and research plan

## Goals

The main quantitative goals of the Centre are as follows:

**Industrial:** 1) To develop methods and tools for credible advanced structural analysis at the user partners. 2) To ensure transfer of technology across business sectors. 3) To arrange courses and case study seminars at the user partners. 4) To facilitate concurrent research projects with the user partners. 5) To facilitate employment of post docs, MSc and PhD candidates at the user partners to strengthen the industrial implementation.

**Academic:** 1) To graduate 20 PhD candidates and employ 5 post docs. 2) To graduate 100-150 MSc students. 3) To attract 10 foreign professors/scientists to the Centre. 4) To publish 100-150 papers in international peer-reviewed journals in addition to conference papers. 5) To arrange two international conferences.

**Media:** 1) To implement a strategy for popular science presentations of the research activities in magazines, newspapers, on television, radio and the web. 2) To establish a media strategy where the female researchers are made particularly visible in order to recruit female PhDs and post docs and contribute to a more even gender balance in this research field.

## Research questions

Discussions with the partners have revealed that more extensive use of advanced numerical simulations will improve their competiveness in making cost-effective, safe and environmentally friendly structures and products. This industrial need is the basis for the three research questions defined as the point-of-departure for the research activities in CASA. The research questions encompass the entire first five-year period as well as the potential subsequent three-year period of the Centre, but additional research questions may emerge in the later phases of the SFI.

**RQ1:** How can we establish accurate, efficient and robust constitutive models based on the chemical composition, microstructure and thermo-mechanical processing of a material?
**RQ2:** How can we apply knowledge of material, geometry and joining technology to obtain optimal behaviour of hybrid structures for given load situations?
**RQ3:** How can we describe the interaction between the load and the deformable structure under extreme loading scenarios?

Motivated by these research questions, five basic research programmes are defined in order to increase the prediction accuracy of numerical simulations.

**Lower Scale:** This programme concentrates on the lower length scales of materials, from atomic up to the micrometre scale, and will provide experimental and modelling input to the multi-scale framework from the lower scale.

**Metallic Materials:** This will develop a physically based and experimentally validated multi-scale framework providing constitutive models for crystal plasticity, continuum plasticity, damage and fracture of metallic materials. The main emphasis will be on aluminium alloys and steels. In many critical structural applications, material properties beyond standard testing conditions are required; hence high and low temperatures, high pressures (from blast waves or water depths) and elevated rates of strain (including shock loading) will be given special attention.

**Polymeric Materials:** This will develop and improve material models representing the thermo-mechanical response up to fracture for polymers, i.e. thermoplastics with or without fibre reinforcement and elastomers. The models will be developed for application in an industrial context. Particular attention is paid to validation and efficient identification of the parameters involved in the models.

**Structural Joints:** This will provide validated computational models for multi-material joints applicable in large-scale finite element analyses. The scope is limited to the behaviour and modelling of structural joints made with screws, adhesive bonding and self-piercing rivets - as well as possible combinations of these. The considered materials are steel, aluminium and reinforced polymers.

**Protective Structures:** This will develop advanced computational tools and establish validated modelling guidelines for computer-aided design of safer and more cost- effective protective structures. Another objective will be to replace phenomenological models with physical models in a top-down/bottom-up multi-scale modelling approach in order to reduce the number of mechanical tests as much as possible in the design phase. The emphasis in this research programme will not be on traditional fortification installations, but on innovative lightweight and hybrid protective structures to meet the future needs of the user partners. Actual materials are those typically used in protective structures such as steel, aluminium, polymers, glass, foams, ceramics and concrete.

# Research methodology and industrial implementation

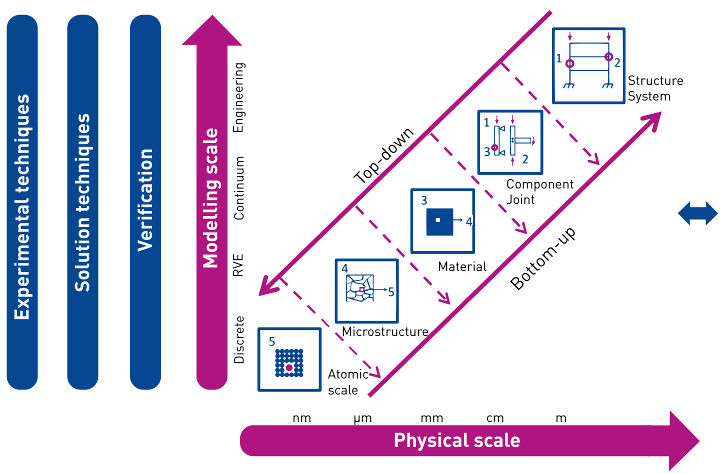



Figure 1: Research methodology

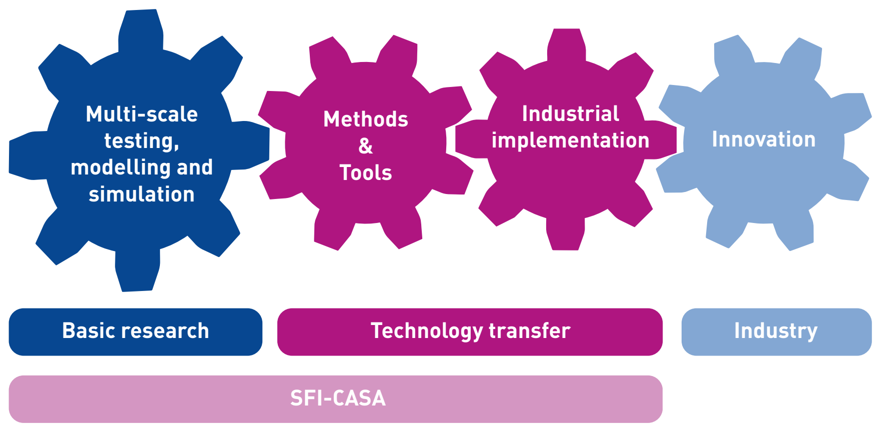



Figure 2: Structure of research

The activities in CASA will represent a step change for advanced structural analysis for industry and public enterprises as it is based on multi- and interdisciplinary research on different physical scales. The research methodology adopted to meet the overall objective is presented in Figure 1. As illustrated, a structure or product can be studied on different physical scales just like the modelling scales (there is also a time scale which reflects the duration of the physical events to be studied, but this is not shown in the figure). By using a top-down/bottom-up approach the main goal of the research will always be the final structure or product. In some cases, microstructural modelling or even modelling on atomic scale may be required to understand the underlying physical mechanisms of the observed material response to loading, whereas for joints or components the behaviour may be sufficiently well understood on the continuum scale. In all cases, research at the Centre will be designed to obtain modelling frameworks on the material and structural levels that are suitable for industrial applications. Many research topics and activities are addressed on the various scales: testing and modelling of materials and structures, numerical solution techniques, experimental techniques, verification and validation approaches, and optimization methods and parametric studies. Verification is the process of determining that a computational model accurately represents the underlying mathematical model and solution, whereas validation deals with the relationship between the computational model and the physical reality.

Figure 2 illustrates the important interlink between Basic research, Technology transfer and Industry. The Methods & Tools programme is a synthesis of Basic research, where guidelines and recommended practice for credible numerical structural analysis will be established. The Industrial implementation programme will be the link between the Methods & Tools programme and the industrial use of the research and technology developed at the Centre for Innovation.

# Research organization

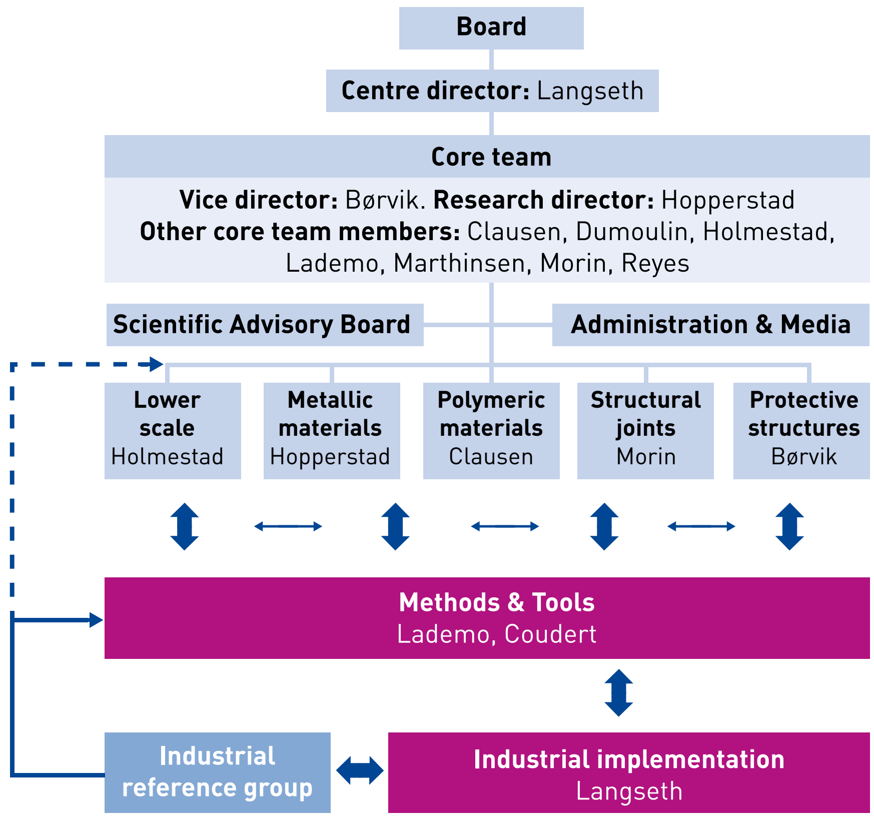



*Figure 3 : Structure of the organization in 2015*

The overall management structure of the Centre consists of a board comprising members from the consortium participants, Figure 3. The Board is to formulate the strategy for the Centre, approve annual operational plans, monitor the performance of the Centre according to the performance indicators described in the project description and annual targets, and propose corrective actions when needed. The Centre director will be in charge of the operation of the Centre, assisted by a core team. A Scientific Advisory Board of international experts will provide scientific and strategic advice. Each of the five research programmes is led by a programme head. These programme heads will also be responsible for the verification and validation of the developed models and technology. Cooperation across the research programmes will ensure the transfer of technology and allow possible synergies. The Methods & Tools programme will be the main instrument to link the research programmes in the Centre and the Industrial implementation at the industrial partners. Also these activities will be led by programme heads. The Centre will have a clear strategy for the management of intellectual property issues, including any assignment for commercialization or development and the distribution of any commercial returns.

# Core team

*From left: Stéphane Dumoulin, Randi Holmestad, David Morin, Knut Marthinsen, Magnus Langseth, Odd-Geir Lademo, Tore Børvik, Odd Sture Hopperstad, Aase Gavina Reyes and Arild Holm Clausen.*

## The Board

- Asbjørn Rolstadås (Chair), NTNU
- Duane Detwiler, Honda R&D Americas Inc.
- Agnes Marie Horn, DNV-GL AS
- Håvar Ilstad, Statoil Petroleum AS
- Andreas Koukal, Audi AG
- Helge Langberg, Norwegian Defence Estates Agency
- Joachim Larsson, SSAB
- Ernesto Mottola, Toyota Motor Europe
- Kjartan Pedersen, Aker Solutions
- Carsten Rapp, Norwegian National Security Authority
- Thorsten Rolf, BMW Group
- Rudie Spooren, SINTEF
- Svein Terje Strandli, Benteler Aluminium Systems Norway AS
- Jan Strid, Sapa AB
- Knut Syvertsen, Ministry of Local Government and Modernisation
- Hans Erik Vatne, Hydro Aluminium AS
- Normann Vikse, Gassco AS
- Gina Ytteborg, Norwegian Public Roads Administration

## Scientific Advisory Board

- Professor Ahmed Benallal, LMT-Cachan, France
- Professor Em. David Embury, McMaster University, Canada
- Professor Jonas Faleskog, Royal Institute of Technology, Sweden
- Professor Norman Fleck, University of Cambridge, UK
- Professor Stefan Hiermaier, Ernst Mach Institute, Germany
- Professor John Hutchinson, Harvard University, USA

## Centre Director

- Magnus Langseth, Professor, Dept. of Structural Engineering, NTNU

## Core team and programme heads

- Tore Børvik, Professor, Dept. of Structural Engineering, NTNU
- Arild Holm Clausen, Professor, Dept. of Structural Engineering, NTNU
- Stéphane Dumoulin, Research Scientist, SINTEF Materials and Chemistry
- Randi Holmestad, Professor, Dept. of Physics, NTNU
- Odd Sture Hopperstad, Professor, Dept. of Structural Engineering, NTNU
- Odd-Geir Lademo*, Research Manager, SINTEF Materials and Chemistry
- Knut Marthinsen, Professor, Dept. of Materials Science and Engineering, NTNU
- David Morin, Associate Professor, Dept. of Structural Engineering, NTNU
- Aase Gavina Reyes, Professor, Dept. of Structural Engineering, NTNU

**Adjunct Professor at Dept. of Structural Engineering (20% position)*

## Administrative and key personnel

- Trond Auestad, Senior Engineer, Dept. of Structural Engineering, NTNU
- Torodd Berstad, Researcher, Dept. of Structural Engineering, NTNU
- Albert H. Collett, Communication Officer, Dept. of Structural Engineering, NTNU
- Egil Fagerholt, Researcher, Dept. of Structural Engineering, NTNU
- Peter Karlsaune, Project Coordinator, Dept. of Structural Engineering, NTNU
- Laila Irene Larsen, Accountant, Dept. of Structural Engineering, NTNU
- Tore Wisth, Staff Engineer, Dept. of Structural Engineering, NTNU

## Partners

**Host institution**

- NTNU

**Research partner**

- SINTEF Materials and Chemistry

**Industrial partners**

- Aker Solutions
- Audi AG
- Benteler Aluminium Systems Norway AS
- BMW Group
- DNV-GL AS
- Gassco AS
- Honda R&D Americas Inc.
- Hydro Aluminium AS
- Ministry of Local Government and Modernisation
- Norwegian Defence Estates Agency
- Norwegian National Security Authority
- Norwegian Public Roads Administration
- Sapa AB
- SSAB
- Statoil Petroleum AS
- Toyota Motor Europe

# Administrative and key personnel

*From left: Tore Wisth, Peter Karlsaune, Trond Auestad, Laila Irene Larsen, Albert H. Collett and Egil Fagerholt.*

Kick off
16 September
2015

# Cooperation within the Centre and with the industrial partners

The basis for the annual work plans for 2015 was the project description in the SFI CASA application. Detailed planning of the research plans for 2016 and the following years was started up in autumn 2015.

Scientists from NTNU and SINTEF and PhD candidates at NTNU have been the main contributors to perform the research work, while the industrial partners have participated based on their defined contribution in kind. Benteler Aluminium Systems, DNV-GL AS and Hydro Aluminium AS are sponsoring one Adjunct Professor position each at the Department of Structural Engineering, NTNU. This ensures a link between the industry and the PhD and Master's students at SFI CASA.

The Core Team has a meeting every week led by the Centre Director. Every two weeks the group has had a seminar on a variety of issues in order to spread knowledge and information in the Centre's research group.

The cooperation with the industrial partners has been through telephone meetings and seminars. Representatives from all the partners in the Centre met in Trondheim on 16-17 September. The research activities were presented and discussed during a seminar on 16 September and the first SFI CASA Board meeting was held the day after on 17 September.

# International cooperation and leading-edge research

International cooperation is one of the success criteria defined by the Research Council of Norway for an SFI centre. Six of the industrial partners in SFI CASA are from outside Norway. SFI CASA also has strong interaction with universities and research organizations abroad. The key researchers in SFI CASA all have an extensive international network. This is a result of many years of high quality research made visible through publication in peer-reviewed journals. In addition, three of the Centre professors are editors in top international journals.
The cooperation with top international research groups ensures that the Centre transfers leading-edge technology to the partners and at the same time is able to define innovative research areas of importance to the partners. SFI CASA has had cooperation with the following universities and research laboratories in 2015:

Ecole Normale Supérieure de Cachan/Laboratorie de Mécanique et Technologie (ENS/LMT), France; Federal University of Rio de Janeiro, Brazil; University of São Paulo, Brazil; Department of Materials Science and Engineering, University of Toyama, Japan; Department of Metallurgy and Ceramics Science, Tokyo Institute of Technology, Japan; Karlsruhe Institute of Technology, Germany; IMPETUS Afea AB, Sweden; KTH Royal Institute of Technology, Sweden; Joint Research Centre, Institute for the Protection and Security of the Citizen, Italy.

Research programmes

# Lower Scale
## Head of Programme: Randi Holmestad

This programme concentrates on the lower length scales of materials, from atomic up to micrometre scale, and will provide experimental and calculated input to the multi-scale framework from the lower scale, see Figure 4. This will provide constitutive models for microstructure evolution, strength and work hardening for metallic materials, such as aluminium and steels, and a foundation for development of physically based models for crystal plasticity, continuum plasticity, damage and fracture.

The overall goal is to connect and coordinate the atom- and microscale framework linking the models and the experiments at the different scales. The results will provide a fundamental understanding of mechanical properties and deformation of metal structures in a multi-scale framework (from the nano-scale to the complete structure). This will work as a basis for achieving improved models and will be used in both model developments and validations.

In 2015 two PhD students were hired to do experiments on the lower scale. The PhD of Emil Christiansen (Department of Physics) is focused around micro- and nanostructure characterization of deformed aluminium alloys using transmission electron microscopy (TEM). The objective is to investigate the underlying physical mechanisms of ductile fracture at low stress triaxiality. In short, this PhD will be concerned with the interaction of dislocations with the aluminium microstructure. He wants to study which role the precipitation free zones (PFZs) play in ductile fracture. A systematic study of PFZs and how they change as a function of strain, quantitation of dislocation densities and type/density of hardening precipitates will be studied. These data will act as input to the different models used to describe deformation response and will be used to verify and develop numerical models in the related SFI CASA projects.

The PhD of Christian Oen Paulsen (Department of Materials Science and Engineering) focuses on combining experimental work and modelling activities to describe the correlation between microstructure and mechanical properties in multiphase steel. In all structural materials the microstructure will be heterogeneous and the mechanical properties will strongly depend on the local variations and the thermomechanical history of the material. A systematic experimental study including nanomechanical study of local properties and in-situ testing using a scanning electron microscope (SEM), with the possibility of cooling the material to sub-zero degrees, gives input data for mathematical models for understanding and describing the performance of heterogeneous materials based on the microstructure information. The experimental tests are combined with Digital Image Correlation (DIC) to obtain detailed information about the local deformation.

During 2016 two new PhD students will be hired, one on atomistic and multiscale modelling and one within dynamic strain aging.

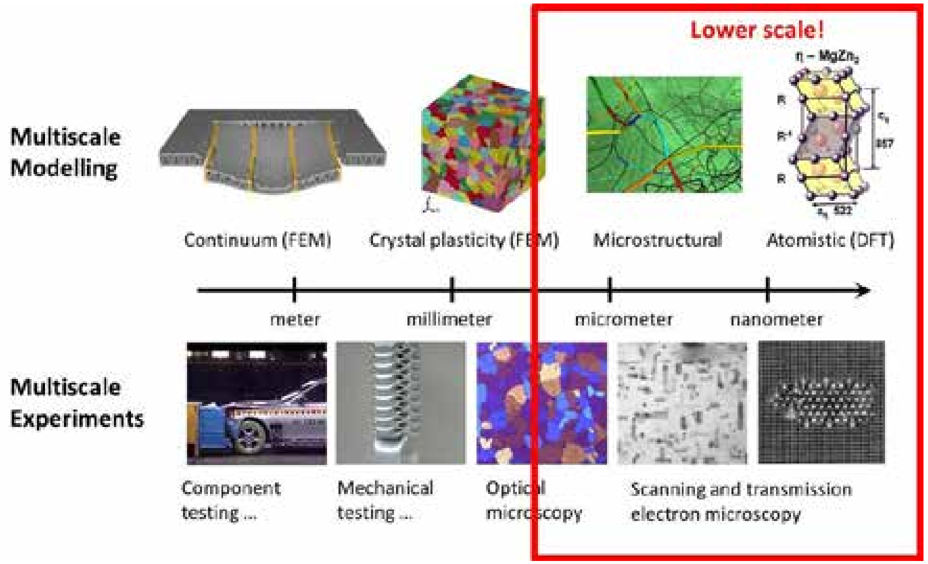



*Figure 4: In a multiscale framework the lower scale programme covers the micrometer and nanometer scales for modelling and experiments.*

# Metallic Materials

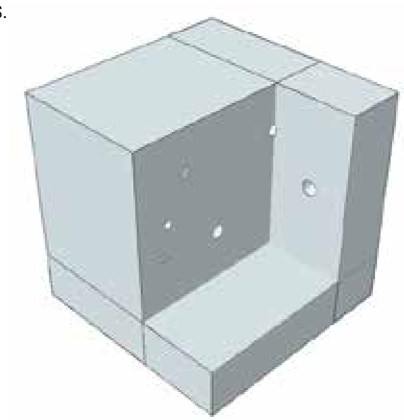
## Head of Programme: Odd Sture Hopperstad

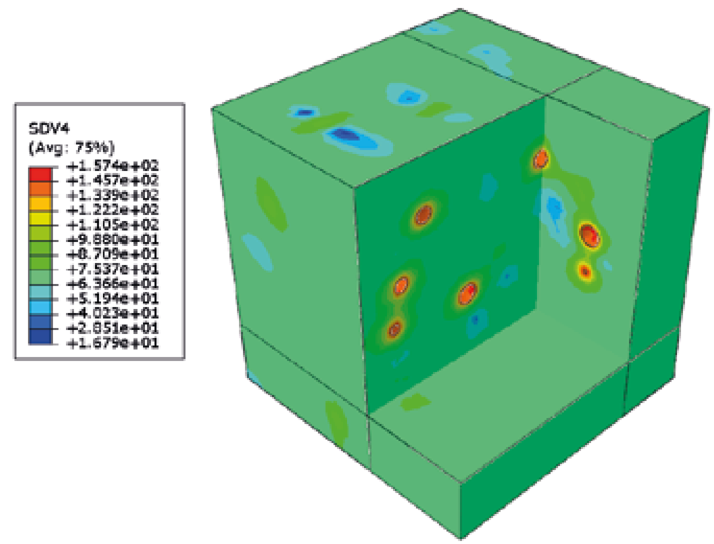
Constitutive models describe the stress and internal variables (representing in an average sense the microstructural rearrangements of the material) as functions of the strain, strain rate and temperature. In large-scale simulations of structures, the framework of continuum thermo-mechanics is typically adopted to formulate the constitutive models, while thermo-mechanical testing is used to identify the model parameters. Advanced constitutive models, including plastic anisotropy, non-linear isotropic and kinematic hardening, strain-rate and temperature dependence, damage evolution and failure, tend to have a large number of model parameters. In close collaboration with the Lower Scale programme, this research programme applies multi-scale methods to develop validated constitutive models for large-scale simulations of metal structures. Thus the need for calibration of the constitutive models against thermo-mechanical tests is reduced and the prediction accuracy of the models increased with respect to properties that are not always easily measured by testing. Qualitative and quantitative descriptions at different length scales are closely accompanied by well-designed experiments at the relevant length scales for the phenomena of interest (from the nano-scale to the complete structure), as a basis for achieving improved understanding, model development and model validation. The quantum, atomistic and nano scales are covered by the Lower Scale programme, while this programme deals with crystal plasticity and continuum plasticity at the micro, meso and macro scales. The themes of the two research activities in 2015 have been:

- Micromechanical modelling of ductile fracture in aluminium alloys: The principal objective of this project is to develop computational micromechanical models for strain localization and ductile fracture, see Figure 5. These mesoscale models are applied to aluminium alloys with various microstructures and used to develop physically-based fracture models for large-scale simulations of structures. However, the computational micromechanical models developed here will be used for steel and polymers in other projects in CASA.

- Ductile fracture of aluminium alloys at low stress triaxiality: an experimental and numerical study: The two main objectives of this project are a) to acquire new knowledge on the physical mechanisms governing ductile fracture in aluminium alloys at low stress triaxiality by use of experiments at various scales and computational cell simulations and b) to develop improved computational material models for damage evolution, strain localization and fracture of these materials.

These activities are in turn the PhD projects of Lars Edvard Bryhni Dæhli (2013-2017) and Bjørn Håkon Frodal (2015-2019). The first is a continued activity from SFI-SIMLab which is highly relevant for SFI-CASA, while the latter activity was started in August 2015. In August 2016, Sondre Bergo will begin his PhD study in this programme. The tentative topic for his PhD project is micromechanical modelling and simulation of steel materials.





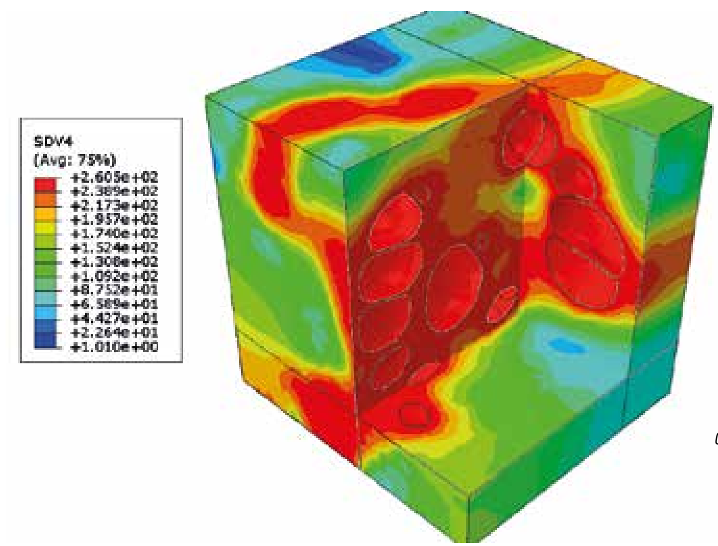




*Figure 5: Simulation of void growth and coalescence in unit cell with multiple pre-existing voids.*

# Polymeric Materials
## Head of Programme: Arild Holm Clausen

Polymers comprise a wide range of materials, including natural and synthetic materials. The demand for such materials has increased considerably during the last few decades. Applications include safety-related parts in cars, coatings, thermal insulation in offshore components, seals and inter-glass layers in laminated windows. The finite element method has only recently been employed as a tool in the design process of parts made of polymers. Therefore, constitutive models for such materials are less mature than for metals. Prediction of fracture is also a topic of interest for research and industry. Knowledge about the physical mechanisms governing the thermo-mechanical behaviour is of utmost importance for successful development of material models.

The main objective of the research programme Polymeric Materials is to develop and improve material models representing the thermo-mechanical response up to fracture for polymers. The models will be developed for application in an industrial context. Particular attention is paid to validation and efficient identification of the parameters involved in the models. Actual materials include commodity thermoplastics (like PE and PP, commonly reinforced with small mineral and/or rubber particles), fibre-reinforced thermoplastics, elastomers and foams made of polymers.

The research activities in 2015 have been within the following fields:

- Modelling of polymers.
- Characterization and modelling of large-strain response of ductile thermoplastics.
- Characterization and modelling of glass-fibre reinforced polymers.
- Start-up of a new PhD project on modelling of ductile failure.

The first of these projects has gained major attention since 2012. The polymer model now includes a hypoviscoelastic–viscoplastic part. Depending on the material and problem at hand, the viscoelastic and viscoplastic parts may be switched on or off. Anisotropic elasticity, which is relevant for fibre-reinforced polymers, is also implemented in the model. Further, three damage models are included. For validation, there has been cooperation with Toyota for a couple of years. It was continued in 2015 through the master's thesis of John Fredrick Berntsen, which was carried out at Toyota Motor Europe's Technical Centre in Brussels from January to June. This joint master thesis served to enhance the application of the model at Toyota, and seems to be an adequate way of implementing technology at the user partners.

The large-strain response of ductile thermoplastics has been the topic of Marius Andersen's PhD project, which is about to be finished. It contains development of robust methods for experimental characterization as well as a constitutive model that is able to represent the stress-strain curve at different strain rates and temperatures. Petter Henrik Holmstrøm started his PhD project on the modelling of fibre-reinforced materials in August 2013. Improved material models should in some way take the distribution of fibre orientation angles into account. A preliminary computer tomography (CT) scan of a polypropylene reinforced with glass fibres, see Figure 6, shows promising results.

The three first activities are continuation activities from SFI SIMLab which are highly relevant for SFI CASA. Sindre Olufsen has been engaged to work on the PhD project on the modelling of ductile fracture in the period 2015 – 2019.

The interaction with the industrial partners engaged in the Polymeric Materials programme is maintained through annual technical meetings. Such a meeting was arranged in Munich in early November 2015, and gathered Audi, BMW, Gassco, Statoil and Toyota.

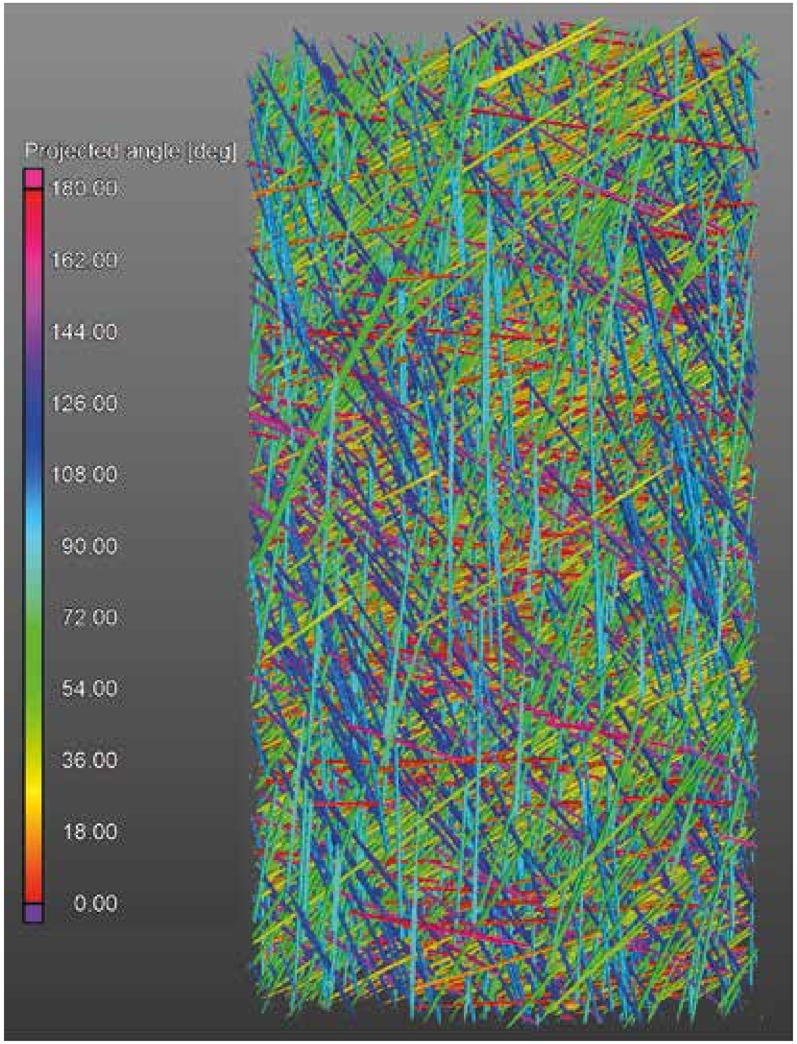



*Figure 6: Computer tomography (CT) scan of glassfibre – reinforced polypropylene (PP).*

# Structural Joints

## Head of Programme: David Morin

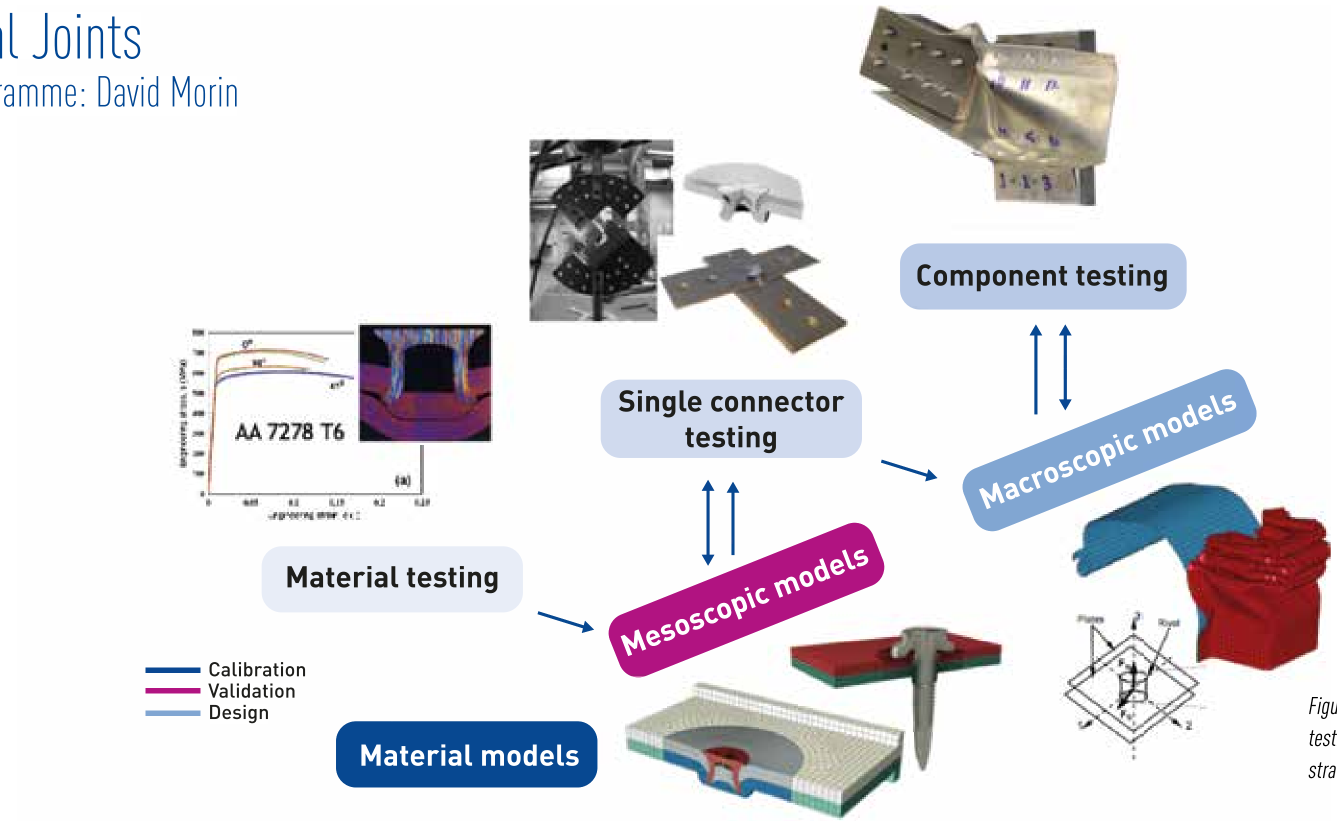



*Figure 7: Multiscale testing and modelling strategy.*

The need for multi-material structures in the automotive, offshore and physical security industries is becoming increasingly important to meet the requirements in terms of performance and weight reduction of their products. Often, the behaviour of a structure is strongly linked to its connections and their capacities to sustain and transfer the applied load to its different members. In this perspective, the design of multi-material structures has to be carried out taking into account how the connections will behave and fail in the numerical simulations used by the designers. Today, large shell elements are used for computational efficiency which hampers an accurate representation of the connections and their failure modes due to a poor discretization of these complex problems. The aim of this research programme is to provide macroscopic models for multi-material connections which are based on a fundamental understanding of the structural joints. These models should be industry-friendly in terms of computational time as well as calibration cost. Here multi-material connections involve aluminium, steel and fibre reinforced polymers.

We will meet this objective using a multi-scale testing and modelling strategy, see Figure 7. This strategy involves testing at different scales from the material within the connector, through single connector tests, to the final component level. Each of these testing levels is important to gain the fundamental understanding of the connections of interest. In terms of numerical modelling, mesoscopic models where the connections are represented with solid elements will be employed to increase the knowledge behind the behaviour and failure of structural joints. However, macroscopic models are the final outcome of the programme.

In 2015, a PhD project was started with John Fredrick Berntsen. He will be working on the joining of fibre reinforced polymers and aluminium alloys using structural bonding. His PhD will involve static to dynamic testing and a strong focus will be placed on industry friendly macroscopic models. Two PhD projects (started in 2013 but relevant to SFI CASA) were continued in 2015. Erik Grimsmo is working on bolted connections in steel structures subjected to impact loading conditions, whereas Johan Kolstø Sønstabø is working on flow-drill screws connections in aluminium structures under crash loading.

# Protective Structures

## Head of Programme: Tore Børvik

Design against accidental loads, such as explosions, impacts and collisions, has become increasingly important for a number of engineering and industrial applications. To meet the challenges posed by such complex loading conditions, product development and structural analysis are increasingly carried out in virtual environments using the finite element method to achieve safer and more cost-effective designs. The fundamental goal of protective structures is to improve the survivability of people and vital infrastructure to a given threat. It is important to realize that the protective structure is the last layer of defence against a threat when all other protective measures have failed. It is thus of utmost importance that such structures are designed and validated on a sound theoretical and experimental basis. To do so, accurate, efficient and robust constitutive models and solution techniques used in a multi-scale modelling context are required. Further, new designs need to be validated through high-precision experiments involving advanced instrumentation such as three-dimensional digital image correlation for full-field displacement and strain measurements. Although much information can be obtained from laboratory tests, relying on such an approach would be too costly and inefficient. Computer-aided design, together with a strategy for material selection, optimization and well-selected validation tests, can significantly lower the cost and enhance the overall quality and efficiency of the required protection.

The main objective of this research programme will be to develop advanced computational tools and establish validated modelling guidelines for computer-aided design of safer and more cost-effective protective structures. Another objective is to replace phenomenological models with physical models in a top-down/bottom-up multi-scale modelling approach in order to reduce the number of mechanical tests as much as possible in the design phase. This will be carried out in close collaboration with the other projects within CASA.

The main research activities in 2015 have been:

- Experimental and numerical study on the perforation of empty and sand-filled aluminium panels and Fracture and fragmentation of AA6070 aluminium plates during impact loading (Jens Kristian Holmen's PhD project).
- Experimental and numerical study on plated structures subjected to blast loading (Vegard Aune's PhD project).
- Fragmentation of window glasses exposed to blast loading (Karoline Osnes' PhD project).
- Impact against coated and uncoated offshore steel pipes (Ole Vestrum's CASA project).

The two first PhD projects are activities from SFI-SIMLab, which are directly pursued in SFI-CASA. Karoline Osnes' PhD project was started in August 2015, while Ole Vestrum started his PhD project on Optimization of protective structures in January 2016. Examples from the PhD projects of Jens Kristian Holmen and Karoline Osnes are shown in Figure 8 and Figure 9.

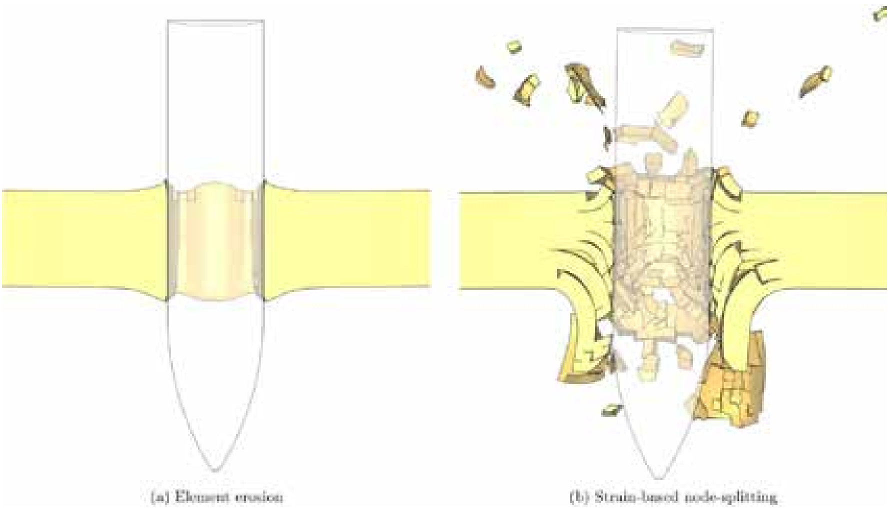



*Figure 8: Images from simulations of a 20 mm thick plate in aluminium alloy AA6070 with (a) element erosion and (b) node splitting in the IMPETUS Afea Solver.*

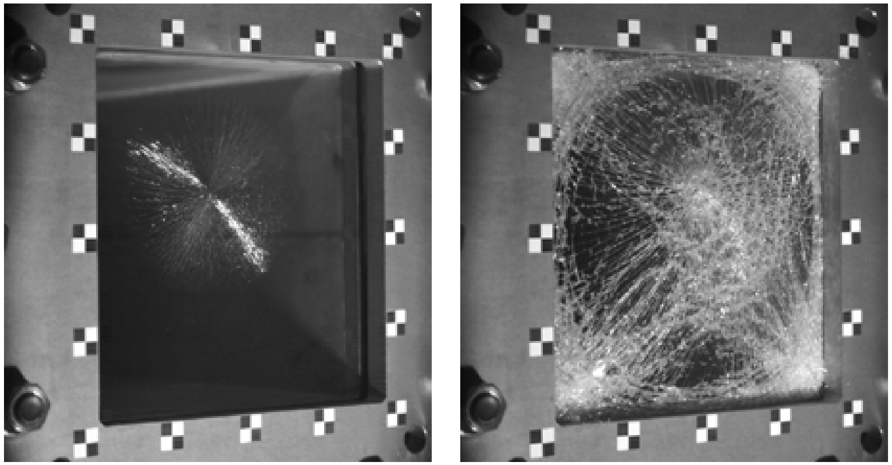


*Figure 9: Images from blast-load experiments in SIMLab's shock-tube facility on a double-laminated window glass showing initial (left) and final (right) cracking.*

Technology transfer

# Methods and Tools

## Heads of Programme: Odd-Geir Lademo and Térence Coudert

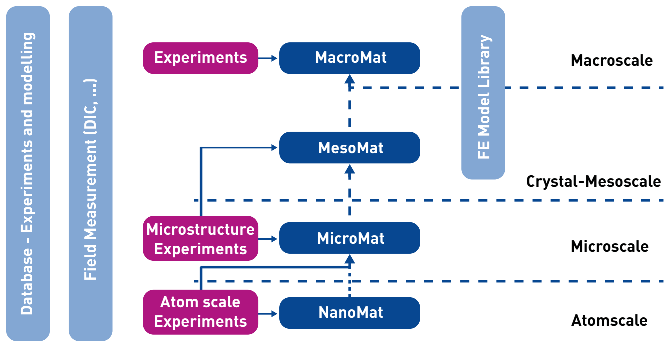



*Figure 10: Draft of multi-scale framework*

The Methods & Tools Programme is to provide a synthesis of the research carried out to facilitate industrial implementation, see Figure 10. In other words, it represents the main instrument to link the Basic research in the Centre and the Industrial implementation at the industrial partners. The work will build upon prior research carried out by NTNU and SINTEF, in particular the research platform generated over the last eight years in the SFI SIMLab, and the associated SIMLab Toolbox. The SIMLab Toolbox will be further developed by enhancing the prediction accuracy, efficiency and robustness of existing models and methods and include novel models and methods based on the basic research programmes. It is planned that the SIMLab Toolbox will support the necessary steps to build a reliable finite element model for advanced structural analysis, including:

- a database solution to store and get access to experimental data and protocols;
- field measurement software to extract accurate data from tests;
- a multi-scale calibration tool to identify the parameters of the proposed models;
- a model library with constitutive models for the different materials used by the partners;
- a set of multi-scale solvers used to develop and improve existing models.

The development work is performed in a professional software development arena 'code.sintef.no', which enables team-oriented development through proper systems for documentation, version control and issue tracking. Through this portal personnel from all Centre partners may also be granted access in order to co-develop and tailor tools. In 2015, some preparatory measures have been taken to ensure maximum efficiency, robustness, and quality assurance of the further team-based development, primarily through definition of each existing tool through scenario-based design technique, and by the establishment and initial implementation of a system for automated testing of tools. A draft of a possible architecture for an overarching multi-scale framework has been crafted, that will be subject to revisions based on discussions with user partners in 2016.

# Industrial Implementation

## Head of Programme: Magnus Langseth

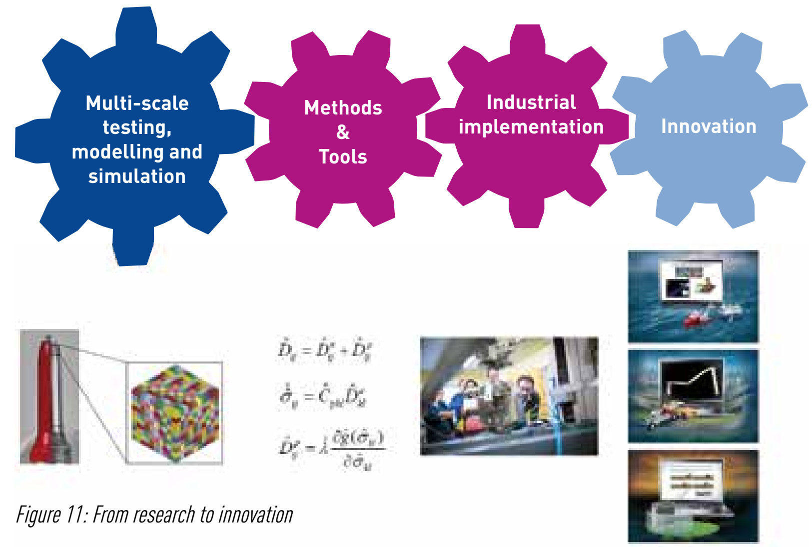



*Figure 11: From research to innovation*

Figure 11 illustrates the important interlink between Basic research, Technology transfer and Industry. Here the Industrial implementation programme will be the link between the Methods & Tools programme and the industrial use of the research and technology developed at the Centre for Innovation. To strengthen the industrial implementation of the research and the cooperation between the partners, an Industrial Reference Group with experts from the partners, supported by professors/scientists from NTNU and SINTEF, has been established. This group will monitor all new developments and assist in the implementation of these at the user partners. The reference group will also at any time evaluate the needs each partner has for support from NTNU and SINTEF in the implementation. The exchange of personnel between the research group and the user partners, industrial PhD candidates and employment of graduate students at the partners will be other means to strengthen the industrial implementation. Establishing concurrent research and development projects with the partners represents an opportunity for technology transfer and enhanced innovation at the user partners. In order to strengthen the share of information across business sectors and between the partners during the industrial implementation, case studies and demonstrators will be used and presented at seminars. Here the user partners representing each of the business sectors oil and gas, physical security and transportation will present typical engineering problems and best practice for modelling. This will contribute to a better understanding of the challenges of the user partners and how advanced structural analysis may be used to meet them.

# Test facilities

SFI CASA has access to test facilities in several laboratories at NTNU and SINTEF. Below is a list of the most important testing equipment. Please go to our website to read more about the Centre's laboratories: www.ntnu.edu/casa

**Gas Gun (1)**

This is a compressed gas gun for ballistic impact studies. A variety of projectile geometries can be fired, with a maximum velocity of 1000 m/s.

**Hydro-pneumatic machine (HPM) (2)**

The hydro-pneumatic machine (HPM) is a device for tensile material testing. It operates in the strain–rate range between 1 and 100 $s^{-1}$.

**Pendulum impactor (Kicking Machine) (3)**

The pendulum accelerator is a device for impact testing of components and structures. The test rig accelerates a trolley on rails towards a test specimen fixed to a reaction wall. The accelerating system consists of an arm that is connected to a hydraulic/pneumatic actuator system. The maximum energy delivered to the trolley is approximately 500 kJ. At present the mass of the trolley is in the range between 800 -1500 kg, giving a maximum velocity between 35 m/s and 26 m/s.

**Self-piercing riveting machine (4)**

In this machine self-piercing riveting can be carried out of sheets under industrial conditions.

**Sheet metal forming machine (BUP) (5)**

This multi-purpose hydraulic sheet metal forming machine is designed to test the formability of sheet metals. The machine has a 600 kN load capacity, a maximum clamping force of 50 kN, a maximum test stroke of 120 mm and a maximum test speed of 750 mm/min.

**Split-Hopkinson tension bar (SHTB) (6)**

The split-Hopkinson tension bar is a device for material testing at strain rates in the range between 100 and 1500 $s^{-1}$. Data is recorded with strain gauges and high speed cameras. An induction heater facilitates tests at elevated temperatures.

**Stretch bending rig (7)**

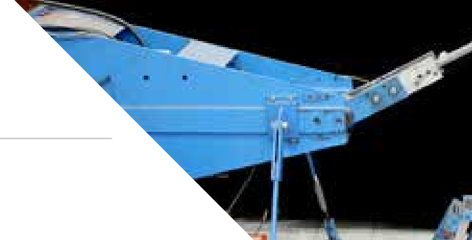
The stretch-bending rig applies a combined bending and axial tensile/compressive loading to the test component. The length of the specimens is 1-2 m, and they are bent around an exchangeable die with a defined curvature. The rig has been employed in tests where the bending operation of car bumpers is studied. It has also been used to study the behaviour of pipelines subjected to impact and subsequent stretching.

**Droptower impact system (8)**

In this machine impact testing of materials and small components can be carried out at low and high temperatures. The mass of the projectile ranges from 2-70 kg and gives an impact velocity in the range 0.8-24 m/s. All tests can be carried out with an instrumented nose which gives the impact force as a function of time.

**Split-Hopkinson pressure bar (9)**

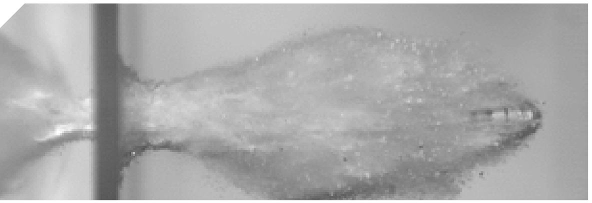
The split-Hopkinson pressure bar consists of a high-pressure chamber unit that can accelerate a projectile against the end of the input bar.





Photos 1, 2, 4, 5, 6 and 7: Melinda Gaal
Photos 3 and 8 – 10 and 12: Ole Morten Melgård



*The picture above shows a test where the Phantom V1610 high-speed camera has been used. A 7 mm laminated safety glass is hit by a 7.62 calibre lead bullet at a speed of 800 m/s. The camera is set to a frame rate of 60 000 FPS and exposure time 0.452 µs.*

**Shock Tube Facility (10)**

The SIMLab Shock Tube Facility consists of a long tube and a tank. The tube is 18.2 m long and is divided into six sections. The tube ends in a 5.1 m$^3$ dump tank. The tube starts with a circular internal cross-section with a diameter of 0.34 m before it is transformed to a square cross-section of 0.3 m x 0.3 m. Threaded holes in the tube floor enable mounting of test specimens in the test section, and windows in the test section and the dump tank allow high-speed cameras to investigate the structural response during an experiment.

**Scanning electron microscope (SEM) laboratory (11)**

SFI CASA has access to a SEM lab with the following equipment: Zeiss SUPRA 55VP (LVFESEM, 2006), Hitachi S-4300SE (FESEM, 2002), Zeiss, Ultra 55LE, FESEM (2007), Jeol 840 (1989). 3 SEMs are equipped with EDS and EBSD. The laboratory have in-situ sub-stage systems for EBSD tensile and thermo mechanical experiments (heating, and cooling down to -60 °C).

**Transmission Electron Microscopy (12)**

SFI CASA cooperates with the TEM Gemini Centre at NTNU, providing SFI CASA access to 5 TEMs: a JEOL double corrected ColdFEG ARM200F (2013), a JEOL 2100F (2013), a JEOL 2100 (2013), a Philips CM30 (1989) and a JEOL 2010 (1993). The TEM Gemini Centre also has a well equipped sample preparation lab and computing facilities.

**Cameras**

SFI CASA has a FLIR SC7500 infrared camera that can convert infrared radiation to a visual image that depicts thermal variations across an object or scene. Thus it can be used to measure the surface temperature of a specimen under inelastic deformations. With a resolution of 320x256 pixels the maximum frame rate is 380 per second, while at a resolution of 48x4 pixels the maximum frame rate is 31 800 per second (FPS).

During impact testing of materials and structures, the events are recorded using high-speed cameras with a maximum frame rate of 1 000 000 FPS. The research group has access to 2 Photron and 2 Phantom cameras.

# Visibility

### Media strategy

CASA aims at a media strategy for popular science presentations of the research activities in magazines, newspapers, on television, radio and the web. It is also an aim to make female researchers particularly visible in order to recruit women fellowship holders and contribute to a more even gender balance in this research field.

The popularized part of this report is an example of how these strategies are carried out. The articles have also been published in our monthly newsletter (see below) and on the blog www.ntnutechzone.no.

### SFI CASA newsletter

As part of the media strategy SFI CASA released a newsletter in September 2015. The newsletter is sent out to partners, contacts and other people in SFI CASA's social and professional network and to professionally interested parts of the media. The newsletter presents both research news and in-depth interviews with key personnel working with SFI CASA. The newsletter is published here: http://sfi-casa.no/ and anyone can subscribe to the monthly newsletter sent out by email.

### Technology evaluation

In 2014, the Research Council of Norway initiated an evaluation of Norwegian research in the field of technology. In the spring of 2015 the international evaluation committee published their report *Basic and long-term research within Engineering Science in Norway*. Three main areas of performance were emphasized in the evaluation; Scientific quality and productivity; Relevance and impact; Strategy, organization and research cooperation. The SIMLab research group hosting SFI CASA received top score in the evaluation and was described as world leading in its field of research.

### Invited and guest lectures

Professor Arild Holm Clausen presented the invited lecture *How does SFF, SFI and SFU contribute towards improving education? Experience from SFI – SIMLab at NTNU* at the NOKUT conference on higher education, 19-20 May 2015, Bergen, Norway.

Centre Director Magnus Langseth gave a presentation of SFI CASA at the official kick-off for the 9 new SFI centres hosted by NTNU and SINTEF on 18 September 2015.


Post doc Martin Kristoffersen presented his project *Explosion loads and load effects on submerged floating tunnels at Teknologidagene*, a conference organized by the Norwegian Public Roads Administration, on 23 September 2015.


### Keynote lectures

Professor Magnus Langseth gave a keynote lecture with the title *Structures subjected to extreme loading conditions. Do we need new knowledge?* at the Design and Analysis of Protective Structures (DAPS2015) conference that took place in Singapore on 19-21 May 2015.

Professor Tore Børvik gave a keynote lecture with the title *Structural impact* at the 8th national conference on computational mechanics (MekIT'15), Trondheim, 18-19 May 2015.

Bil og trafikk. Trafikksikkerhet.

# Northugs kollisjon nær perfekt

Forskere ved NTNU fastslår at Petter Northug var heldig da han krasjet natt til 4. mai i fjor. Materialene i bil og autovern reagerte nær perfekt for å beskytte livet til fører og passasjer.

Jo mer sammenkrølla rekkverket og fronten på bilen er, jo bedre. Da har disse tatt imot støyten fra kollisjonen og forskånet menneskekroppene.

Fakta

Dette er saken:

Forstå materialet

# GEMINI

SCIENCE NEWS FROM NTNU AND SINTEF

Technology Energy and environment Natural science Fish and aquaculture Innovation Health

The more the bumper and front of the car deform, the better it is for the people inside a car during a car crash. That is how NTNU experts evaluated the car that cross-country ski racing star Petter Northug drove off road on 4 May last year. Photo: Henrik Sundgård

## Creating the perfect collision

To you and me, this might look like a disaster. But Norwegian ski star Petter Northug's car crash was actually pretty ideal. The materials in the car and guard rail acted just the way they were designed to in order to save the lives of passengers in the car.

**CASA in the media**

Centre director Magnus Langseth was interviewed by the online science magazines Gemini and Forskning.no. The article was published on 4 May 2015. This article on forskning.no and gemini.no was used as background for an article in the local newspaper Trønder-Avisa published on 7 October 2015. Magnus Langseth was also interviewed for an article in the Norwegian online newspaper Din Side published on 22 August 2015.

EVALUERING AV TEKNOLOGIFAGFORSKINGA I NOREG:

## Rom for forbetring for teknologifaga

På oppdrag frå Forskingsrådet har tre internasjonale panel evaluert forskinga innanfor teknologifaga i Noreg. Forskinga på feltet viser seg å vere jamnt bra og samfunnsrelevansen høg, men det er få miljø som har kvalitet i verdstoppen. Panela oppfordrar til meir grunnforsking, meir kommersialisering og auka internasjonalt samabeid.

(Illustrasjonsfoto: Shutterstock)

Teknologifagene er evaluert:

## Fra under middels til briljant

**Et par NTNU-miljø briljerer i verdenstoppen, mens andre stemples som under middels. Norsk teknologiforskning får passet påskrevet i fersk evaluering.**

Strategi pluss hardt arbeid. SIMLab troner i den internasjonale verdenstoppen.

TEKNOLOGIMILJØER I NORGE

## Internasjonalt panel: Norge har kun to teknologimiljøer i verdenstoppen

Olje er ikke ett av dem.

The Technology Evaluation, where the principal research group in SFI CASA, SIMLab, was assessed as world leading, also received media coverage. The weekly technical journal Teknisk Ukeblad and the University newspaper Universitetsavisa published articles about the evaluation on 7 and 8 May 2015.


14 | ØKONOMI

Forskere i Trondheim og Oslo får tilgang til en verden som ville vært umulig å se uten fem nye mikroskop til 120 millioner kroner.

# Supermikroskop skal få flere i arbeid

Fakta

Transmisjons-elektronmikroskop

NTNU has invested in three new Transmission Electron Microscopes (TEM) in the recent years. The new TEMs at NTNU are part of a newly established research infrastructure named NORTEM (Norwegian Transmission Electron Microscopy) where Professor Randi Holmestad at NTNU and CASA is a key researcher. The establishment of NORTEM was covered by the weekly technical journal Teknisk Ukeblad and the local newspaper Adresseavisen and on 11 and 12 September 2015.


Norge betaler 120 millioner for fem helt spesielle mikroskoper

**Guest lectures at SFI CASA**

- Professor Em. David Embury from McMaster University in Hamilton, Canada, stayed at SFI CASA 9-13 November 2015. He gave two guest lectures at SFI CASA on 11 November 2015. The lecture titles were *Do we need homogeneous or heterogeneous microstructures?* and *Controlling the competition between plasticity and fracture.*

- Representatives from Dynamore Nordic, a vendor of the software LS-DYNA gave three guest lectures for SFI CASA personnel on 14 and 15 December 2015. The title of the lectures were 1) *Recommended control card and other settings in LS-DYNA for vehicle crash analysis*, 2) *Information on implicit capabilities for struct. analysis in LS-DYNA and example(s) on how to convert an explicit analysis to an implicit analysis*, and 3) *LS-OPT material parameter identification - introduction and demo.*

**Research visits abroad by CASA staff**

- PhD candidate Lars Edvard Dæhli stayed at the Royal Institute of Technology (KTH) in Stockholm, Sweden, 11 October - 28 November 2015.

- Professor Odd Sture Hopperstad visited LMT-Cachan, France, 19-26 April 2015.

**Prize**

Former SFI SIMLab PhD and now SINTEF researcher involved in SFI CASA Marion Fourmeau received the James Clerk Maxwell Young Writers Prize 2015 for her paper *A study on the influence of precipitate free zones on the strain localization and failure of the aluminium alloy AA7075-651*. The article is co-authored by Calin D. Marioara (SINTEF), Tore Børvik (NTNU), Ahmed Benallal (LMT-Cachan) and Odd Sture Hopperstad (NTNU). Peter S. Riseborough, Professor of Physics at Temple University, Philadelphia, USA and editor of Philosophical Magazine, gave the prize to Marion Fourmeau at the annual APS (American Physical Society) March meeting held in Baltimore.

**Concurrent projects**

- *Fundamental studies of materials´ behaviour in future cold climate applications (SMACC)* (2013-2018): NTNU and SINTEF are involved in this joint industry project. SINTEF is the project host. SIMLab is involved in the project with a PhD candidate working on behaviour and modelling of thermoplastics at low temperatures.

- *Joint research project with Honda R&D Americas* (2013-2017): The objective of the project is to model the behaviour and failure of flow drilling screws submitted to crash loadings. One PhD candidate works on the project supervised by personnel from the Centre.

- *Alumast* (2015-2017): NTNU is one of several partners in a consortium working on aluminium power pylons. A post doc at SIMLab works on the project.

- *Closing the gaps in multiscale materials modelling of precipitation free zones in aluminium* (2014-2017): NTNU and SINTEF are involved in this project on modelling of aluminium. A post doc at SIMLab works on the project.

- *Behaviour and modelling of elastomers subjected to a wide range of pressures and temperatures* (2013-2016): Aker Solutions is funding this project under the industrial PhD scheme supported by the Research Council of Norway. One PhD candidate is working on this project supervised by personnel from Aker Solutions and NTNU's Department of Structural Engineering.

- *Ferry-free coastal route E39* (2015-2017): The Norwegian Public Roads Administration heads an investigation of the possibilities for a ferry-free coastal route along the western coastline of Norway. The project funds a postdoctoral research fellow who is working with submerged floating tunnels subjected to internal blast loading.

# Personnel

# A FAMILY

*From left: Peter Karlsaune, Mikhail Khadyko, Marius Andersen, Arne Ilseng, Martin Kristoffersen, Sindre Olufsen, Tore Wisth, Hieu Nguyen Hoang, John Fredrick Berntsen, David Morin, Joakim Johnsen, Lars Edvard Dæhli, Randi Holmestad, Vegard Aune, Gaute Gruben, Jesper Friis, Trond Auestad, Knut Marthinsen, Egil Fagerholt, Stéphane Dumoulin, Magnus Langseth, Calin Marioara, Christian Oen Paulsen, Jens Kristian Holmen, Albert H. Collett, Arild Holm Clausen, Tore Børvik, Odd-Geir Lademo, Erik Løhre Grimsmo, Aase Gavina Reyes, Odd Sture Hopperstad, Laila Irene Larsen, Petter Henrik Holmstrøm, Karoline Osnes, Bjørn Håkon Frodal and Ole Vestrum.*

# PhD candidates and post docs

*From left: Vegard Aune, Joakim Johnsen, Arne Ilseng, John Fredrick Berntsen, Lars Edvard Dæhli, Marius Andersen, Emil Christiansen, Christian Oen Paulsen, Martin Kristoffersen, Sindre Olufsen, Jens Kristian Holmen, Karoline Osnes, Erik Løhre Grimsmo, Mikhail Khadyko, Ole Vestrum, Petter Henrik Holmstrøm, David Morin and Bjørn Håkon Frodal.*

# PhD candidates and post docs

PhD candidates with funding from SFI CASA

| Name | Start | Planned exam | Programme | Nationality | Gender M/F |
|---|---|---|---|---|---|
| John Fredrick Berntsen | 2015 | 2019 | Structural Joints | Norwegian | M |
| Emil Christiansen | 2015 | 2019 | Lower Scale | Norwegian | M |
| Bjørn Håkon Frodal | 2015 | 2019 | Metallic Materials | Norwegian | M |
| Sindre Olufsen | 2015 | 2019 | Polymeric Materials | Norwegian | M |
| Karoline Osnes | 2015 | 2019 | Protective Structures | Norwegian | F |

PhD candidates and post docs with funding form other sources. The topics are highly relevant for SFI CASA

| Name | Start | Planned exam | Programme | Nationality | Gender M/F |
|---|---|---|---|---|---|
| Arne Ilseng | 2013 | 2016 | Polymeric Materials | Norwegian | M |
| Joakim Johnsen | 2014 | 2017 | Polymeric Materials | Norwegian | M |
| Mikhail Khadyko* | 2015 | 2017 | Metallic Materials | Russian | M |
| Martin Kristoffersen* | 2015 | 2017 | Protective Structures | Norwegian | M |
| Christian Oen Paulsen | 2015 | 2019 | Lower Scale | Norwegian | M |
| Johan Kolstø Sønstabø | 2013 | 2017 | Structural Joints | Norwegian | M |

*Post doc

PhD candidates with funding from SFI SIMLab. The topics are highly relevant for SFI CASA

| Name | Start | Planned exam | Programme | Nationality | Gender M/F |
|---|---|---|---|---|---|
| Marius Andersen | 2011 | 2016 | Polymeric Materials | Norwegian | M |
| Vegard Aune | 2012 | 2016 | Protective Structures | Norwegian | M |
| Lars Edvard Dæhli | 2013 | 2017 | Metallic Materials | Norwegian | M |
| Erik Løhre Grimsmo | 2013 | 2017 | Structural Joints | Norwegian | M |
| Jens Kristian Holmen | 2013 | 2016 | Protective Structures | Norwegian | M |
| Petter Henrik Holmstrøm | 2013 | 2017 | Polymeric Materials | Norwegian | M |

# Recruitment

In order to recruit top Master's student and PhD candidates, visibility is important. Top quality research makes the Centre visible in the academic world but not necessarily among students. Six PhD students started in August 2015. Many of them were recruited as a result of a recruitment campaign in the spring of 2015. One of SFI CASA's goals is to train 20 PhDs over eight years. The Centre organized a seminar for Master's students at NTNU on 9 November 2015 in order to attract students for Master's studies at SFI CASA. Two other goals for SFI CASA is to attract Norwegian PhD candidates and to improve the gender balance in this field of research as traditionally there is a vast majority of male students and researchers. Further recruitment measures are needed, and will be initiated in the years to come.

# Publications and annual accounts

The following lists journal publications and conference contributions generated in 2015.

**Journal publications**

1. V. Aune, T. Børvik, M. Langseth. *Behaviour of plated structures subjected to blast loading.* Proceedings of the XI International Congress on the Mechanical and Physical Behaviour of Materials under Dynamic Loading (DYMAT), European Physical Journal – Web of Conference 94, 01015 (2015).

2. T. Børvik, S. Dey, L. Olovsson *Penetration of granular materials by small-arms bullets.* International Journal of Impact Engineering 75 (2015) 123-139.

3. M. Fourmeau, C.D. Marioara, T. Børvik, A. Benallal, O.S. Hopperstad. *A study of the influence of precipitate free zones on the strain localization and failure of the aluminium alloy* AA7075-T651. Philosophical Magazine (2015).

4. H. Fransplass, M. Langseth, O.S. Hopperstad. *Experimental and numerical study of threaded steel fasteners under combined tension and shear at elevated loading rates.* International Journal of Impact Engineering 76 (2015) 118–125.

5. E.L. Grimsmo, A.H. Clausen, M. Langseth, A. Aalberg. *An experimental study of static and dynamic behaviour of bolted end-plate joints of steel.* International Journal of Impact Engineering, 85 (2015) 132–145.

6. N.-H. Hoang, O.S. Hopperstad, O.R. Myhr, M. Langseth, C. Marioara. *An improved nano-scale material model applied in axial-crushing analyses of square hollow section aluminium profiles.* Thin-Walled Structures 92 (2015) 93–103.

7. J.K. Holmen, T. Børvik, O.R. Myhr, H.G. Fjær, O.S. Hopperstad. *Perforation of welded aluminum components: microstructurebased modelling and experimental validation.* International Journal of Impact Engineering 84 (2015) 96–107.

8. J.K. Holmen, O.S. Hopperstad, T. Børvik. *Low-velocity impact on multi-layered dual-phase steel plates.* International Journal of Impact Engineering 78 (2015) 161–177.

9. M. Khadyko, S. Dumoulin, T. Børvik, O.S. Hopperstad. *Simulation of large-strain behaviour of aluminium alloy under tensile loading using anisotropic plasticity models.* Computers & Structures, 157 (2015) 60-75.

10. T. Mánik, B. Holmedal, O.S. Hopperstad. *Strain-path change induced transients in flow stress, work hardening and r-values in aluminum.* International Journal of Plasticity 69 (2015) 1–20.

11. K.O. Pedersen, I. Westermann, T. Furu, T. Børvik, O.S. Hopperstad. *Influence of microstructure on work-hardening and ductile fracture of aluminium alloys.* Materials and Design 70 (2015) 31–44.

12. A. Saai, I. Westermann, S. Dumoulin, O.S. Hopperstad. *Crystal plasticity finite element simulations of pure bending of aluminium alloy* AA7108. International Journal of Material Forming (2015).

13. M. Storheim, H.S. Alsos, O.S. Hopperstad, J. Amdahl. *A damage-based failure model for coarsely meshed shell structures.* International Journal of Impact Engineering 83 (2015) 59–75.

14. J.K. Sønstabø, P.H. Holmstrøm, D. Morin, M. Langseth. *Macroscopic strength and failure properties of flow-drill screw connections.* Journal of Materials Processing Technology 222 (2015) 1-12.

15. V. Vilamosa, A.H. Clausen, T. Børvik, S. R. Skjervold, O.S. Hopperstad. *Behaviour of Al-Mg-Si aluminium alloys under a wide range of temperatures and strain rates.* International Journal of Impact Engineering 86 (2015) 223-239.

16. K. Zhang, B. Holmedal, O.S. Hopperstad, S. Dumoulin, J. Gawad, A. Van Bael, P. Van Houtte. *Multi-level modelling of mechanical anisotropy of commercial pure aluminium plate: Crystal plasticity models, advanced yield functions and parameter identification.* International Journal of Plasticity 66 (2015) 3–30.

**Keynote lectures**

1. T. Børvik. *Structural impact.* Proceedings of the 8th national conference on computational mechanics (MekIT'15), Trondheim, 18-19 May 2015.

2. M. Langseth. *Structures subjected to extreme loading conditions. Do we need new knowledge?* Design and Analysis of Protective Structures (DAPS2015) conference, Singapore, 19-21 May 2015.

**Invited and guest lectures**

1. A.H. Clausen. *Hvordan bidrar SFF, SFI og SFU til å gjøre utdanningen bedre? Erfaringer fra SFI – SIMLab ved NTNU.* NOKUT-konferansen om høyere utdanning, 19-20 May 2015, Bergen, Norway.

2. M. Kristoffersen. *Explosion loads and load effects on submerged floating tunnels.* Teknologidagene, a conference organized by the Norwegian Public Roads Administration, 23 September 2015.

**Conference contributions**

1. M. Andersen, A.H. Clausen, O.S. Hopperstad. *Large strain measurements of HDPE subjected to uniaxial tension using DIC.* 16th International Conference on Deformation, Yield and Fracture of Polymers, Kerkrade, the Netherlands, 29 March – 2 April, 2015.

2. V. Aune, T. Børvik, M. Langseth. *On the fluid-structure interaction effects of plated structures subjected to blast loading – an experimental and numerical investigation.* Proceedings of the 8th national conference on computational mechanics (MekIT'15), Trondheim, Norway, 18-19 May 2015.

3. V. Aune, T. Børvik, M. Langseth M. *Behaviour of plated structures subjected to blast loading.* Proceedings of 11th International DYMAT Conference, Lugano, Switzerland, 7-11 September, 2015.

4. M.J. Forrestal, T.L. Warren, T. Børvik, W. Chen. *Perforation of 6082-T651 Aluminum Plates with 7.62 mm APM2 Bullets at Normal and Oblique Impacts.* In: B. Song et al. (eds.), Dynamic Behavior of Materials, Volume 1: Proceedings of the 2014 Annual Conference on Experimental and Applied Mechanics, Conference Proceedings of the Society for Experimental Mechanics Series, Volume 65, Issue Volume 1, 389-402, 2015.

5. E.L. Grimsmo, A.H. Clausen, A. Aalberg, M. Langseth. *Beam-to-column joints subjected to impact loading.* Nordic Steel Construction Conference, 23-25 September 2015, Tampere, Finland.

6. J.K. Holmen, T. Børvik, O.R. Myhr, O.S. Hopperstad. *Perforation of welded aluminum extrusions: Numerical prediction and experimental validation.* 11th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading, 7-11 September 2015, Lugano, Switzerland.

7. P.H. Holmstrøm, A.H. Clausen, D. Morin, O.S. Hopperstad. *Experimental and numerical investigation of tensile properties of glass fibre-reinforced polypropylene.* 16th International Conference on Deformation, Yield and Fracture of Polymers, Kerkrade, the Netherlands, March 29 – April 2, 2015.

8. A. Ilseng, B.H. Skallerud, A.H. Clausen. *Experimental study of the compressibility of an HNBR and an FKM elastomer.* 16th International Conference on Deformation, Yield and Fracture of Polymers, Kerkrade, the Netherlands, 29 March – 2 April, 2015.

9. A. Ilseng, B.H. Skallerud, A.H. Clausen. *Case study of elastomer seals using FEM.* Proceedings of the 8th national conference on computational mechanics (MekIT'15), Trondheim, 18-19 May, 2015.

10. A. Ilseng, B.H. Skallerud, A.H. Clausen. *Volumetric compression of HNBR and FKM elastomers.* Proceedings of Constitutive Models for Rubber IX, Prague, Czech Republic, 1-4 September, 2015.

11. M. Kristoffersen, T. Børvik, M. Langseth, O.S. Hopperstad. *X65 steel pipes subjected to combined stretching and bending.* Proceedings of Marine 2015 – VI International Conference on Computational Methods in Marine Engineering, Rome, Italy, 15-17 June 2015.

12. J.K. Sønstabø, D. Morin, M. Langseth. *Macroscopic Modeling of Flow-Drill Screw Connections.* 10th European LS-Dyna Conference, 15-17 June 2015 Würzburg, Germany.

13. V. Vilamosa, T. Børvik, O.S. Hopperstad, A.H. Clausen. *Behaviour and modelling of aluminium alloys subjected to a wide range of strain rates and temperatures.* Proceedings of 11th International DYMAT Conference, Lugano, Switzerland, 7-11 September, 2015.

# Annual accounts

The tables give an overview of the distribution of funding and costs in the Centre for 2015. The funding plan shows where the funding comes from. The cost plan shows where the research work has been carried out.

**SFI CASA funding 2015 (All figures in 1000 NOK)**

| Item | Host NTNU | Research partner SINTEF | Public partners | Industrial partners | RCN Grant | Total funding |
|---|---|---|---|---|---|---|
| Research programmes | 3 355 | 550 | 1 294 | 4 616 | 1 503 | 11 318 |
| Equipment | | | | | | 0 |
| Administration | 500 | | 781 | 1 184 | 137 | 2 602 |
| Total budget | 3 855 | 550 | 2 075 | 5 800 | 1 640 | 13 920 |

**SFI CASA cost 2015 (All figures in 1000 NOK)**

| Item | Host NTNU | Research partner SINTEF | Public partners | Industrial partners | Total cost |
|---|---|---|---|---|---|
| Research programmes | 6 417 | 3 001 | 350 | 1 550 | 11 318 |
| Equipment | | | | | 0 |
| Administration | 2 453 | 149 | | | 2 602 |
| Total budget | 8 870 | 3 150 | 350 | 1 550 | 13 920 |

For the Stories & Profiles part of the report, continue to page 33

# CASA

Annual Report 2015

Centre for Advanced Structural Analysis

# Stories & Profiles

sfi Centre for Research-based Innovation

SINTEF

NTNU

# What is an SFI, what is SIMLab, what is CASA...

**SFI IS A FUNDING SCHEME**

SFI, Centre for Research-based Innovation, is a funding scheme administered by the Research Council of Norway (RCN).

The main objective for the SFIs is to increase the capability of business to innovate by focusing on long-term research. The idea is to forge close alliances between research-intensive enterprises and prominent research groups.

The host institution for an SFI can be a university, a university college, a research institute or an enterprise with a strong research activity.

The partners (enterprises, public organisations and other research institutions) must contribute to the centre in the form of funding, facilities, competence and their own efforts throughout the life cycle of the centre.

The life cycle is eight years. Each centre receives roughly 12 MNOK per year from RCN. The host institution and partners must contribute with at least the same amount.

**SIMLAB IS A RESEARCH GROUP**

Structural Impact Laboratory, SIMLab, is a research group at the Department of Structural Engineering, NTNU. From 2007 to 2014, SIMLab hosted an SFI with the same name, SFI SIMLab. This double use of the name sometimes causes confusion, but now you know:

SFI SIMLab is history; the SIMLab research group is alive and kicking.

All the more comforting, since the group carries with it all the expertise that brought SFI SIMLab to a world-leading position in the design of crashworthy and protective structures.

**CASA IS AN SFI**

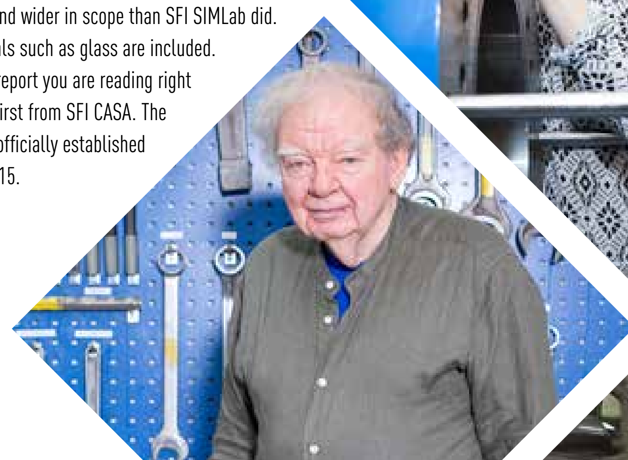
CASA, Centre for Advanced Structural Analysis, is the name of the new SFI hosted by the SIMLab research group.

The vision of SFI CASA is to establish a world-leading centre for multi-scale testing, modelling and simulation of materials and structures for industrial applications.

In doing so, CASA will both go further down in scale to nano level and wider in scope than SFI SIMLab did.

New materials such as glass are included.

The annual report you are reading right now, is the first from SFI CASA. The Centre was officially established on 1 July 2015.



**Cover:**
PhD candidate Karoline Osnes,
test specimen in hand,
inside the NOK 6 million shock tube.

**All photos this section:**
Ole Morten Melgård.

**Layout:**
NTNU Grafisk Senter

# ...and what is this?

This is the popularized part of the annual report.
This is a glimpse of what CASA is all about for those of us who don't deal with precipitate free zones or constitutive models on a daily basis.
The aim is the same as the rest of this report: to explain what goes on in CASA and why it is important to society.
The articles here come in two categories; stories and profiles.

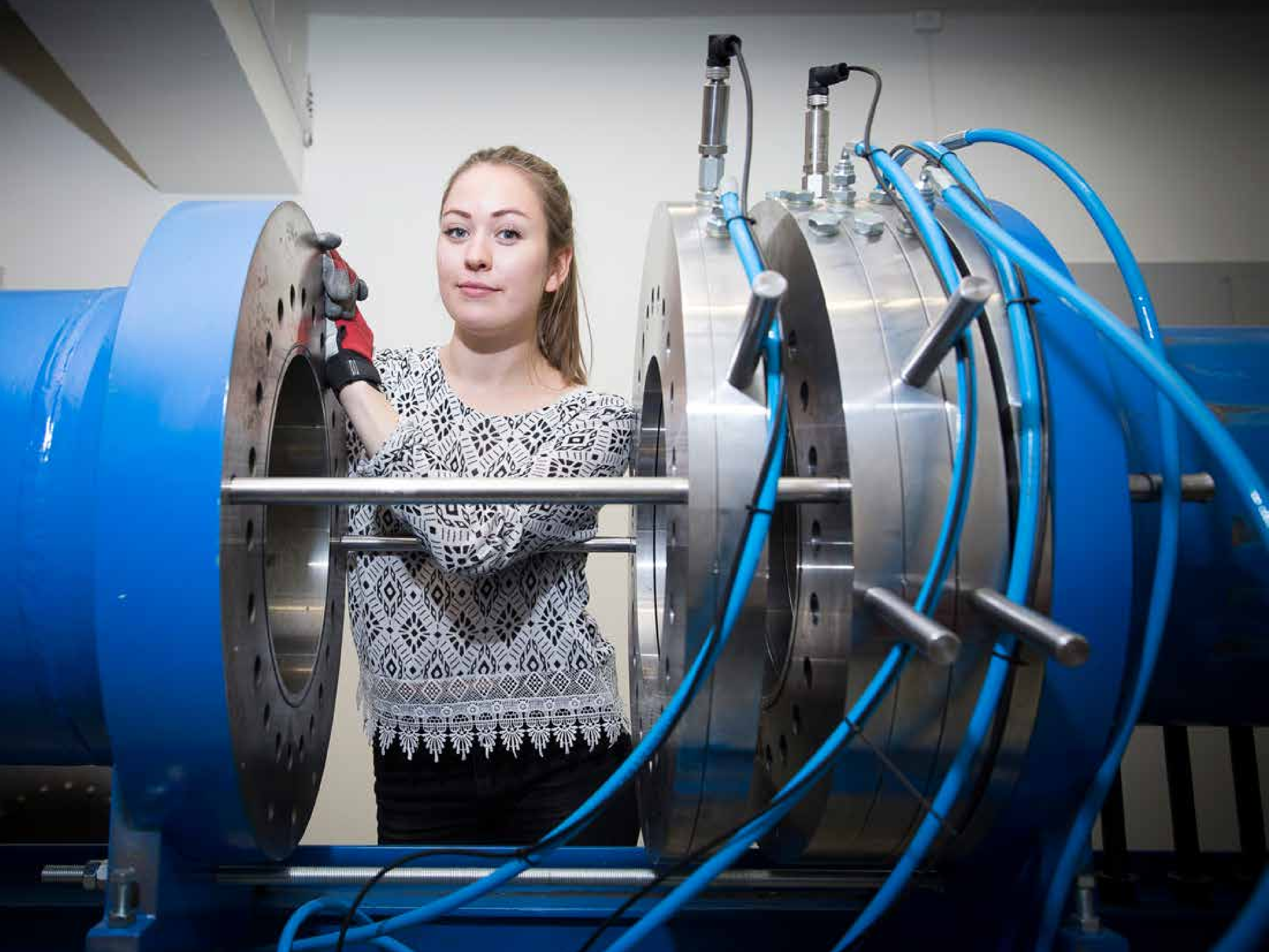
**THE GLASS MANAGER**

PhD Candidate Karoline Osnes is the complete opposite of Laura Wingfield in "The Glass Menagerie". Wingfield polishes her little glass objects. Osnes subjects hers to destructive blasts.
The next profile is also new to CASA. Professor Randi Holmestad's physicist expertise is needed to understand on atomic level how aluminium behaves under attack.
The lucky guy appearing on the pages between these two has well deserved his position. After all, he sits on CASA's Scientific Advisory Board. David Embury has news about hybrid and architectured materials.
Thereafter you will learn how NTNU and SINTEF have joined forces to give the business partners in CASA a tool box. These tools help industry transform scientific findings into safer, less costly and more eco-friendly products and processes.

**THE PERFECT MATCH**

Alexandra Bech Gjørv became a household name when she headed the fact-finding commission after the 2011 terrorist attack in Norway. Now she is SINTEF's new CEO. Her thorough insight in aluminium, automotive industry and anti-terror makes her a perfect match for CASA.
In the following story, you'll learn how the master's students at CASA may each spend half a year with one of our partner's. John Fredrick Berntsen got the chance to join Toyota Motor Europe in Brussels and has no regrets.
Then there's the boss. About time he was portrayed. Thanks to his wife, he never took over the family farm. He became a professor. As most readers of this report already know, he has no small part in his research group's position as world leaders in their field. And still, come late September, he's gone. Every year.
Following that, you'll learn why the Ministry of Local Government and Modernisation decided to join CASA. Deputy director general Christian Fredrik Horst shares the insight that CASA's expertise simply cannot be bought elsewhere.
Finally there's a story you shouldn't read. So stay away, please.

# Contents



# The GLASS Manager

Judging by industry and public interest in her subject, Karoline Osnes has brilliant prospects. In a few years she will know more about the behaviour of glass in explosions than most people on the planet.

PhD candidate Karoline Osnes is quite the opposite of Laura Wingfield in "The Glass Menagerie". The character in Tennessee Williams' classic play spends time polishing and arranging her collection of little glass animals. Karoline Osnes takes professional pleasure in breaking glass. Not only that; she studies the process in great detail. The aim of her PhD is to describe the characteristics of glass and laminated glass as precisely as possible.

There is another contrast as well: Laura Wingfield is shy and isolates herself in her room. Karoline Osnes is a lively and including participant in any social setting. Her laughter is audible from far away.

**NEW TOPIC**

Osnes is very much aware that her PhD work is being followed with considerable interest. When SFI SIMLab decided to direct their attention towards anti-terror just months prior to the attack on 22 July 2011, they showed almost spooky foresight. Since then, the labs at NTNU have been even better equipped for what Osnes is concentrating on. The new shock tube will play a central part in her experimental work.

While glass wasn't a research topic for CASA's predecessor SIMLab, the inclusion of the new material is particularly interesting for the Ministry of Local Government and Modernisation; one of CASA's new partners. They are responsible for building the new government administration in Oslo.

**CAR MAKERS EAGER TO KNOW**

"Due to micro cracks, glass will behave differently in each blast although the impact is the same. I will try to capture this behaviour in the numerical models I plan to develop and validate. I want to describe the fragmentation and, in the case of laminated glass, the interaction with polymers," Osnes explains.

At the same time, the generic nature of research comes through: several of CASA's partners in the automotive industry quickly signalled their interest. It is no wild guess that there will be more PhD work on glass in the eight years ahead.

**AN ARTIST LOST**

Osnes' way into breaking glass was not a given. Growing up in a town southwest of Trondheim she can only remember one related incident: she accidentally broke a mirror.

As a youngster, she enjoyed painting and drawing and wanted to be an artist. However, she was also good at maths. In the end, she decided that an engineering career might be a safer livelihood.

Her joining up with NTNU's SIMLab happened rather by accident: a friend had heard about it and she decided to go for it when she got a chance to do a student project there.

She went on to write her master's thesis in the same place, studying what happens to a floating tunnel exposed to an internal explosion. The subject has great interest in Norway, since Parliament has decided to build a ferry-free highway along the west coast from Kristiansand in the far south to Trondheim in Mid-Norway. This implies crossing the Sognefjord, which is too deep for a conventional tunnel and 3.7 kilometres wide at the crossing point. A floating tunnel is one of the options under consideration.

**DROPPED CONSULTANCY**

After finishing her masters' degree, Karoline Osnes landed a job with a well-known Norwegian engineering consultancy. Then, before she had even started, she received an email.

"Professor Tore Børvik invited me to a meeting in his office. Flattered by the invitation, I accepted. When I got there, CASA Director Magnus Langseth was present as well. They wanted me to consider going for a PhD. We didn't talk for very long, but there was something in their message that triggered me. Something along the line of "This is a kind of chance you only get once", and "Nobody who takes a PhD ever regrets". It made me think "This is a bigger challenge than I'll get at the consultancy". So here I am, without having tried the alternative," she says.

**PART OF THE BUNCH**

"And now, three months into your PhD work, have you had moments of regret?"

"No. There have been times when I have asked myself if I made the right choice, but I'm confident that I would have regretted it if I hadn't joined."

"At the moment, you are the only female PhD candidate at SIMLab. Does that bother you?"

"Not at all. I feel as much part of the bunch as everyone else. It wasn't a surprise to me now, but when I started on my master's thesis I was struck by the good atmosphere. SIMLab has a well-earned fame for that, in addition to the high qualifications. People are very open, I always feel I can ask and people always take time to answer. It's a great place to be!"

Are you listening, Laura Wingfield? And bring your unicorn.

## How to replace

# Stainless Steel with a Hybrid

Stainless steel is expensive. What if you could get the same user qualities more cheaply by combining a stainless surface with a conventional steel substrate using a surface modification technique? David Embury shares a peek into a new world of hybrid and architectured materials.

In the real world, companies like Statoil demand materials that can transport energy. The automotive industry transports people and products. To do so cost effectively, they push conventional materials to the limit. Conflicting properties are required, e.g. high strength and high ductility which are difficult to achieve in a single material. Can we take a different approach? Can we combine materials in new geometries and devise new processes to make these architectured materials?

**TAILORING MATERIALS AND PROCESSES**

The idea is to combine laminated metals, foams and polymers, to modify existing casting and heat treatment processes to produce both hybrid materials and hybrid processes. David Embury exemplifies:

"If you take, say five millimetres of conventional steel and coat it with 100 microns of high chromium steel on the surface to produce an adherent protective oxide, you could save a great deal of money compared to a stainless steel structure."

At 76, Embury is not only an Honorary Doctor at NTNU; he has just been recruited as member of SFI CASA's Scientific Advisory Board, (SAB). Last November he gave two lectures in Trondheim: "Do we need homogeneous or heterogeneous microstructures?" and "Controlling the competition between plasticity and fracture".

**RELEVANT TO INDUSTRY**

He is a professor emeritus from McMaster University in Canada, but far from curling up on a sofa he still collaborates with researchers around the world. During his stay in Trondheim he talked to people from Hydro, a CASA partner, about the design of aluminium cables for transporting electricity across the deep waters of the North Sea.

"The concept of architectured materials has a lot of relevance for industry. There is great interest in lightweight structural applications for different demands, including energy transport and energy absorption, using architectural materials. Take titanium alloys. If we could make them transform like steels to achieve very high strengths, they would be applicable for a number of new purposes.

The concept of hybrids is known. What we are looking at now, are new combinations of materials and new ways of fabricating complex geometries that is new ways of combining existing knowledge to design new engineering solutions," Embury says.

**INFLUENCES CASA**

David Embury expects SFI CASA to become more flexible and inclusive than SFI SIMLab was:

"The Centre is still in the process of evolving, but the new research field of ultra-high strain testing and the broadening of perspective with glass is likely to increase the social impact. One example is that work on glass in buildings also will be interesting for glass in cars and other forms of transport."

Without knowing, Embury confirms the interest Honda's Eric DeHoff showed at CASA's kick-off, where he made exactly the same point. Since then, other CASA partners have expressed the same interest.

**INTELLIGENT MATERIALS**

CASA's SAB hasn't had its first meeting yet, but David Embury served on SIMLab's SAB as well. He would like to contribute to future activities:

"CASA can clearly utilize the experience of SIMLab in encouraging the inclusion of more partners. CASA should also build on SIMLab's strength in the interface between mechanics and materials. Then all kinds of things might emerge, such as a variety of intelligent materials. The social relevance of the products will increase with the combination of glass and polymers."

"So who would you welcome as new partners?"

"I would be happy to see a big glass producer on board. A broadening of large producers would be valuable for all," he says. He thinks CASA's portfolio may change more rapidly than SIMLab's did, with a broader range of applications where products can be applied.

**AVOID OVERLOAD**

The scientific advisor has one more piece of advice:

"CASA is going to need good postdoctoral staff and visiting faculty. You have very good students, but will need to increase the manpower in the system with people from all over the world. I am concerned that you do not increase the load on faculty. They should remain truly productive and not overloaded as they are in many North American universities."

# New Girl on the BLOCK

The folks at SIMLab know better than anyone how aluminium grains behave under attack. Because of that, they decided that the follow-up - CASA - needs expertise on atomic level. Randi Holmestad's expertise.

Aluminium grains are tiny. There are as many in one cubic millimetre as there are sand grains on a beach. In working with these aluminium grains, SIMLab realized that they needed to learn more about the details inside the grains. There were indications that lower scale matters. The logical consequence is that studies down to atomic level are needed to establish material properties with greater certainty. Studying details in the microstructure - such as particles, precipitates, dislocations and grain boundaries - gives a better understanding. This in turn will help with experiments, simulation and modelling as basis for innovation.

**THE MICROSCOPE**

Enter Professor Holmestad and her team at NTNU's Department of Physics. They possess a NOK ~20 million state-of-the-art transmission electron microscope (TEM) allowing studies down to 0.06 nanometre. The distance between atoms in materials is in the order of 0.2 nanometres, so only now will the researchers be able to study in detail what happens to the atom structure when the materials are subjected to impacts such as collisions and explosions. The same goes for temperature changes. One of the many areas where such knowledge will become increasingly important is operating oil rigs in Arctic waters.

**RANDI RUNS**

Randi Holmestad runs. Literally. If colleagues observe her walking in the corridor, they will pop out of their office and ask if something is wrong.

Running can bring you pretty far. In 1998, at 30, Randi became the youngest female professor in the university. A few years later, her supervisor fell ill and she had to step up as group leader. Since then she has guided 52 master's students and 13 PhD candidates through thick and thin. Two years ago her department acquired the world class microscope as part of the NORTEM large scale infrastructure project, where NTNU collaborates with SINTEF and the University of Oslo. Starting now, SFI CASA will be able to share the benefits. Emil Christiansen, the first PhD candidate on this task, is already working on this with a thesis on precipitate microstructures.

**KNOWS ALUMINIUM**

If Professor Holmestad is new to CASA, she is by no means new to aluminium or to external partners. Norwegian aluminium producer Hydro has a decades-long relationship with NTNU's Department of Physics and depends on its scientific results to keep up front. Part of the current cooperation through the "Hydro Road Map" scheme was developed in the tripartite relation between Hydro, SINTEF and NTNU. CASA director Magnus Langseth was one of the creators. Holmestad is one of many contributors and is the proud holder of a patent on an aluminium alloy.

"I feel privileged for taking part. This kind of long-term cooperation has huge, mutual benefits," she says.

Likewise, she has cooperated with CASA research partner SINTEF for years and years. She thoroughly enjoys the exchange:

"It's rewarding when partners like Hydro, Benteler and SAPA need input."

**USEFUL NEEDLES**

In its pure form, a piece of aluminium is bendable with pure manpower. The application value starts when alloying with silicon, magnesium, zinc, copper, silver, germanium and other metals, where only a per cent or two dramatically changes the characteristics of the material. In age hardenable aluminium alloys this is due to nano-sized precipitates – small needles precipitating all over the place in the alloy, which you can observe in the microscope. As is the case for any cake in the oven, time and temperature are crucial factors.

In Holmestad's case, she admits a special weakness for one of the alloying atoms:

"I'm particularly fascinated by the copper atoms."

At the moment, Holmestad is working on a project that seeks to reduce the alloying content of extruded and rolled aluminium without loss of strength.

"By smart alloy design, we can reduce the total solute, the alloys can be easier processed and Hydro saves money."

**AS FAR AS NECESSARY**

Holmestad's role in CASA will be to go as far down in detail as necessary, not further. She and her collaborators will try to establish what is needed to make more suited materials for any given purpose; be it construction details that might be applicable in the new government administration complex in Oslo, a car part or another industrial application.

With time, the findings will be added to the SIMLab Tool Box for the partners to use.

**FAITHFUL**

CASA's newly recruited professor has remained faithful to Trondheim and NTNU throughout her career, with the exception of four half-year visits to US universities in Arizona and Illinois. She's run since childhood. Early on she was attracted to orienteering. Now she's taken up the activity, but at a more modest level. And of course, she still runs in the corridors.

# Partner Tools save MILLIONS

On the one hand, SFI CASA is brand new. On the other, the partners can start using a wealth of scientific findings right from the start. Here's the SIMLab Tool Box for you.

When predecessor SFI SIMLab was halfway through its eight year programme, some of the partners expressed concerns: would the research give them the innovative tool they needed? That's when Audi's Thomas Hambrecht came up with the idea of a Tool Box. He was familiar with similar tools elsewhere.

**IN USE WITH SUCCESS**

Now the Tool Box is in place and available to all partners. In many respects it is the very foundation of CASA.

It has already proven useful. Industrial implementation is accelerating. Many of the partners will naturally want to protect their innovations, but this much can be said: one partner has made large improvements on their products thanks to one of the models in the Box. Another partner has compared a Tool Box model with competing models and received more reliable results with SIMLab's Box. So, better products is one result. Money saved is another.

**THEN...**

When the first Tool Box version was presented in 2011, it contained four basic tools, and bear with us for a bit of scientific speak in the rest of the paragraph: the Results Organizer is designed to support experimental planning, execution and processing, the Digital Image Correlation allows determining the displacement field on material/structural tests based on digital images and Mat-Pre-Post is a tool for parameter identification and tailored pre- and post-processing. Finally, the Model Library is a collection of customized, user-defined material models and solution techniques.

**...AND NOW**

Since then, a number of dedicated researchers and students have worked steadily to develop the Box further. The four initial tools have become eight, including micro generator and forming limit apps, the latter being used on metal sheets in car production and the like. New programs are added, database solutions attached, structure and user-friendliness improved.

Today, the Tool Box can be used to model materials, move further down in scale and work on multi-scale modelling. Industrial applications are ever increasing. The image of the basic research being performed in the SFI, the partner logos in a circle around it and the Tool Box between them is increasingly accurate and truthful. This includes assistance from members of the research team at NTNU and SINTEF when partners write applications for innovation projects. It also includes commissioned testing and development of dedicated software. The portfolio is steadily growing.

**JOINT OWNERSHIP**

The SIMLab Tool Box is developed and owned jointly by NTNU and its research partner SINTEF. This cooperation is reflected in CASA's Methods and Tools Programme being headed by Research Director Odd-Geir Lademo and Research Scientist Térence Coudert at SINTEF Materials and Chemistry. The development of the Tool Box is a central part of the programme. This will include improvement of prediction accuracy, efficiency and robustness of existing models and methods as well as the development of new ones.

**MET WITH SCEPTICISM**

At the start, the idea of the Tool Box was met with considerable scepticism, not the least on the Scientific Advisory Board. There was fear that it would be costly to maintain due to the financial and manpower requirements and have negative impact on research. Today, Odd-Geir Lademo is in no doubt whatsoever that the Box is a success.

"In fact, we have saved money and we are more efficient than we would have been without it. The synthesis of our joint efforts is the decisive factor. None of us could have carried this through on our own. Other research centres are looking to us to learn from what we have achieved.

The partners get access to massive amounts of research at a low cost. It is a very good deal for them."

**FUNDING INCLUDED**

To some extent, Lademo understands the original scepticism on the Advisory Board:

"I think it has to do with the board members not being familiar with our Nordic tripartite model of universities, independent research organizations and innovative business working together for the common good. The continued benefits of the Tool Box is part of the package. It is funded by the partnership fees, as simple as that," he states.

That is not to say that the Tool Box doesn't cost. Several researchers are closely involved with improving the Box. This is not in conflict with the basic research to be carried out in an SFI as methods and tools are a must with respect to innovation and value creation at the industrial partners.

*The SIMLab Tool Box crew:*
*from left David Morin, Torodd Berstad, Egil Fagerholt,*
*Stéphane Dumoulin, Odd-Geir Lademo and Jesper Friis.*

# A perfect MATCH

With thorough insight in aluminium, automotive industry and anti-terror, it's hard to imagine a better match for SFI CASA than SINTEF's new CEO Alexandra Bech Gjørv.

She is a lawyer by training, with a degree from Oslo, a diploma in legal studies from Oxford and a licence to practice law in New York. Today, she regards this part of her past more like a detour: "Looking back, I see a pattern that almost looks planned, with three significant threads. First, I have always taken an interest in industrial development. Second, I enjoy the challenge of getting complex organizations to work well. Third, advanced sales of services in highly competent enterprises has been a recurring trigger."

**HYDRO AND STATOIL**

SINTEF is not new to Bech Gjørv. She's been a board member for four years. At the time, she was a Hydro executive with several years behind her in the automotive structures division. When Hydro and Statoil joined forces, Bech Gjørv was the only Hydro executive to continue on top in the merged company. All in all, she worked 17 years for the two companies. The tasks ranged from wind turbines to carbon capture, from aluminium to HR.

The multifaceted experience is no handicap in her new position: SINTEF develops everything from data chips for space stations to fodder for fish farms.

**BEST FRIENDS**

Alexandra Bech Gjørv gave her first major address as SINTEF CEO at the annual conference of the Confederation of Norwegian Enterprise. In her presentation, she said: "We are best friends with NTNU".

She is well aware that her 2000 colleagues in Scandinavia's largest independent research organization rely heavily on the cooperation with the neighbouring university. For the partners in SFI CASA, access to the SIMLab Tool Box, owned jointly by NTNU and SINTEF, is an essential foundation for innovation and commercial harvest from the scientific findings.

**LESSONS LEARNED FROM TERROR**

As most Norwegians know, Bech Gjørv headed the fact-finding commission appointed by the government after the 2011 terrorist attacks.

She makes a point of not commenting whether the police have taken on the lessons learned. On the other hand, few have a better impression of the results of the terrorist attack. This includes the massive impact of the explosion outside the government administration complex.

She readily recognizes the importance of SIMLab's and CASA's advances in multi-scale testing, modelling and simulation of materials and structures. One of the many areas where this kind of research is needed is in the planning of the new government administration complex:

**SIMULATIONS SHOWED THE NEED**

"Simulations of structural vulnerability are a critical enabler of planning a government complex with an architecture and choice of materials that balances the real needs for security with the equally important need for democratic access.

Our commission did in fact document that such simulations done before the terrorist attack showed a need to block the street leading to the Prime Minister's office for vehicle access, while allowing pedestrian access was an acceptable risk. The mistake made was in not implementing the governmental decision to block the road for vehicles," she says.

**CURIOSITY-DRIVEN**

Curiosity killed the cat. Luckily, it doesn't work like that for humans. In Alexandra Bech Gjørv's case, it is what drives her.

"At the same time, I'm disciplined. In spite of a spontaneous nature, over the years in executive positions, I have learned to enjoy working systematically and with a plan. It definitely helps that I find whatever I'm working with at any given moment very exciting. I get completely absorbed," she confesses.

At the time of the interview she is full of enthusiasm over the fruits of a long-lasting collaboration between her old employer Hydro, and SINTEF and NTNU: Hydro has decided to invest almost NOK 4 billion in a pilot for the world's most environmentally friendly aluminium plant at Karmøy.

**A NEED TO CULTIVATE**

SINTEF's new CEO stresses the importance of high ambitions as well as the courage to ask difficult questions. This includes a diligent search for the highest risks, whether the topic is avalanches, terror or refugees.

"SINTEF's mission is to guide enterprises on the road to creating value by solving problems in society," she says.

She looks forward to continue the cooperation with best friend NTNU, including CASA. She also is well aware of the continuous tension between a university dedicated to basic research and an independent research organization that must always have the market in mind.

"I think this fundamentally is a constructive tension that has served NTNU, Norwegian industry and SINTEF well over the years. However, as the institutions have grown, there is a need to cultivate and perhaps formalize the relationship a bit more. I also have some ideas around how the Ministry of Education could facilitate the university/institute relationship, but I shouldn't get too excited before the ideas are fully explored with people more experienced in university politics than myself," she sums up.

Potentially, a hundred years of student labour is available to the partners in SFI CASA. Toyota has caught the essence. They've got help twice already.

# John, Yann, Avensis and POLYMERS

For his project assignment before starting as a master's student, John Fredrick Berntsen planned to crush aluminium profiles. In came an email from SIMLab Professor Arild Holm Clausen: "Toyota in Brussels is looking for a master's student to work as an intern." John Fredrick applied and got the post.

"It was a childhood dream come true: to be able to work in the automotive industry, to get hands on experience at a workplace abroad, to see what it was like. It was a great opportunity to learn," he says. Learn he did. After surmounting some serious obstacles, he was relieved to get some valuable results in the end.

## A WISH TO VERIFY

Toyota's ambition was to verify the qualities of the material model in SIMLab's Tool Box.

To start with, they wanted to perform a test on a simple polymer box of the kind you find in any hardware store. This was easier said than done:

"We discovered that the boxes didn't have the properties described by the producer. The geometry was wrong; the thickness and quality varied. This affected the results of our tests significantly and reduced their value. It also stole time," John Fredrick confesses.

## REALIST

Luckily, Ernesto Mottola at Toyota's Technical Centre reacted with a realist's attitude. "This is research. There are always unexpected results," he said, quickly followed by suggestions for solving the issues.

His attitude came in useful in two ways, since John Fredrick and his Toyota mentor Yann Claude Ngueveu ran into serious obstacles on the real thing as well.

Toyota wanted to use the lower absorber of an Avensis as a test specimen for industrial verification of SIMLab's polymer model. After meticulous preparations in Brussels, John Fredrick returned to NTNU in Trondheim for intensive days of component testing. That's when the real trouble started.

## DISASTROUS RESULTS

"My task was to reproduce the pedestrian protection simulation in the lab. We wanted to put the absorber in the drop tower. That turned out to be a challenge in itself. The absorber has complex geometry and for the test to give valuable results we needed to control the movements. There was a risk that the impactor would bend out of shape or break.

The first real tests were a total disaster. We started at a very low speed, with impacts at four metres per second. The video footage showed bending far beyond the expectations, endangering harm to the impactor. At the same time, the cause of the vibrations measured was not visible in the video footage. The results were nowhere near the simulations. Something was very wrong," John Fredrick confesses.

## A BETTER MODEL

The situation obviously put him under a lot of stress. Returning to Brussels without results was not an option and the results he had were useless. In the end, he and the scientific staff at SIMLab had to improvise with pieces of wood to keep the absorber in place. Finally, he succeeded: with surprises alleviated, SIMLab's polymer model showed significant improvements from currently implemented models right from the first simulation. It proved to have qualities that describe the physics of polymers better than alternative models

Interestingly, in John Fredrick's words: "It was almost scary to see how even small details could greatly influence the results."

## TOYOTA FOLLOWS UP

Toyota's satisfaction is illustrated by the fact that they have decided to follow up on the work with a clear ambition to reach industrial implementation.

"The merit of SIMLab's material model and John Fredrick's activity is that realistic simulation can really help in making a good and robust design," says Ernesto Mottola.

CASA is also continuing. David Morin, head of the structural joints programme, is doing further modelling.

## MUTUAL BENEFIT

Professor Arild Holm Clausen, head of CASA's Polymeric Materials programme, stresses the mutual benefit of such exchanges:

"This is an invaluable method for technology transfer. The first master's student that visited Toyota did so as a result of his personal initiative. It was an immediate success, so the people at Toyota were eager to continue. I hope and think this will serve as a trigger for further exchange of scientific staff," Holm Clausen says.

John Fredrick Berntsen is in no doubt whatsoever about the usefulness of his stay: "It has given me much better basis for my present PhD work on structural joints than I would have had otherwise."

Over CASA's eight year programme period, 200 master's students can potentially spend half a year with a partner.


HYBRID
Continental
SONIC

# Hunter INSIDE

If you're grateful for Magnus Langseth's scientific contributions, say thank you to his wife. She stopped him from taking over the family farm. What she hasn't done, is take the hunter out of him.

A good number of Norwegian municipalities don't hold meetings for several weeks each autumn. During the moose hunt, no one will show up. The hunt is sacred. The mixture of excitement, companionship, autumn leaves at their most colourful and an occasional blue sky beats everything. Plus, there's delicious food to be harvested. One of this writer's fondest childhood memories is the smell of moose kidneys sizzling in the pan.

**WORLD LEADER...**

Point taken? SFI CASA Director Magnus Langseth is a hunter. Come late September, he's gone. Crocs empty in the office, toes happily curling in forest boots.

The link? Possibly none, but a moose hunter needs to be alert, focused, patient and good at communicating with the rest of the team. This just might be some of the qualities that have brought SIMLab and CASA to their current position.

When the Research Council of Norway wrote their Midway Evaluation of SFI SIMLab, they described Professor Langseth like this: "of remarkable scientific and professional management quality".

He is Editor-in-Chief of the International Journal of Impact Engineering and sits on two more editorial boards. In other words, he is a world capacity in his field.

**...AND BOY**

At the same time, he is a boy, beaming with childish joy. His energy and enthusiasm never fails, his creativity and ability to act swiftly likewise. His laughter echoes in the corridors.

There are other sides, too, he confesses:

"I very much need to feel that everyone is on board. Sometimes, when I say or do things, I can spend days waiting for signals that everything is OK."

"The group has been likened to a family. What do you think?"

"I sympathize with that. Everyone knows each other really well; the atmosphere is friendly and very open. In a family, mom and dad should be present. With us, senior professors arrive early and they are not the first to leave. There is a general sense of well-being. We enjoy each other's company."

**WHAT WOULD HAPPEN IF...?**

A recent evaluation by three international panels found that 2 out of 64 Norwegian technology research groups were world leading. SIMLab was one of them.

Professor Langseth emphasizes the combined effort behind. The group that has so far culminated in the NOK 300 million SFI CASA programme has taken 25 years to build.

Some people and institutions have been particularly important. Professor Per Kristian Larsen was vital from the start. He was Langseth's supervisor for his PhD thesis.

Statoil Director and NTNU Adjunct Professor Jon M. Huslid played a decisive role in choosing impact as the focus point. In 1983/84, he commissioned and financed Langseth's PhD thesis.

"Statoil were concerned what would happen if a 3-ton drill pipe dropped to the deck of an oilrig during installation. He wanted us to find out. We wrote a description of the project and applied for NOK 80 000. We got one million. This enabled us to build a test rig that is still in use. We developed a formula model that describes how much energy is needed to penetrate a steel plate. The formula still stands," says Langseth.

**IN COMES ALUMINIUM**

The focus on impact in turn triggered Arnfinn Jenssen, Head of R&D at the Norwegian Defence Estates Agency. He and Hydro Director Einar Wathne were central in the funding of research activities and the lab that is such a crucial part of SIMLab.

Hydro's interest started after another decisive moment in SIMLab/CASA's history, namely the discussion between Larsen, Langseth and Odd Sture Hopperstad about the future of the research group. They decided to dive into aluminium and the focus was placed on the modelling of the material and its use in structural applications.

As Langseth puts it: "Hydro had a lot of metallurgists, but limited competence in modelling and structural design."

**RECRUITMENT**

Arnfinn Jenssen also provided valuable staff by sending newly graduated civil engineers to SIMLab for their military service. One of them was Professor Tore Børvik. Today he is CASA's Co-Director. Professor Arild Holm Clausen and SINTEF Research Director Odd-Geir Lademo were recruited in the same way.

In addition, Professor Langseth stresses the theoretical capacity of CASA's Research Director Odd Sture Hopperstad: "Our cooperation has been extremely rewarding, with me on the more practical and administrative side."

Some of this is history, some is still actual fact. As far as the future is concerned, Magnus Langseth is happy to see that CASA succeeds in its strategy of recruiting candidates primarily from NTNU.

And the farm? Hasn't seen cows and sheep in decades.

Bullet proof windows don't help much if the whole building comes down on you. Obvious? Sure, and it is one of the classic dilemmas facing the people who plan the new government administration complex in Oslo.

# Solid may be DANGEROUS

In the US, they construct huge buildings for the sole purpose of studying the effects of massive impacts. A time-consuming and costly procedure. In Norway, other methods are chosen. A decades-long cooperation between the Norwegian Defence Estates Agency (NDEA), a growing number of industrial partners and NTNU has carried SIMLab to a world-leading position in the design of crashworthy and protective structures. When the research group was awarded another eight year programme, SFI CASA, the Ministry of Local Government and Modernisation decided to join as partners. Deputy director general Christian Fredrik Horst at the Department for Buildings, Security and Services explains why:
"We need an environment that can find the structural solutions for the objects we are going to build. This includes the capacity to simulate with a high level of precision how impacts affect whole structures, what fragments do to them, how resilient they are and so on. We need to be certain that they can handle an impact. Concluding afterwards that they didn't is not an option."

**NOT FOR SALE**

"Can't you just buy this knowledge abroad?"
"We have experienced more than once that this kind of expertise is much more accessible if we have some competence of our own to offer in exchange. Our partnership gives us access to the international expert network CASA is part of. The value of this should not be underestimated."
"You already cooperate closely with NDEA and the Norwegian National Security Agency, another CASA partner. Wouldn't it work just as well getting the results from them?"

"We could and do get results from them. In fact, we rely heavily on their expertise and we specifically do not have any ambition to carry out research in this field on our own. However, we are constantly challenged by our suppliers on the specifications of our orders. Statsbygg, which is also part of our ministry, will be the formal commissioner of the government administration complex. Along with us, they will have to draw on advice from a number of expert groups, including the military services and the police.

We obviously don't want the buildings to look like fortresses. This means that we will be on constant lookout for vulnerable areas, compensatory measures and so on. This is where CASA is so valuable. They will be able to provide us with much more accurate information about what is needed than we would have had otherwise. We need to approach this from a scientific point of view."

**PHD PROJECTS COMING UP**

"Does this also mean that you see the need for specific PhD projects linked directly to your needs?"
"Certainly. There is a need for basic research for instance concerning what materials to use where. We also expect that the increased expertise will save us a lot of money. As an example, we reduce the risk of building something much more solid and expensive than necessary.

Furthermore, CASA will produce a lot of students with more expertise and closer attention to this area than would have happened otherwise. This is useful both to the ministry and to society as a whole," Horst says.

The plan is for the administration complex to be finished in ten years' time. Three years ago the price tag was estimated at NOK five billion upwards. Since then it has increased considerably.

**HISTORIC BROADCAST**

A news broadcast on Norway's state channel NRK from 2006 will sit in many people's memory as long as they live. It opens with the following words:
"The obstructions outside the high-rise in the government administration aren't exactly deterring. Anyone can place a car full of explosives in front of the government building."
Five years later, on 22 July 2011, that is exactly what terrorist Anders Behring Breivik did.
The broadcast was only aired locally in 2006. After the attack it became known to the whole nation. It contained an interview with Christian Fredrik Horst where he presented the result of a risk analysis, concluding that the street in front of the building needed to be closed to public traffic. As we all know, nothing happened. Protests sent the plans on a journey that still hadn't finished in 2011.

**"WHAT HAVE WE LEARNED?"**

"Above all that the unthinkable isn't unthinkable and that the time factor is crucial. The challenges posed by varying proposals, solution procedures and so on are massive and demand cooperation on a scale nobody had foreseen."

# Don't READ this

Really, you shouldn't. It doesn't belong here. It's not about CASA.
It didn't even take place last year. OK?

Not OK? Still reading? Well, don't say you didn't get warned! Any further reading is at your own risk. So, here goes:

**NOK 30 MILLION GRANT**

SFI CASA Professors Odd Sture Hopperstad, Tore Børvik and colleagues have just received a NOK 30 million grant to investigate new ways of designing aluminium structures to prevent failure. The title of the project is "Microstructure-based Modelling of Ductile Fracture in Aluminium Alloys", abbreviated: "FractAl".

"What we are aiming at is to enable the design of both the material and structure in an optimal combination without having to use time-consuming and expensive mechanical tests," Hopperstad and Børvik explain.

**IN POPULAR WORDS**

An attempt at a popularized explanation of their ambition might go like this:

Imagine you understand better than anyone before you what happens when aluminium breaks. Imagine you know the properties of different alloys down to the nano level and how the atoms react to different kinds of strain. Imagine you are able to build models that identify the optimal combination of alloy and structural components with much less testing than previously. Then you will have saved a lot of money and laid the foundation for vastly improved products and production processes.

**ONLY THE BEST**

Grants from the FRIPRO Toppforsk scheme from the Research Council of Norway are highly prestigious and aim at world leadership. In this case, it gives the core team of Hopperstad, Børvik and Ole Runar Myhr from NTNU's Structural Impact Laboratory along with partners Ahmed Benallal from the French university ENS Cachan and Jonas Faleskog from the Royal Institute of Technology in Sweden the opportunity to "develop and validate a novel microstructure-based modelling framework for ductile fracture in aluminium alloys – thus reliably introducing multi-scale simulation in design of aluminium design against failure".

This is basic research with no strings attached. The five-year project involves four PhD candidates and two post-docs and is financed by the Research Council of Norway and NTNU. Start-up is in August this year.

**WIN-WIN**

If there ever was a win-win situation, this is one. SFI CASA stands to reap great benefits from the research. Where CASA is a NOK 300 million eight-year programme working on structural analysis of steel, aluminium, polymers and glass, Toppforsk enables researchers to dedicate a concentrated effort in a very specific area. The challenges of FractAl could have been approached through CASA, but not to the same extent and in such detail.

The outcome for CASA is a wide range of scientific findings that will be made available to the partners by help of the SIMLab Tool Box, where everything will be implemented. In this way, NOK 30 million of research will give an important boost to the rest of CASA's activity.

Since this is basic research, the results will be published in peer-reviewed journals and be made available to the public.

**SAME PEOPLE ON SAB**

The close relationship between the FractAl project and CASA is underlined by the composition of the project's Scientific Advisory Board, consisting of CASA Director Magnus Langseth and CASA Scientific Advisory Board members John Hutchinson and David Embury.

"We are very happy to have them on board, both because of their capacities and because their double position will help us avoid overlapping work in the two programmes," Hopperstad and Børvik underline.

The international partners - Benallal and Faleskog - are leading international researchers within their fields. While Benallal is a long-standing professional companion, the collaboration with Faleskog is more recent. The five researchers also complement each other scale-wise, ranging from Myhr at nano level to Børvik at the top.

**HEADING FOR THE ERC**

It is an explicit requirement for the Toppforsk grant that the project will file an application for a grant from the European Research Council (ERC). In the recent international evaluation of Basic and Long-term Research in Engineering Science in Norway, SIMLab received top score on scientific quality, productivity, relevance and impact for society, illustrating the group's world-leading position.

So, when you are world-leading, where do you go? Triggered by their faculty, Hopperstad, Børvik and colleagues decided to go for a Toppforsk grant which will in turn direct them towards the ERC.

Sometimes, uncovering the secrets of a very specific area of research can bring the big picture significant steps ahead. The topic for the project is an area where SIMLab is already world-leading. FractAl aims at consolidating this position.

**THANKS TO SIMLAB**

Today, Odd Sture Hopperstad and Tore Børvik are Research Director and Vice Director at SFI CASA, respectively. They strongly emphasize that qualifying for the Toppforsk grant would have been impossible without the foundation they have been part of in the SIMLab research group.

There will be close interaction between the CASA and FractAl programmes which was an important feature that was stressed in the application for the Toppforsk grant.