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[1]2013-06-20

Business Plan for the CEN Workshop WS 71 on "Validation of solid mechanics simulation"

Contents

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[1] *Here the date of updating should go, updated by the last editor*

1. Status of the Business Plan

This Business Plan was approved at the Kick-off meeting of the CEN Workshop 71 on 2013-06-12. This BP has been elaborated and is supported by the core team of the FP7 NMP CSA project "Validation of Numerical Engineering Simulations: Standardisation Actions".

2. Background to the Workshop[2]

Computational solid mechanics models are widely used in the simulation of engineering designs and existing artefacts. In general, the models are based on the finite element method[3] with some use of the boundary element method[4]. A large number of commercially available software packages provide end-users with varying degrees of modelling capability based on these methods. It is the norm for the suppliers of these packages to perform verification of the modelling method; in which verification is defined as *'The process of determining that a computational model accurately represents the underlying mathematical model and its solution'*[5]. However, it is the responsibility of the user to perform adequate validation of each model developed with a package. Validation is defined as *'The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model'*[5]. A large number of benchmarks are provided by e.g. NAFEMS[6] to support vendors of packages in verifying finite element packages; but support for the validation process is almost non-existent. The American Society of Mechanical Engineers has developed a Guide for Verification and Validation of Computational Solid Mechanics Models[7] which describes what is required but does not provide any methodology for performing a validation. The objective of this CEN Workshop is to fill this gap by providing a general approach to the validation of computational solid mechanics models used in engineering design and evaluation of structural integrity.

At the moment there are no directives or relevant national legislation and very little documentation in the form of standards or standardization related activities. The United States Department of Defense issued a glossary of terminology for modelling and simulation in 1998[8], while the American Society for Testing of Materials has published a "Standard Guide for Evaluating Non-Contacting Optical Strain Measurement Systems"[9], which describes the principal approach for obtaining data for the validation process. There has been some activity

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[2] *Use font Arial 12 bold for headers (header tab stop at number 1), Arial 11 for body text*

[3] Zienkiewicz, O.C., & Taylor, R.L., The finite element method: basic formulation and linear problems, McGraw-Hill, New York, 1989.

[4] Banerjee, P.K., Butterfield, R., Boundary element methods in engineering science, McGraw-Hill Book Co., London, 1981.

[5] Computational Fluid Dynamics Committee on Standards, "Guide for Verification and Validation of Computational Fluid Dynamics Simulations," American Institute of Aeronautics and Astronautics, AIAA G-077-1998, ISBN 1-56347-285-6, January 1998.

[6] National Agency for Finite Element Methods and Standards, www.nafems.org

[7] ASME V&V 10-2006, Guide for verification & validation in computational solid mechanics, American Society of Mechanical Engineers, New York, 2006.

[8] DoD Modeling and Simulation Glossary, Under Secretary of Defense of Acquisition Technology, Washington DC., January 1998, available at http://www.dtic.mil/whs/directives/corres/pdf/500059m.pdf

[9] ASTM E2208 - 02(2010)e1 Standard Guide for Evaluating Non-Contacting Optical Strain Measurement Systems, American Society for Testing of Materials, West Conshohocken, PA, 2010.

in the scientific literature with Schwer[10] describing in outline the 'Guide for verification and validation in computational solid mechanics'[7]. He identified that verification can be achieved largely without reference to the real-world. Whereas, validation should be achieved by reference to experiments conducted specifically for this purpose, but no insight is provided for the conduct of such experiments.

The traditional approach to validation of computational solid mechanics models is to obtain experimental data from strain gauges bonded to a physical prototype at locations of high stress indicated by the model simulation. There are two major flaws with this approach: (i) the locations of high stress may be elsewhere than identified by the model simulation and could lead to component failure; and (ii) no validation is performed in regions of apparently low stress where the design may have been optimised by removal of material mass, so again high stress in these regions would lead to component failure. More complete strain data from experiments for validation is available from optical techniques such as digital image correlation, photoelasticity, and thermoelastic stress analysis. These techniques provide data over a full-field of view, and thus can generate maps of strain (or stress) containing of the order of 10^6 data points, which is comparable to the nodal density found in computational models. A point-by-point comparison of such data-rich strain maps from different sources and in different coordinate systems is computationally expensive, maybe impractical, and leads to a result that is not useful or at least cumbersome to interpret. Consequently, it is common practice to extract sections of data from such maps for comparison to values predicted by simulations[11,12,13] and, while this is an improvement on validation using data from a small number of points at which strain gauges are located, it falls short of the comprehensive, quantitative validation that is sought to provide high levels of confidence in engineering design simulations. Recently, it has been proposed that, for static applications, comparisons of maps of strain data from computational models and experiments can be performed straightforwardly using shape descriptors[14]. Since these maps contain some level of redundant information, shape descriptors that are rotation, scale and translation (RST) invariant provide an effective means of comparison. Shape descriptors, including geometric moments, Fourier descriptors and wavelet descriptors are used in the field of image recognition for applications such as finger print[15], face recognition[16], target recognition[17], and medical diagnostics[18]. They allow the

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[10] Schwer, LE,2007, An overview of the PTC 60/V&V 10: guide for verification and validation in computation solid mechanics, *Engineering with Computers*, 23, 245-252.

[11] De Strycher, M, Lava, P.,van Paepegem, W., Schueremans, L., Debruyne, D., 2011, Validation of welding simulations using thermal strains measured using DIC, *Applied Mechanics and Materials*, 70, 129-134.

[12] Lomov SV, Ivanov DS, Verpoest I, Zako M, Kurashiki T, Nakai H, Molimard J, Vautrain A, 2008, Full-field strain measurements for validation of meso-FE analysis of textile composites, *Composites A: Applied Science and Manufacturing*, 39(8):1218-1231.

[13] Miao HY, Larose S, Perron C, Lévesque M, 2011, Numerical simulation of the stress peen forming process and experimental validation, *Advances in Engineering Software*, 42(11):963-975.

[14] Mottershead J, Patki A, Patterson EA, Wang W, Image decomposition as a tool for validating stress analysis models, *Proc. Int. Conf. Exptl. Mechanics (ICEM 14)*, Poitiers, France, July , 2010, paper #271.

[15] Ismail R.A., Ramadan M.A., Danf T.E., and Samak A.H., 2008, Multi-resolution Fourier-Wavelet descriptors for fingerprint recognition. *Int. Conf. on Computer Science and Information Technology,* 951-955.

[16] Nabatchian A., Abdel-Raheem E., and Ahmadi M., 2008, Human face recognition using different moment invariants: a comparative review. *Congress on Image and Signal Processing*, 661-666.

decomposition of high resolution images into only a hundred or less unique moments, which are a faithful representation of the features in the corresponding image. Recently[19], it has been demonstrated that a comparison of two sets of Zernike moments[20], describing the strain maps obtained from digital image correlation and computational modelling, can be used to update a finite element model[21] and improve its fidelity. In parallel work, the use of the same moments to establish confidence limits for this fidelity has been explored[22]. These studies break new ground by treating maps of strain as images and representing them with a small number of information-preserving moments which allows statistical measures to be applied effectively.

The output from the validation process needs to be in a format that allows decision-makers to quantify their confidence in the computational models used in the design process. A key step in this quantification is establishing the uncertainty in the source data. The uncertainty in the strain maps from experiment can be evaluated via the calibration[23] of the optical system employed for their measurement using calibration guidelines[24]. Recently, the reliability of data collected in experiments involving variable amplitude loading has been considered and statistical methods have been developed to quantifying the associated uncertainties based on probability density functions[25].

Engineering simulation is an essential feature of the design and manufacture of all engineered products at all scales. In particular, simulation based on computational solid mechanics models permits designers to optimise the load-bearing components in devices, machines and structures so that a satisfactory level of reliability is achieved for an acceptable cost. The desire for a sustainable society stimulates designers to create elegant, light-weight designs in which embedded energy and material is minimised; however at the same time consumers demand total reliability that often can be achieved most easily by heavy, conservative designs in which additional material provides additional factors of safety. Removal of these safety factors to create light-weight and efficient designs requires a very high level of confidence in the engineering simulations used routinely in design. These confidence levels should be

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[17] Bhanu B., and Jones T.L., 1993, Image understanding research for automatic target recognition. *IEEE Aerospace and Electronic Systems Magazine*, 15-22.

[18] Ahmad W.S.H.M.W, & Fauzi M.F.A., 2008, Comparison of different feature extraction techniques in content based image retrieval for CT brain images. *IEEE 10th workshop on multimedia signal processing, Cairns,* 503-508.

[19] Wang, W., Mottershead, J.E., Sebastian, C.M., Patterson, E.A., 2011, Shape features and finite element model updating from full-field strain data, *Int. J. Solids Struct*. 48(11-12), 1644-1657

[20] Teague MR, Image analysis via the general theory of moments. *Opt. Soc. America*, **70**, 920-930, 1980.

[21] Friswell MI, Mottershead JE, *Finite Element Model Updating in Structural Dynamics*, Kluwer Academic Publishers, 1995.

[22] Sebastian, C., Hack, E., Patterson, E.A., 2013, An approach to the validation of computational solid mechanics models for strain analysis*, J. Strain Analysis*, 48(1):36-47.

[23] Patterson, E.A., Hack, E., Brailly, P., Burguete, R.L., Saleem, Q., Siebert, T., Tomlinson, R.A., & Whelan, M.P., 2007, 'Calibration and evaluation of optical systems for full-field strain measurement', *Optics and Lasers in Engineering*, 45(5):550-564.

[24] *Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement, SPOTS,* www.opticalstrain.org, 2010.

[25] Baharin, MN., Nopiah, ZM., Abdullah, S., Khairir, MI., Lennie, A, 2011, The development of validation technique in variable amplitude loadings strain repetitive data collection, *Key Engineering Materials*, 462-463:337-342.

acquired through rigorous, quantitative validation of the models employed for the simulations. Although many engineering companies and organisations have developed internal procedures for validating the computational models that are essential to their engineering design activities, there are no standards for the validation of computational solid mechanics models used in engineering design. Consequently, many engineering artefacts are designed using inadequately validated models which when this is recognised leads to conservative design, and when it is not recognised leads to unreliable design. The lack of standardisation inhibits the exchange of both data from simulations and of models used for simulation, which in turn slows down innovation, particularly in industries producing engineering systems that are composed of many sub-systems produced by different manufacturers.

3. Workshop proposers and Workshop participants

The original proposers of the CEN Workshop are the beneficiaries of the European Commission's 7th Framework Programme project VANESSA (Validation of Numerical Engineering Simulation: Standardisation Actions)[26]. These are: The University of Liverpool (UK), Dantec Dynamics GmbH (DE), EMPA Eidgenössische Materialprüfungs- und Forschungsanstalt (CH), University of Patras (GR), High Performance Space Structures GmbH (DE), Schweizerische Normen-Vereinigung (CH), Centro Ricerche Fiat (I) and National Nuclear Laboratory (UK).

It is anticipated that the following will be present at the kick-off meeting:

Eann Patterson (University of Liverpool), Thorsten Siebert (Dantec Dynamics GmbH), Erwin Hack (EMPA), George Lampeas (University of Patras), Alexander Ihle (High Performance Space Structures GmbH), Rolf Widmer (Schweizerische Normen-Vereinigung), Andrea Pipino (Centro Ricerche Fiat) and Phil Ivison (National Nuclear Laboratory).

4. Workshop scope and objectives

The Workshop will build on two completed projects from European Commission's Framework Programme 5 and 7 with the aim of bridging the gap between the research outputs of these projects and their implementation in engineering industry. The FP5 project SPOTS[27] (Standardisation Project for Optical Techniques of Strain measurement) led to a unified calibration methodology for all optical systems capable of measuring strain fields on the planar surfaces of engineering components subject to static and pseudo-static loading[23]. Calibration provides traceability via a continuous chain of comparisons to an international standard, in this case for length, and also allows the minimum measurement uncertainty to be established. Traceability is important in areas such as aerospace and nuclear power, which require certification of designs by regulatory authorities. The establishment of minimum measurement uncertainties is critical in making quantitative judgments about comparisons between datasets. Thus, the SPOTS project provided an initial step in the process of validating computational

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[26] VANESSA, Validation of Numerical Engineering Simulation: Standardisation Actions, Grant Agreement NMP3-SA-2012-319116

[27] SPOTS, Standardisation project for optical techniques of strain measurement, GROWTH Project No. G6RD-CT-2002-00856, see www.opticalstrain.org

solid mechanics models by creating a route for providing high quality data from experiments that could be used in the validation process. A set of guidelines[28] were published from the SPOTS project and have been approved by VAMAS TWA26[29].

The FP7 project ADVISE[30] finished in November 2011 and extended the research outputs from SPOTS in two important areas, i.e. developing an efficient quantitative method of comparing very large datasets[19] and extending the calibration methodology to include dynamic and out-of-plane loading of engineering components[31]. The ADVISE work on calibration extends the procedures to important cases in which the rate of deformation and out-of-plane components of deformation are significant. Impact loading occurring either intentionally, such as during landing of an aircraft, or unintentionally, such as in an automotive crash, is one of the most important categories that the ADVISE project considered.

Recent developments in optical measurement have led to a number of very powerful techniques for acquiring strain data in engineering components subject to service loads[32], of which digital image correlation is becoming ubiquitous. These techniques are capable of generating high-density maps of strain fields containing of the order of 10^5 to 10^6 data values, which with careful experimental design could cover the majority of the surface of an engineering component. The quantitative comparison of such data with corresponding data generated by engineering simulations based on computational solid mechanics models is challenging because the datasets are obtained in different coordinate systems, with different orientations and in data arrays with different pitches. In the ADVISE project, techniques used in image decomposition were used to develop procedures for strain field decomposition that are invariant to rotation, scale and translation and which allow enormous data compression while preserving all of the relevant information[6,33]. These procedures were used to create a validation protocol that involved comparing output from simulations with high-density datasets from optical measurement of strain fields in engineering components or prototypes. The protocol is efficient to apply, takes account of uncertainties, and can be adapted to give a quantitative measure of the level of agreement between of the datasets from experiment and simulation[34,35].

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[28] *Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement, SPOTS,* www.opticalstrain.org, 2010.

[29] VAMAS Technical Working Area 26: Full-field optical stress and strain measurement, www.twa26.org

[30] ADVISE, *Advanced Dynamic Validations using Integrated Simulation and Experimentation*, www.dynamicvalidation.org.

[31] Davighi, A., Burguete, R.L., Feligiotti, M., Hack, E., James, S., Patterson, E.A., Siebert, T., Whelan, M.P., 2011, The development of a reference material for calibration of full-field optical measurement systems for dynamic deformation measurements', *Applied Mechanics and Materials*, 70:33-38.

[32] Burguete, R.L., Lucas, M., Patterson, E.A., Quinn, S., 2011, *Advances in Experimental Mechanics VIII*, Applied Mechanics and Materials, vol. 70, Trans Tech Publications, Durnten-Zuerich, Switzerland.

[33] Wang, W., Mottershead, J.E., Sebastian, C.M., Patterson, E.A., Siebert, T., Ihle, A., Pipino, A., 2011, Image analysis for full-field displacement/strain data: methods and applications, *Applied Mechanics & Materials*, 70:39-44.

[34] Sebastian, C.M., Patterson, E.A., Ostberg, D., 2011, Comparison of numerical and experimental strain measurements of a composite panel using image decomposition, *Applied Mechanics and Materials*, 70:63-68.

[35] *Guideline for validation of computational solid mechanics models using full-field optical data*, deliverable D4.7 from ADVISE project (www.dynamicvalidation.org).

The objective of the Workshop is to establish the protocol developed in the EU FP7 ADVISE project as the internationally recognised process for the validation of computational solid mechanics model using strain fields from calibrated measurement systems. The workshop agreement will include both the methodology for calibration of optical systems for measurement of strain fields and the protocol for validation using the strain field data. This workshop will provide a general approach to the validation of computational solid mechanics models used in engineering design and evaluation of structural integrity.

In addition to the usual distribution and dissemination routes, it is planned, as part of the EU FP7 VANESSA project, to hold a knowledge exchange workshop in the summer of 2014 following the publication of the CWA at which European industry and academia will be encouraged to utilise the CWA.

5. Workshop programme

CEN/WS 71 official language will be English. The CWA will be in English.

The process of elaborating the CWA will be according to the following tentative time plan (dates and meeting places are tentative and subject to confirmation):

Tentative Time Plan

Description	Time	Place	Duration
CEN/WS Business Plan submitted to CCMC	2013-03-20		
Announcement of the CEN/WS on CEN website	2013-04-17		60 days notice
CEN/WS Kick Off Meeting	2013-06-12	Brussels	1 day
Circulation of 1st Draft CWA and collection of comments by the CEN/WS participants	2013-08-04		
1st CWA Plenary Meeting • Discussion of comments	2013-09-04	Cardiff, UK	1 day
Circulation of 2nd Draft CWA and collection of comments by the CEN/WS participants	2013-12-14		
2nd CWA Plenary Meeting • Discussion of comments • Approval for submission to CCMC	2014-01-14	Duebendorf, CH	1 day
Prepare 3rd Draft/CWA to be submitted to 60-day public commenting phase (draft text of the CWA deliverable made available on CEN Web Site)	2014-02 to 2014-04		60 days
Implement comments from public commenting by CCMC			
Circulation of final Draft CWA	2014-05-10		
Final CWA Plenary Meeting (final version/approval of deliverable)	2014-06-10	Munich, DE	1 day
Publication of CWA deliverable after editorial check by CCMC	2014-07		

6. Workshop structure

The following Workshop structure has been approved during the Workshop Kick-Off Meeting:

Chair: Prof. Eann Patterson (University of Liverpool)
Main responsibilities:

- to preside at the Workshop plenary meetings;
- to ensure that the Workshop delivers in lines with its Business plan;
- to manage the consensus building process;
- to interface with CEN/WS Secretariat and CEN Management Centre regarding strategic indications, problems arising in the development of the CWA.

Vice-Chair/Project leader: Dr. Erwin Hack (EMPA – Swiss Federal Laboratories for Material Science and Technology)

Main responsibilities:

- to support the Chairman in the development process of the CWA;
- to consolidate the comments received on the drafts during the enquiries and propose a resolution of comments for discussion with workshop participants;
- with the support of the Secretariat, to prepare the drafts CWA to be circulated to CEN/WS participants.

Secretariat: Rolf Widmer (SNV – Swiss Association for Standardization)
Main responsibilities:

- to offer the infrastructure for electronic operation (i.e. Livelink platform);
- to administer the CEN Workshop's members list(s) and official registration of participants;
- to manage documents and their distribution, and to update the document register;
- to prepare and distribute CEN/WS Documents (i.e. draft agendas and information on meetings arrangements, minutes of the meetings, draft CWAs, etc.);
- to chase actions as decided by the CEN Workshop meeting;
- to advise on the requirements of the CEN/CENELEC Internal Regulations and decisions of the CEN/CA and CEN/BT in the development of a CWA;
- to provide expertise in standardization and provide relevant standards to the Workshop, when or where necessary;
- to check conformity of all of the versions of the draft CEN Workshop Agreement to CEN rules;
- to initiate and manage the CWA approval process, upon decision by the Chairman;
- to record expression of support to the CWA for transmission to the CEN Management Centre;
- to participate in CEN Workshop plenary meetings, audio conferences and meetings with the Chairmen.

7. Resource requirements

The registration and participation at this CEN Workshop is free of charge for every member of the Workshop, but each participant will bear his/her own costs for travel and subsistence.

The administrative costs of the Workshop Secretariat and other logistical support will be covered by the VANESSA project through FP7 funds.

8. Related activities, liaisons, etc.

Liaisons will be established with VAMAS TWA 26: Full-field optical stress & strain measurement, and with the ASME V&V 10 committee (Verification and Validation in Computational Solid Mechanics).

Additional liaisons may be identified at the kick-off meeting or at subsequent plenary meetings.

A number of knowledge exchange workshops will be organised as part of the EC FP7 VANESSA project on associated topics and will assist in promoting and disseminating the Workshop Agreement.'

9. Contact points

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