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Compact Modelling of High-Tech Systems for Health Monitoring and Optimisation along the Supply Chain

INTRODUCTION

In the industrial supply chain, cutting-edge technologies are required to produce high precision engineered components and assemblies. These high-tech systems are made of numerous complex components. In order to ensure their reliability and robustness, numerical simulations are made at various design stages of production. The bottleneck is that due to the complexities of these systems, time, resources, and efforts are heavily paid for when performing such simulations. Therefore, there is a need for reduced dynamical models which can capture the same behaviour of the original real complex model.

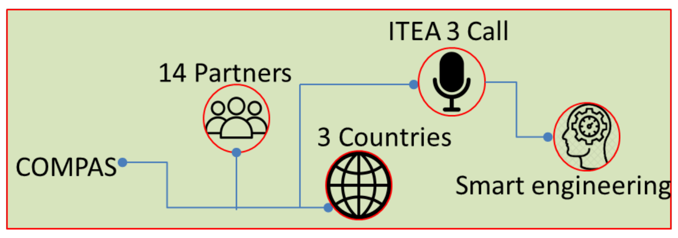


Fig. 1. Project general flow chart

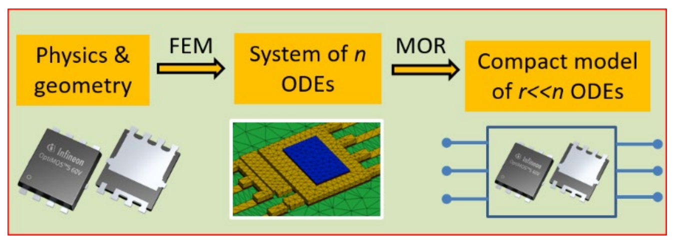


Fig. 2. Workflow in generating compact models

PROJECT DESCRIPTION

High-tech systems integrate numerous highly complex components. Simulations are necessary at various stages of their design process, to ensure mechanical robustness and reliability. In this context, the EU project COMPAS that aims to develop novel, compact models and ultra-compact digital twins for the supply chain of high-tech systems, was recently initiated. COMPAS investigates the thermo-mechanical reliability of high-tech systems, such as motor control units for automated factories, smart infrastructures, or autonomous vehicles. Infineon Technologies and NXP semiconductors provided packaged chip test-models (see figure 3) for automotive MOSFET applications in body electronics, chassis and safety, electric drive drain, infotainment systems, and car security.

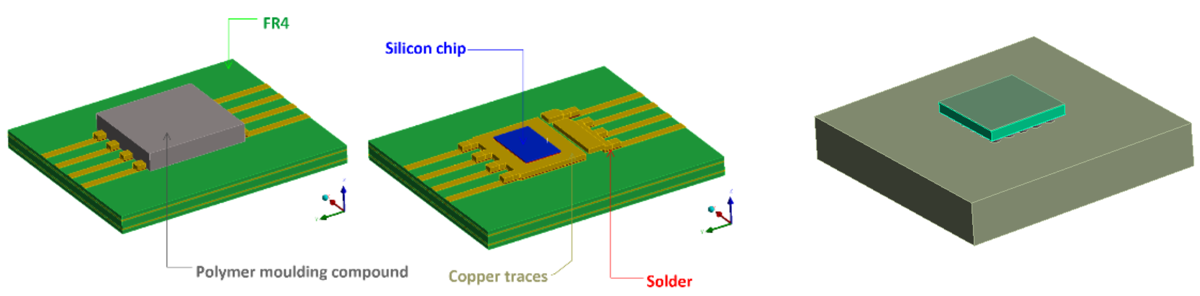


Fig.3: Model geometries of consideration

COMPAS targets a substantial improvement in efficiency along the supply chain by providing a simulation-based reliability assessment basis for the entire supply chain. By making use of the compact models developed, prognostic health management can be achieved with the help of digital twin technology

For performing the life assessment, the packaged chip is exposed to temperature cycles ranging from -40°C to 125°C. Heat, having a significant influence on the package reliability, can lead to structural failures such as solder joint fatigue, die cracking, and delamination [1]. As performing such experiments is costly and time consuming, they are preceded by computer simulations.

Mathematical methods of model order reduction (MOR) can speed-up the simulation times significantly and enable system level simulations.

The compact models will be obtained via model order reduction techniques which are developed by Jade University of Applied Sciences. These compact models will be used to predict the lifetime of high-tech systems.

MODEL ORDER REDUCTION (MOR)

Non-Parametric Linear Thermo-Mechanical Model Order Reduction

MOR is a numerical technique that enables an automated extraction of accurate, low dimensional models directly from high-dimensional finite element models [1].

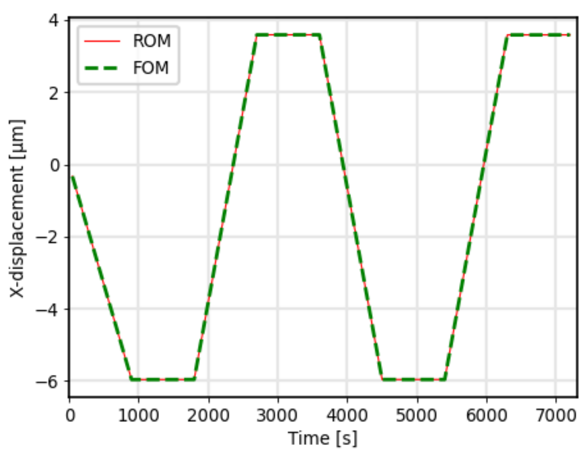
The approximation of linearized thermo-mechanical quasi-static system is attained by projection onto an appropriate low-dimensional subspace V. The approximated state vector becomes $x \approx V \cdot z$, where $z \in R^r, r \ll n$ can be considered as a vector of generalized coordinates leading to the reduced system of the form:

$$\underbrace{V^T E V}_{E_r} \frac{dz(t)}{dt} + \underbrace{V^T K V}_{K_r} z(t) = \underbrace{V^T B}_{B_r} \cdot u(t)$$

$$y(t) = \underbrace{CV}_{C_r} z(t)$$

where the state vector $x \in R^n$ contains nodal displacements U and temperatures T. E and $K \in R^{n*n}$ are the system matrices, $B \in R^{n*m}$ and $C \in R^{p*n}$ are the input and output matrices respectively, $u \in R^m$ is the input vector, m and p represents the number of input and outputs respectively.

Simulation Results



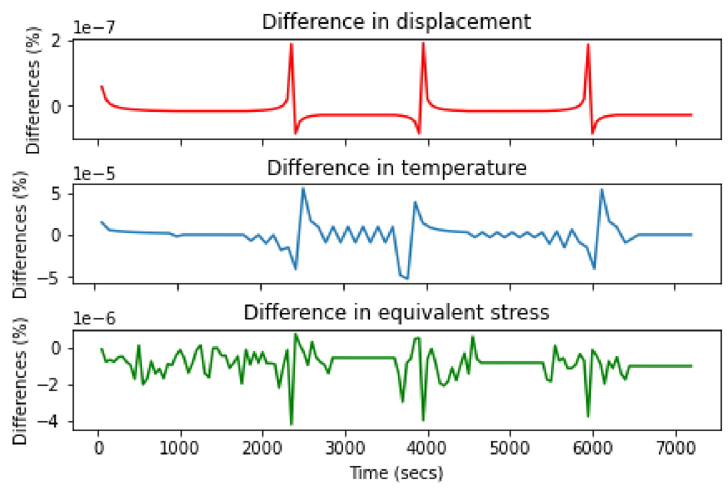


Fig.5: Error plots between ROM and FOM

	FOM	ROM
DOFs	1,238,972	30
Simulation time (secs)	39,600	240

Fig 6: Computational time comparison between full order model (FOM) and ROM. (Processor @3.0 GHz Intel Broadwell)

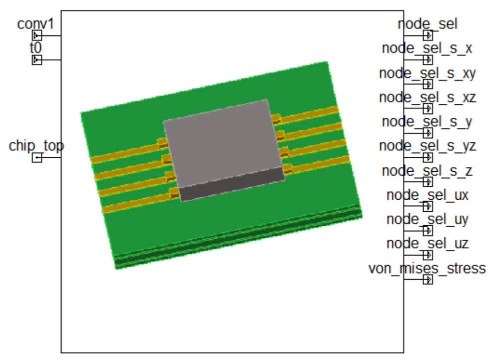


Fig.7: System level simulation

Parametric Linear Model Order Reduction

Parametric model order reduction (pMOR) is a novel numerical technique that enables an efficient construction of low dimensional but accurate models, directly from high-dimensional finite element models, while preserving material parameters in a symbolic form [2]. Krylov subspace based pMOR was already successfully applied to heat transfer or mechanical models. The main contribution here is a reduction of static mechanical system (exposed to thermal expansion due to temperature cycling), in which the Young's modules appears as a parameter on the left and the right-hand side of the spatially discretized model, as follows:

$$\Sigma_r: \begin{cases} \underbrace{V^T(K_0 + E \cdot K_1)V}_{K_r(E)} \cdot x = \underbrace{V^T(B_0 + EB_1)}_{B_r} \cdot u(t) \\ y_r = \underbrace{CV}_{C_r} \cdot x \end{cases}$$

where $x \in R^r$ is a reduced state vector of generalized coordinates.

Simulation Results

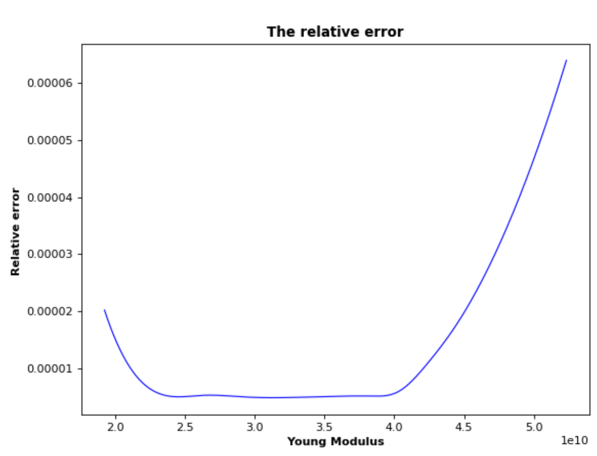


Fig.8: Results comparison at parameter validation point

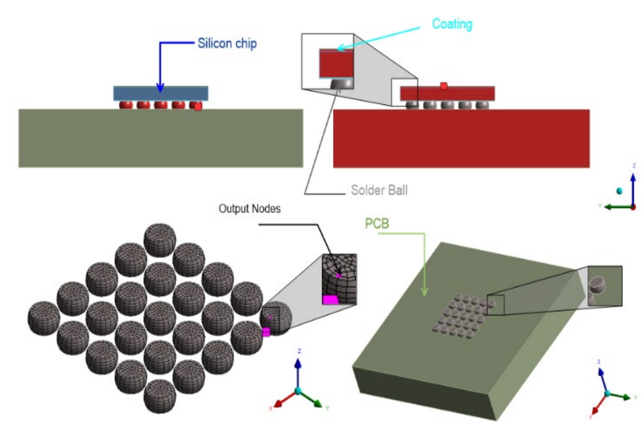


Fig.9: Nxp model General outlook.

CONCLUSIONS

- We present how Krylov-based MOR technique accurately approximates the thermo-mechanical behavior of the original linearized model within a transient simulation.
- We can conclude that the parameterized compact model accurately represents the mechanical behavior of the original one. It can be further employed at the system level and account for temperature dependent Young's modulus.

LITERATURE

[1] M. Thoben, X. Xie, D. Silber, J. Wilde, "Reliability of Chip/DCB solder joints in AlSiC base plate power modules: influence of chip size", *Microelectronics Reliability* vol. 41 (2001) no. 9-10, p121-1223.

[2] L. H. Feng, E. B. Rudnyi and J. G. Korvink, "Preserving the film coefficient as a parameter in the compact thermal model for fast electrothermal simulation," in IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 24, no. 12, pp. 1838-1847, Dec. 2005, doi: 10.1109/TCAD.2005.852660.

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