

Insight from a NAFEMS Technical Fellow

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This is the third article in our series where we ask the NAFEMS Technical Fellows to share some of the insight that they have gained over the course of their careers. In this article Klaus Rohwer, editor of NAFEMS German Magazine and Technical Fellow, shares his thoughts on the future of our organization.

Insights usually contain some ideas concerning the current situation and possible future development. They are not objective, but depend predominantly on the author's personal experience. Keeping this in mind it seems suitable to start this small elaboration with an overview of my development in the field of numerical simulation.

During the 1960's I studied Civil Engineering at the Technical University of Braunschweig, Germany. Though this branch of study had a good reputation in those days, the distinguished professors were focused more on technical and material aspects and had little background in numerical simulation. I had to use my own initiative in order to learn more about numerical methods and teach myself finite difference methods to calculate plate deformation under transverse loads. As I was coming to the end of my study, Dr. Heinz Duddeck was appointed head of the structural analysis institute. His main interest was tensorial shell analysis, but he also promoted numerical methods. It was through him that I first got to know the term 'Finite Element'.

In 1968 I joined the German Aerospace Center (DLR) and it was here that I learned more about fibre composites. At the Institute of Structural Mechanics there was a group of researchers around Prof. Wilhelm Thielemann who were very active in studying buckling and post-buckling behaviour of thin cylindrical shells under axial compression. Differential equations were solved by means of the Ritz method using harmonic functions in circumferential direction.

Prof. Thielemann was sceptical about the accuracy of solutions from large equation systems, and with good

reason: he once came back from an Advisory Group for Aerospace Research and Development (AGARD) meeting to report that Prof. John Argyris had worked with one thousand (!) Degrees of Freedom (DOFS). Fortunately, however, it turned out that it is not the sheer number of DOFS that governs the solution accuracy but rather the relation between largest and smallest eigenvalue which counts. Nowadays equation systems with millions of DOFS are, of course, quite common.

For simulating the behaviour of sandwich panels with laminated composite face sheets we applied the Ritz method with piece-wise Hermite interpolation polynomials, an approach quite close to finite elements. Such an approach had been proposed by the mathematicians Richard Courant and David Hilbert some 30 years earlier. At that time, however, the necessary computational means were not available, and the proposal was simply left behind. This suggests that a breakthrough for a new method needs adequate frame conditions.

In 1976/77 I had the chance to spend one year as a faculty member at the California Institute of Technology in Pasadena. During that time, I extended the piece-wise Hermite interpolation approach to the geometric nonlinear behaviour of sandwich panels. With a quadratic strain displacement relation, the total potential energy results in a fourth order polynomial in the DOFS. For each search direction, determined by the conjugated gradient method, there are at most two minima which are easily determined. Each converged energy minimum represents a state of equilibrium. At that time computational speed as well as storage volume was rather limited; It required considerable programming effort to get reasonable results.

On returning to Braunschweig I developed efficient triangular shell elements which were implemented into a commercial FEM system and successfully used by aircraft industry. The definition of a suitable model is of major importance for a successful numerical simulation. It should be simple enough in order to keep the computational effort low, but must mirror all important features. Sandwich shells we modelled as 2D continua, where the core undergoes transverse shear rotations whereas the face sheets behave according to the classical lamination theory. Several higher order theories for composite laminates are published. A comparison with exact 3D solutions indicated that for slenderness ratios $a/h \rightarrow 25$ the classical lamination theory is accurate enough; for a/h between 25 and 5 the first order shear deformation theory with an adequate shear correction factor is suitable, and for even lower slenderness rates a 3D model should be applied. Therefore, higher order plate theories are not very useful. In addition, it turned out that transverse shear and normal stresses are much more accurate if determined by equilibrium conditions rather than from the material law.

In order to catch the free edge effect in fiber composites corresponding models have to be more detailed. I used volume finite elements to model each orthotropic layer of a laminate. Micromechanical aspects were captured when I analysed the stresses at the free end of a single fiber during cooling down from curing. In both cases convergence studies pointed to stress singularities at the free edge. In reality, singular stresses do not exist; the material avoids them either by yielding or by fracture.

In 1990 I felt that I had acquired enough knowledge to teach in the field of fiber composites. I did that at the Universities of Stuttgart and Magdeburg, and later at the Private University of Applied Sciences Göttingen. During this time, the DLR Institute for Composite Structures and Adaptive Systems, joined NAFEMS. I was selected as a member of the DACH steering group, where I got to know NAFEMS as an ideal platform for the exchange of ideas and facilitating cooperation between academic findings and industrial needs. I have initiated and led several successful seminars on composites, and was one of the founding members of the Composites Working Group. In 2005 the steering group decided to edit an online magazine in German, and as its Editor-in-Chief I was - and am still - responsible for the quality of the scientific contributions therein.

In my opinion, the current situation in numerical simulation is governed by an ever-increasing faith in computational results. Virtual testing is envisioned to supplement or even

to replace reality. Certainly, there are problems where real tests must not be performed, like an aircraft crash on a nuclear power plant. In such cases virtual test can be helpful. But when evaluating the numerical results, one should always be aware that it was just a model which was analysed.

Model development already plays a prominent role in numerical analysis, and I envision that this will only increase with time. Two different development directions can be distinguished. In the first, more and more details are included in order to better map the real behaviour. With respect to structures, for instance, that means going as far as considering molecular or even atomistic aspects. In the second developmental direction, models are simplified in order to reduce computational effort. Even meta-models are developed, especially for optimization tasks where the model must be analysed very often.

Besides these two general directions there are several other topics which currently attract the interest of model developers. Multi-scale problems is one of those, where effects of very different size are treated in one go. Furthermore, multi-physics models, as indicated by the name, comprise effects from different subjects. These tendencies are often combined with the aforementioned movement towards more detailed characterization of the problem at hand. One can observe a development towards a full life-span simulation, starting with the initial design of a product, via the manufacturing aspects, its usage up to its final failure. Unfortunately, the very last aspect i.e. recycling and disposal is often neglected.

Finally, I would like to pose an answer to the question "*In what way can and should NAFEMS contribute to the further advancement of numerical simulation?*" To illustrate, let us look at the example of the current situation with failure prediction of fiber composites. The situation can be described as follows: Three elaborate world-wide failure exercises, initiated and managed by scientists from different universities and research institutes have compared several failure models against blind tests and it has turned out that none of the models can solve all tasks to full satisfaction. Furthermore, the number of models has mushroomed often without adequate validation. Such a situation exists for many simulation problems. I believe NAFEMS can play a role in alleviating this issue by providing, through its various Working Groups, well-documented test results as benchmarks for certifying new models.

The NAFEMS community is made up, in large part, by a network of volunteers, supported by the core staff members. These volunteers dedicate their time and experience to the community in order to advance both the technology and the people who work with that technology. Over the past 35 years, we have seen hundreds of people engage in the NAFEMS working group and steering committee structure, with many of these individuals being a part of the organisation for much of that time

In June 2018, NAFEMS' Council decided to recognise these outstanding contributions by introducing the award of "NAFEMS Technical Fellow". The award will be made at Council's discretion to those who have dedicated themselves over a period of time to the advancement of the organisation, and made a significant contribution to the community through their continued participation.